# Risk exposure assessment of pedestrians in urban area using a GIS

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## Abstract

A pedestrian is mainly exposed in urban area to traffic accident when crossing the street. A pedestrian in a trip spent time during a crossing in a micro-environment characterized by the volume and the speed of the flows of vehicles. The objectives of the research are:

1. to define the methodology to collect by survey and to code in a GIS, information about the trip and the crossings made on the urban network by a pedestrian and to match it with information on traffic flows on the street network,
2. to test this methodology on a sample of trips made by adult pedestrians in order to quantify the length of the trip, the number of crossings, the part of crossings made at mid-block or junctions on a specific urban setting, la ville nouvelle de Villeneuve d'Ascq.

## I. Introduction

A pedestrian is mainly exposed in urban area to traffic accident when crossing the street. A pedestrian in a trip spent time during a crossing in a micro-environment caracterised by the volume and the speed of the flows of vehicles. To estimate the risk exposure, one has to compute the time spent when crossing in different settings : mid-blocks or junctions and pedestrian protections : red ligths, pedestrian crossings, under different configutations of traffic measured by the volume and the speed of the flow. To acheive this estimation, one has to collect appropriate individual data about the trips and crossings made in the urban network. Detailed information about the trip and the crossings of the pedestrian in the urban network requires a record of the trajectory either by technical device such as a GPS or by reporting the trip by hand on a map. Both kind of data are then treated inside a GIS in order to extract the indicators related to the risk exposure.

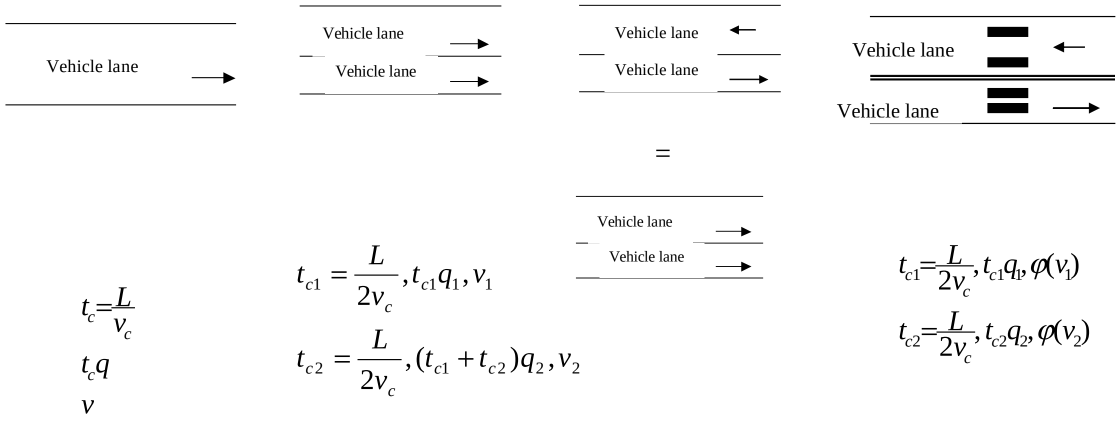
The objectives of the research are:

1. to define the methodology to collect by following up pedestrians and code in a GIS information about the trip and the crossings made on the urban network by a pedestrian and to match it with information on traffic flows on the street network,
2. to test this methodology on a sample of trips made by adult pedestrians in order to quantify the length of the trip, the number of crossings, the part of crossings made at mid-block or junctions on a specific urban setting, la ville nouvelle de Villeneuve d'Ascq.

# II. What is exactly exposure to accident risk for pedestrian ?

We define the exposure to the accident during the crossing of a street by analogy with the exposure to air pollution when walking in urban areas (Lassarre and al., 2007). In the street, there is a virtual contact between a road user and an « atmosphere » generated by the traffic. The quality of the atmosphere depends on the presence of contaminants in the traffic which are the moving vehicles described by a volume flow and a speed flow. The time of exposure is defined by the time spent by the pedestrian to cross the street of a certain width with a walking speed. Time spent in the traffic has always been a recommended indicator of what the road safety specialists call a measure of the "exposure to the risk". The walking speed depends on the age of the person, the motivation of the trip etc. To assess exposure a walking trip, one has to localise the crossings made on the trip in order to count the number of crossings made, to compute the time of each crossing, to estimate the traffic volume and speed at the place and time of the crossing. In fact, we start by defining a kind of quantum of exposure for each one-lane flow of vehicles crossed P equal to the product of the time of crossing $t_c$ by the volume of the flow $P=kt_cv=t_cq$

Its origin comes from Routledge's formula (1974). We can interpret P as the average number of virtual vehicles of one unit length, which one can meet when crossing the street. k is the concentration in number of vehicle per kilometre, $t_cv$ is the distance run by a vehicle during a crossing of $t_c$ seconds with v the speed of the flow..According to the mid-blocks (Figure 1) or junctions crossings, different forms of exposure arise in accordance to the number of lanes crossed, the presence of a pedestrian crossing and island, the presence of red ligths.



$$t_c=\frac{L}{v_c}$$
$$t_cq$$
$$v$$

$$t_{c1}=\frac{L}{2v_c}, t_{c1}q_1, v_1$$
$$t_{c2}=\frac{L}{2v_c}, (t_{c1}+t_{c2})q_2, v_2$$

$$t_{c1}=\frac{L}{2v_c}, t_{c1}q_1, \varphi(v_1)$$
$$t_{c2}=\frac{L}{2v_c}, t_{c2}q_2, \varphi(v_2)$$

Figure 1. Crossing situations and exposures for mid-blocks.

# III. Methodological considerations about coding information on walking trip and crossing for accident risk exposure

A trip is a spatio-temporal process going through different states : walking, waiting, ... and related to different decisons : stopping, crossing, ...made at certain times and places on the urban network. Knowing that two technics are used to collect data on individual walking trip: either you could equip pedestrian with a GPS and record automatically the trajectory of the trip in the city with the limits of precision and the failures of the system, or you can follow up a person in the street with or without its agreement and record the trip either with a GPS or by drawing the trajectory on a map, how to code these changes of states into a spatio-temporal referential geographical system ?

A trip is a set of locations (x,y) and state indicators (walking, standing, running) continuously changing in time. With a GPS, you get coordinates (x,y) at regular time step. From manual drawing on a map, you get a continuous line following the trajectory more or less exactly according to the precision of the map, plus the moment of the crossings if you have a chronometre.

By means of a GPS, the trajectory is automatically recorded and georeferenced into the GIS at the geometrix level. At the semantic level, for each point of the trajectory, one gets time related information such as the time elapsed since the beginning of the trip, an exact position, and an instantaneous speed. According to that, GPS data are quicker to get and to treat. But even if the devices are equipped with a powerful "head" such as Type SIRF III, there are still reliability problemes in urban settings. Figure X shows the same following up with two identical devices used in parallel. Some important deviations are observed because of the variation in the receprion of the signals in very dense urban areas A solution to avoid these distortions is available. By adding an antenna in the measurement field in order to triangle and correct the signal received by the portable GPS device.

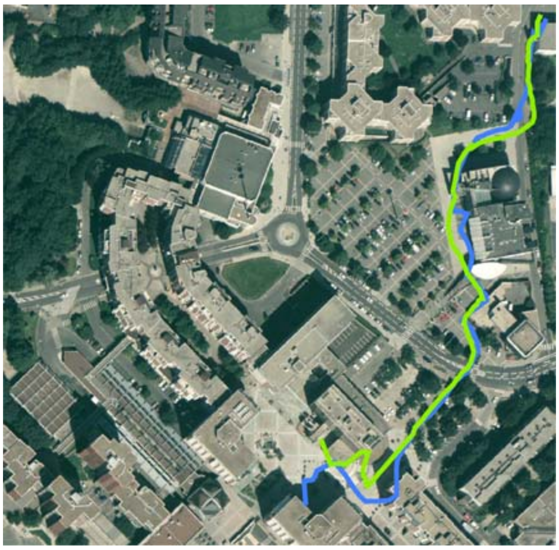


Figure 1 : Simultaneous recording of a follow up by two GPS devices.

Consequently, we have decided to follow up pedestrians in the street by drawing up their trajectory on an orthomap and by manually recording on a sheet the informations related to the trip.

The first problem is to segment a trip into sequences from an origin to a destination : walking along a pavement, walking on the street, walking on pedestrian lane, crossing a street at a junction or mid-block on or out a pedestrian crosswalk. A second problem is to localise, to count and to discriminate the different types of crossings, where pedestrian trips may be more or less complex and include several changes of direction. In order to illustrate the different types of crossings, trips with several changes of direction are considered to be similar to respective trips with no change of direction, i.e. road sections along a trip are transformed to a single, linear, uni-directional sequence of roads, as illustrated on the following Figure 2. Accordingly, the origin and the destination of a trip are determined on the basis of the sides of this single direction. More specifically, trips with origin-destination on the same side of the trip direction are labeled O/D=1, while trips with origin-destination on different sides of the trip direction are labeled O/D=2.

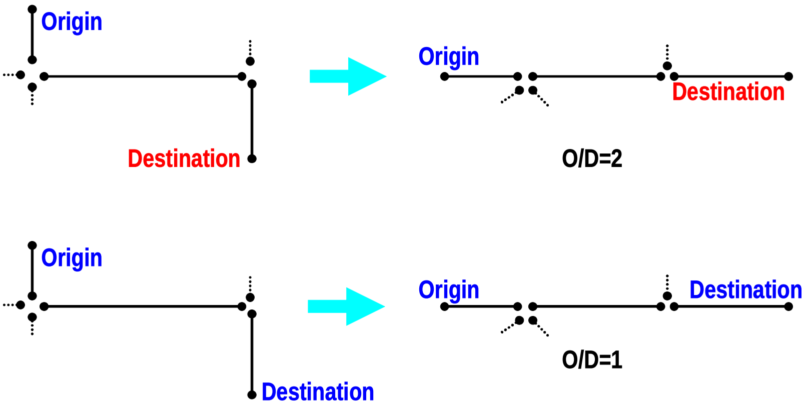


Figure 2 - Transformation of complex trips (several changes of direction) to simple trips (no change of direction)

Based on the above, two categories of crossings can be considered, taking into account the network layout and the trip characteristics:

- "Primary" crossings made at junctions or mid-block locations (across the trip direction) in order to follow the origin - destination setting.
- "Secondary" crossings made at junctions on either side of the road (along the trip direction) while moving along sequential roads (i.e. supplementary crossings made as a consequence of following the path).

An example of "primary" and "secondary" crossings is presented in Figure 3 below:

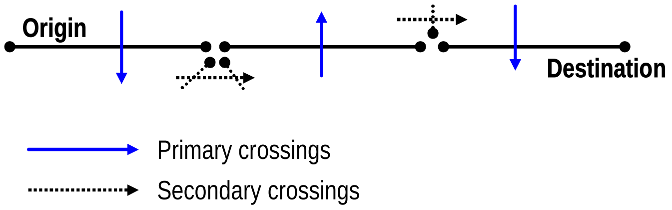


Figure 3. "Primary" and "secondary" crossings along a pedestrian trip

Consequently, according to the sides of the origin and destination, the number of primary crossings is random while the number of secondary crossings is deterministic. For example, in Figure 3 above, a primary crossing takes place across the first road segment; therefore the first two secondary crossings takes place "below" the trip direction. However, if no primary crossing took place across the first road segment, then the first secondary crossing would take place "above" the trip direction.

The total number of primary crossings along a trip depends on the origin-destination combination in relation to the side of the roadway along the trip. In particular, if the origin and destination are on the same side of the roadway, a pedestrian would not have to cross; if the origin and destination are on different sides of the roadway, a pedestrian would have to cross in order to reach his destination. Moreover, in complex trips with several changes of direction, pedestrians are likely to make additional primary crossings, in order to minimize walking distance.

On the basis of the above, the total number of crossings N along a pedestrian trip can be estimated through a probability distribution as follows:

- If origin-destination are on the same side of the roadway, then N {0, 2, 4, …}
- If origin-destination are on different sides of the roadway, then N {1, 3, 5, …}

These probability distributions of primary/secondary crossings, as well as the probability distributions of crossing at junctions (protected or not) or at mid-block locations, which are important determinants of the risk exposure of the pedestrian population in the study area, have to be estimatedon the basis the analysis of the sample of collected trips. This analysis requires first a data base on the street network and secondly a methodology to match by means of a GIS the trajectories collected by GPS or manually on a map on the digitised street network to identify the sequences of the the trip and the crossings.

## III.1. Urban network data base

Information on the urban network has to be structures in order to be stored and represented in a GIS. We rely on official data files concerning the street network, but a lot of complementary informations has to be collected on pedestrian crossings.

In France, georaphical dta come from the National geographical Institute (IGN). We get an objective ans officialy centralised information of the territory. To assess the exposure of pedestrian with a GIS, we have first to complete the information about the network and the regulation of the junctions, seondly to create new geographical data not given by IGN such a s the zebra crossings.

The GIS we use dis composed by 5 information layers in order to model the urban network and to assess the exposure of pedstrains when crossing a street.

1) A file which is a description of the street network divided into segments of three categories: pedestrian only, car/pedestrian, car only and a representation by means of a graph (arcs and nodes). When the segment is for both use, we know if both sides of the street or just one side(left/rigth) is available for pedestrian. A column for each side of the road is coded to match the node-to-node directions in the road attribute table (for example : Dir_AB_side, Dir_BA_side (i.e. nodes A & B)), to specify if walkways are on one side of road or on both sides of the road

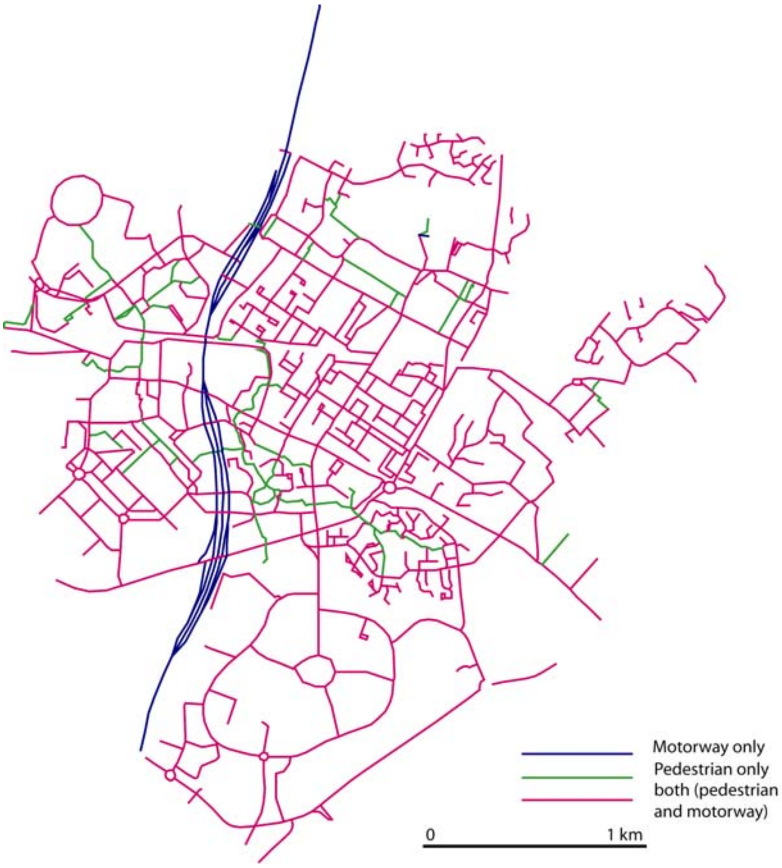


Figure 4 : Typology of the transportation network

2) A file containing all the zebra crossings coded as a node on the lines representing the street network. Each crossing is defined by a set of attributes which gives the number of lanes to cross, the nature of the protection offerd (island) and the type of the crossing (zebra, pelican, bridge, tunnel). The source of information is aerial photography.

3) A file containing the set of the red ligths. They are nodes located on the street network. The attributes give the kind of location (mid-block or junction), and the coverture in term of way of traffic.

4) A layer containing information on the types of usage of the network with three possibilities : pedestrian only, motorised vehicle only, mixed use.

5) A layer giving information on the existence and position of pavements for each street.

Finally in the GIS, we need 5 layers. All these informations are necessary to study the pedstrian's behavior.

The design of this assessment tool is only possible by getting or creating the data adescribed above. The main source of information is the orthography endowed with a great resolution and essential to treat and analyse the pedestrians’ trips in a city. The scale is the most important criteria to decide to create information because the behaviour of the pedestrian is located on the pavement and the places of crossing.

Table 1. Attributes description according to the layers.

| **Feature / description** | **Parameters** | **Notes** |
|---|---|---|
| Road characteistics | - Number of directions<br>- Road width (metres)<br>- Number of lanes in each direction<br>Presence of lane separation<br>1 = separation<br>0 = no | *Number of directions and number of lanes in each direction are available in the same field by description.<br>*Another field is available where the number of lane is estimated.<br>*Road width in metres Corresponds to the maximum width of the way |
| Pedestrian crossings | Type and number of crossings per road link : Zebra/Footbridge | Create separate columns for each type of crossing (e.g. zebra, subway) and provide counts of each type of crossing |
| | X/Y coordinates | Attributed with type of crossing. E.g. zebra, subway |
| Traffic Lights | X/Y coordinates | Only traffic lights in the main roads. |
| Network characteristics | 1 = pedestrian only<br>2 = motor vehicles only<br>3 = both | A single column called ‘mode’<br>Type = integer |
| Pedestrian walkways | 1 = walkway<br>0 = no walkway | A column for each side of the road, coded to match the node-to-node directions in the road attribute table. E.g. Dir_AB_side, Dir_BA_side (i.e. nodes A & B), to specify if walkways are on one side of road or on both sides of the road. |

## III.2. Spatial matching in GIS

The integraion in the GIS of the trips and the coding of information relative to the pedestrain’s behavior are made in two steps. The first one consists in digitalising the trips traced on the orthophoto during the field observation. The trips are georeferenced by positioning them as precisely as possible in accordance to the field characteristics. Due to the great precison of the orthophoto, the pavements are easily identified and one can track the trips on them. This step is repeated for each individual into a propoer and unique layer.

The second step consists in caractirising the crossings made by an individual by indicating the respective code at each created point. Note that all the crossings are obtained by just one operation : intersecting two polylines, one for the trip and the other for the street. At the location of the intersection, a point is created and added to the pedestrian trip polyline. The table with the attributes contains too the geographical coordinates of its position but also some geographical informations related to the crossed street (name of the street, width of the street, traffic data, …). Manually, one adds information on the crossing related to primary/secondary as defined in II above.

1. Identification of the trajectory as a polyline

   From the origin, connect to the network,
   From the destination, connect to the network,
   Do from origin to destination
   Find the segment, the direction and the side.

2. Identification of the crossings and caracterisation

   Identify manually the points of crossing (a cell or a pair (x,y))
   Look for the place : junction/midblock, with the segment
   Check if there is a protection : crosswalk/red ligth,
   Caracterise the crossing as primary or secondary manually

The last operation could be done automatically by unfolding the segments of the trip and using the summital graph at each nodes.

# IV. Trip data collection

Two technics are used to collect data on individual walking trip. You could equip pedestrian with a GPS and record automatically the trajectory of the trip in the city with the limits of precision and the failures of the system. Or you can follow up a person in the street with or without its agreement and record the trip either with a GPS or by drawing the trajectory on a map. As our intention is to develop the methodolgy, we choose to follow up a sample of people at the exit of a metro station without being noticed by the person during 5 minutes maximum in order to preserve as much as possible his or her privacy. In fact we have use orthophotographies. These images have a great spatial resolution, a pixel by 16 cm, which provides a very precise localisation of the person (on a pavement by exemple). One surveyor collects the trajectory and one other collects information on the crossings by means of a grid about the caracteristics of the crossings and of the traffic. The site is the area around the metro station "hotel de ville" (town hall) in Villeneuve d'Ascq. The urban environment is dedicated to administrative tertiary sector, trade, services of proximity, culture (forum of sciences)

housing, plus a school of architecture and a primary school. 78 adult people have been followed at the end of march 2004 on weekdays at different time of the day (morning, evening, off peak hours).

# V. Integration of the trajectories and the crossings using a GIS

Two operations are undertaken using the GIS : the transormation of the trajectories into polylines and the identification of the crossings with their caracteristics.

## V.1. Transformation of the raw trajectories into polylines

From the survey, we get 78 individual trips starting from the metro station. Thes trips have been drawn on the paper aerial views and reported in the GIS under the form of a georeferenced object. Each trip consists in one layer which could be combined with the other layers containing the information about the street network, the zebra crossings and all the geographical objects related to the network and rerlevant for the analysis of the pedestrian behavior. Each trajectory is represented as a polyline from which we can calculate the distance of the trip and the average walking speed. The local walking speed is not computable as the time is not registered. One advantage of the use of a GPS is to get simustanuously the time and the coordinates at a regular interval. Each trajectory could be studied in relation to the other geographic objects describing the network. Note that some of the trajectories are truncated at the end if the trip lasts more than 5 minutes which the maximum duration allowed for following up.

Figure 5. A trajectory as a polyline among the network and the zebra crossings.

By putting a grid over the aera with 3 metres cell (average width of a pavement), we can count the number of passing trough each cell. We could visualise on the map of the frequencies of the trips on the grid the distribution of the walking trips from the metro station and explore the strategies used by the pedestrians in their trips.

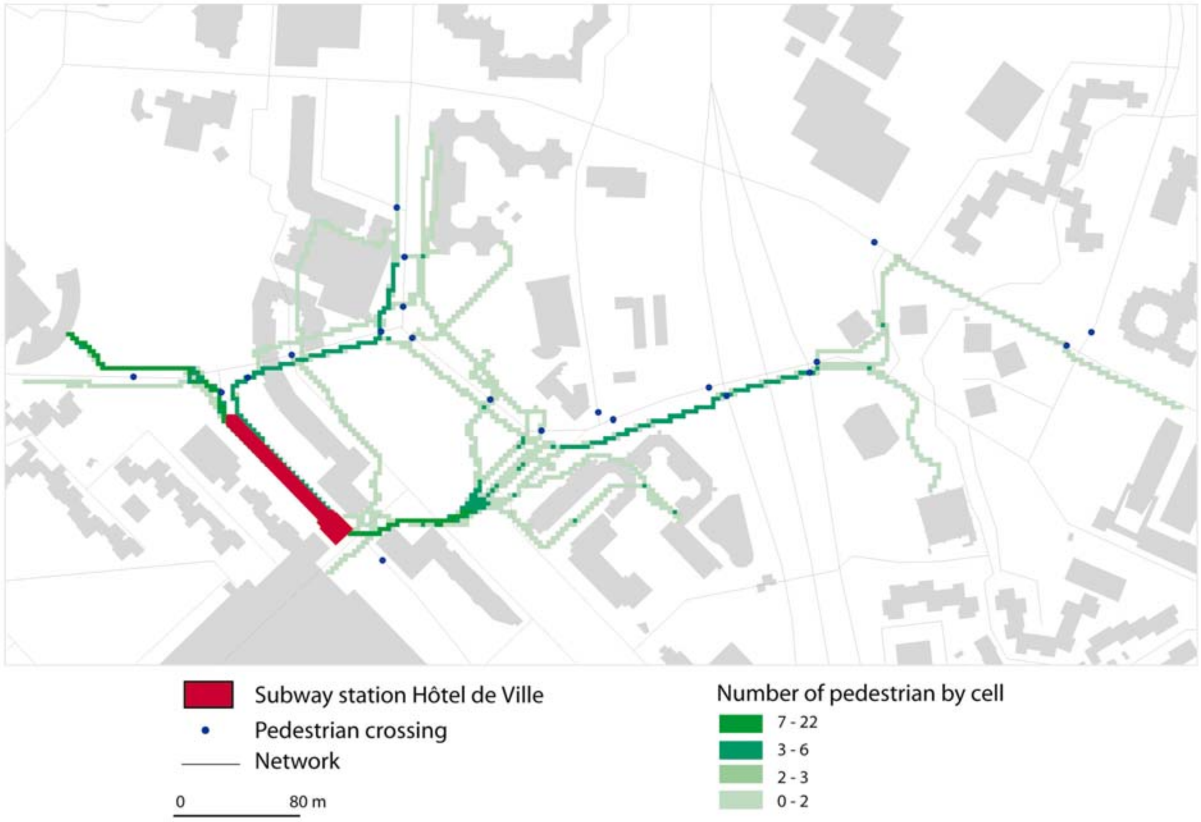


Figure 6 : Density of trips from the survey round the metro station Hotel de Ville.

## V.2. Identification of the crossings with their caracteristics

Where the polyline of the trajectory intersects the street network, we localise a point and enter three types of information : the situation in which the crossing is made, the vertex used and their orientation (origin-destination, right/left side) and their number. In the last, the kinds of protection and exposure are precised. Thest are the data from which we can compute the statistics related to the accident exposure when crossing a street.

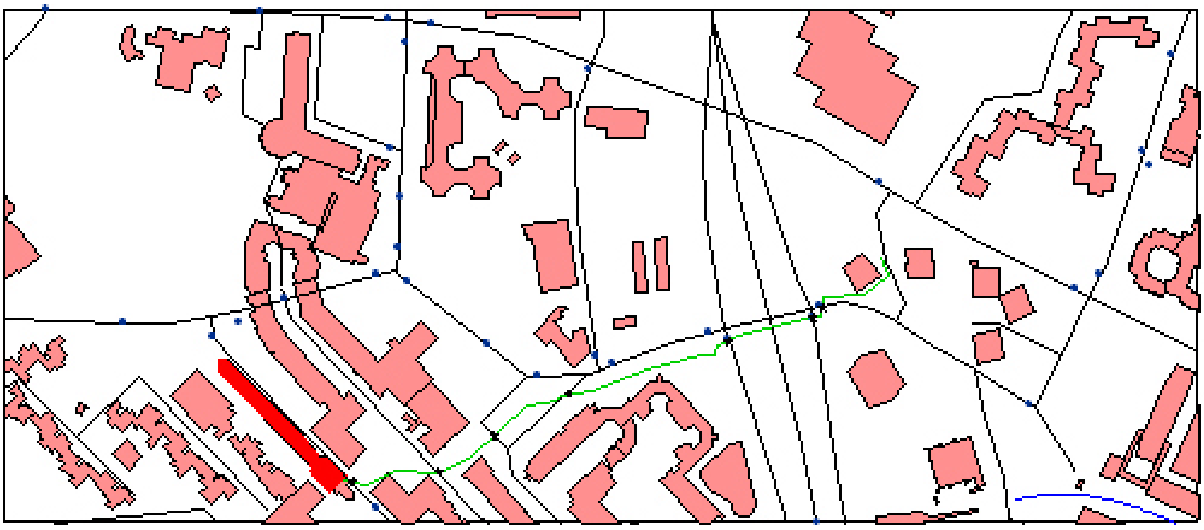


Figure 7. Manual coding of information related to crossings.

# VI. Estimation of indicators related to crossing behavior

On the basis of the geographical data collected, a typology of pedestrian crossing behavior can be created. In particular, the number and type of crossings per trip characteristics are examined. Moreover, a breakdown of crossing decisions per junction or mid-block, protected or non-protected is created. A comparison of these decisions with the available crossing options is useful for the identification of the degree of compliance of pedestrians to traffic rules and the crossing strategy adopted along a trip.

## VI.1.Number and type of crossings

The survey results confirmed the initial assumption that, in trips where origin and destination are on the same side of the trip direction, the number of primary crossings is even {0, 2, 4, …}, whereas where origin and destination are on different sides of the trip direction, the number of primary crossings is odd {1, 3, 5, …}. Moreover, pedestrians appear to minimize the total number of primary crossings per trip. It is also interesting to note that most trips include at least one secondary crossing. The frequencies of number of crossings per trip for the examined trips are summarized in Table 2 below:

Table 2. Frequency of number of crossings per trip

| | **Number of trips** | | | |
|---|---|---|---|---|
| | Side O/D 1 | Side O/D 2 | Total | |
| **Crossings per trip** | Primary | | | Secondary |
| 0 | 23 | | 23 | 0 |
| 1 | | 32 | 32 | 11 |
| 2 | 22 | | 22 | 16 |
| 3 | | 5 | 5 | 10 |
| 4 | 0 | | 0 | 8 |
| 5 | | 1 | 1 | 4 |
| 6 | 0 | | 0 | 2 |
| 7 | | 0 | 0 | 2 |
| 8 | 0 | | 0 | 1 |
| **Total trips** | 45 | 38 | 83 | 121 |
| **Total crossings** | 44 | 52 | 96 | 159 |

Various statistical distributions for discrete data were fitted to the counts of primary and secondary crossings per trip, including Binomial, Poisson, Negative Binomial, Integer Uniform and Geometric distributions. Results showed that the total number of primary crossings per trip is best described by a Binomial distribution with parameters n=4 and p=0.277, for which a chi-square goodness-of-fit statistic equal to 0.482 is obtained, corresponding to a p-value equal to 0,923. It should be noted that this best fit was achieved once the sample values (crossings per trip) were truncated to 4; including the extreme case of 5 primary crossings per trip resulted to a less satisfactory fit.

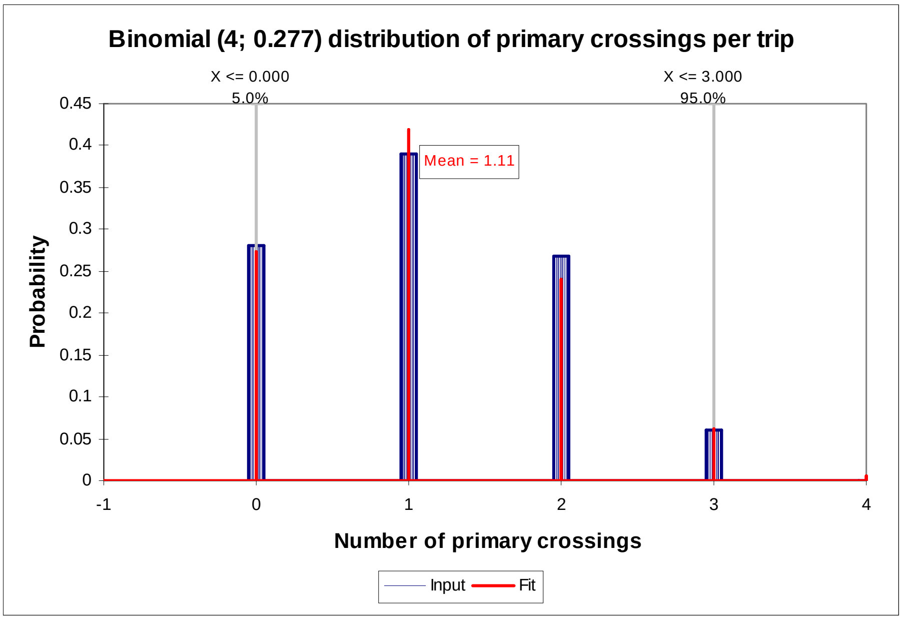


Figure 8. Observed and fitted distribution of the number of primary crossings per trip

The above distribution concerns the total number of primary crossings; however, the values {0, 2, 4…} refer to trips with side O/D=1 and the values {1, 3, …} refer to trips with side O/D=2.

As far as the number of secondary crossings per trip is concerned, it was found that it is best described by a Poisson distribution with parameter λ=2.94, which corresponds to a chi-square goodness-of-fit statistics equal to 1.58 with a p-value equal to 0.812.

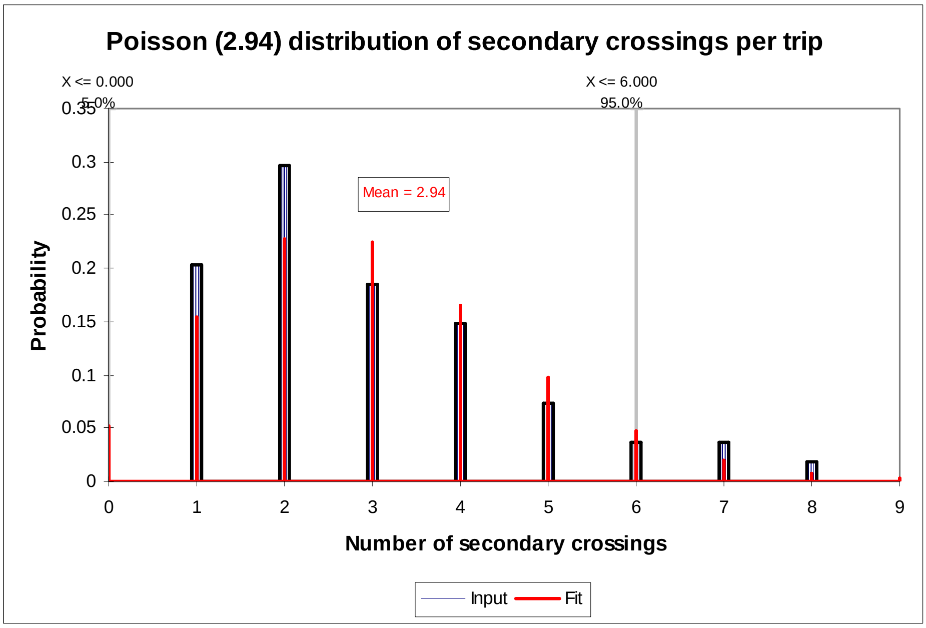


Figure 9. Observed and fitted distribution of the number of secondary crossings per trip

The above probability distributions can be exploited for the aggregation of the exposure of a population with a given pedestrian activity (number of trips).

However, another parameter of pedestrian behavior affecting the amount of exposure is the location of crossings within the trip i.e. the tendency of individuals to cross earlier or later along the trip. This analysis only concerns primary crossings, as the secondary crossings are a consequence of the choice of primary crossings. The results of the survey are presented in the following Figure 10.

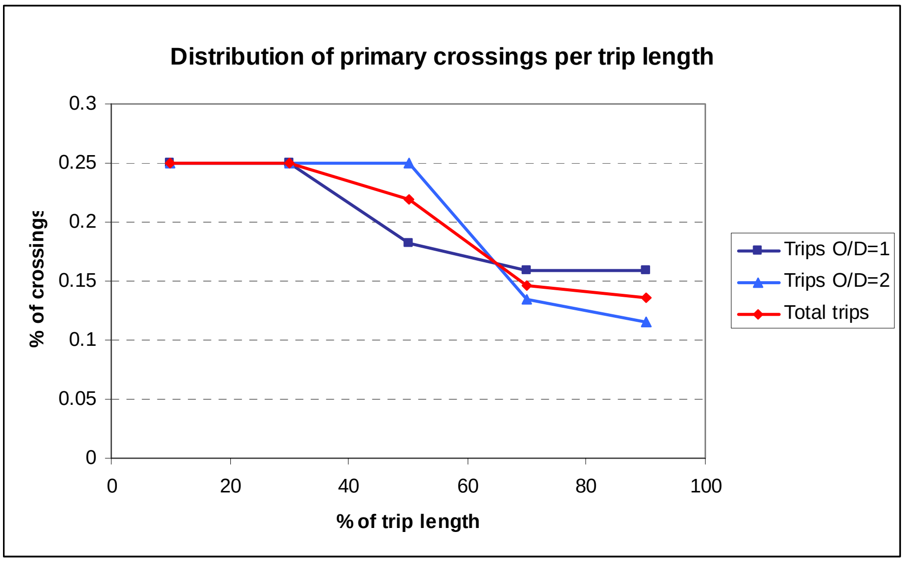


Figure 10. Distribution of primary crossings per trip length

It is interesting to note that 25% of primary crossings take place during the first 20% of the trip length and 50% of primary crossings take place during the first 40% of the trip length, regardless of the relative setting of origin and destination. This strongly suggests that pedestrians are more likely to cross earlier along the trip, i.e. reach the side of the roadway corresponding to their destination as soon as possible and then carry out only the necessary secondary crossings. In particular, in trips with origin and destination on the same side of the trip direction (O/D=1), where it was shown that pedestrians are more likely to carry out two crossings, the crossings are distributed along the trip in a more uniform way. More specifically, there is a higher probability of crossing towards the end of the trip compared to the average, obviously due to the fact that there is a second crossing to be carried out. On the contrary, in trips with origin and destination on different sides of the trip direction (O/D=2), where it was shown that pedestrians are more likely to carry out one crossing, 75% of primary crossings take place on the first 60% of the trip length, while the probability of crossing towards the end of the trip is lower compared to the average.

The above probability distributions can be exploited for weighting the number of crossings along the related trips in relation to the total trip length.

## VI.2. Analysis of the distribution of crossings between mid-block and junction

As mentioned above, the selected location of a crossing is an important determinant of risk exposure. The decision between junction and mid-block location, in combination with the related selection of a protected or unprotected one, may imply significantly different amount of exposure for a given trip. In the following Figure 11, the decisions of pedestrians in the study area are examined in relation to the respective options available.

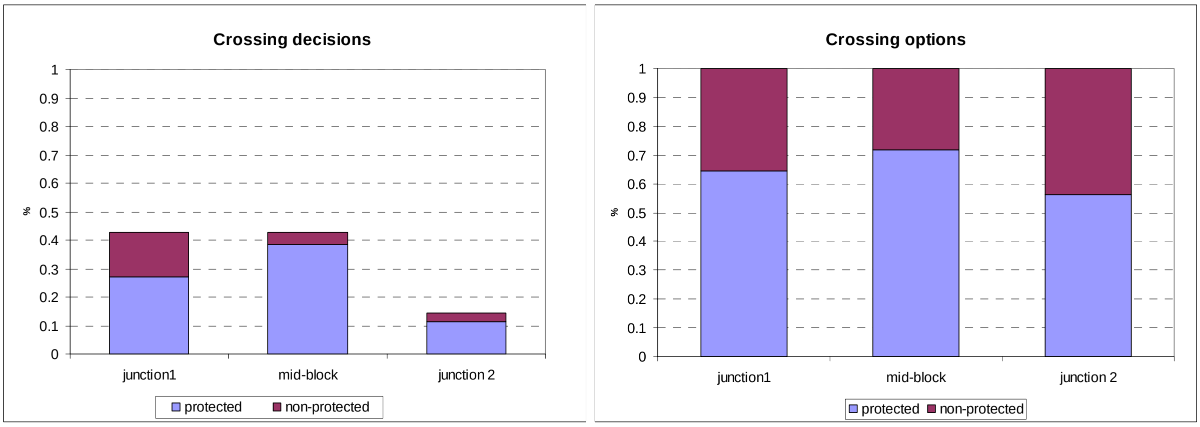


Figure 11. Pedestrian crossing decisions (junction or mid-block / protected or non-protected) and related options available.

These Figures are explained as follows: on each road link where a crossing took place, there were three options available, junction 1 (i.e. the first junction on the pedestrian's way), mid-block and junction 2 (i.e. the second junction on the pedestrian's way). The Figure on the right shows the proportion of protected options for junction or mid-block. A protected option refers to the presence of a zebra crossing or a traffic signal. The Figure on the left presents the breakdown of crossing decisions of pedestrians per crossing option. It should be noted that these sum up to 100% of the total crossings in the study area.

The results show that, in general, pedestrians prefer protected over non-protected crossing options. Moreover, only 15% of crossing decisions concern junction 2; in most cases, crossing decisions are evenly shared between junction 1 and mid-block. Additionally, it is interesting to notice that, although the proportion of protected crossing options is similar for junction and mid-block, an increased percentage of non-protected crossing decisions is observed at junctions 1. This may be attributed to the fact that pedestrians feel more protected at junctions in general, or they sense that vehicles are more likely to yield for them at junctions, and consequently they do not distinguish between protected and non-protected junctions.

In general, from the above results, it can be deduced that pedestrians are more likely to cross on the first option along their way (junction 1 or mid-block), however they are more conservative as far as mid-block locations are concerned and avoid non-protected ones.

Summarizing, the above results concern an in-depth empirical investigation of pedestrian behavior along a trip. The estimated probability distributions can be exploited for aggregating exposure over a population with a given pedestrian activity according to the following hierarchical structure:

- Estimation of the number of crossings (by type) per trip
- Estimation of the location of these crossings along the trip
- Estimation of the specific location of each crossing on the crossing area

It should be noted, though, that part of these results may reflect particularities of the specific network (few traffic signals, low traffic volumes etc.) It would also be interesting to investigate these issues on a more urban network.

# VII. Conclusion

The use of a GIS is mandatory to localise and code information on walking trips and street crossings obtained from a sample of individula trips monitored either by GPS or by surveyor reporting on an orthophoto of the urban zone. An important indicator useful for a accident risk exposure assessment has been estimated: the distribution of the number of crossings made along a trip according to its type : primary/secondary. As these crossings have been localised as points on the network, we could transfer information about the caracteristics of the mid-block or junction crossed (number of lanes, red ligths, zebra crossing) and of the caracteristics of the traffic flows and be able to compute the risk exposure indicator which has been defined at the beginnig.

Furthermore, from an in-depth empirical investigation of pedestrian behavior along a trip by means of a GIS, we have been able to analyse the location of these crossings along the trip (not unifromly distibuted but rather concentrated at the beginning) and the attractiveness of the protection offerd by the zebra crossings and the red ligths for the pedestrian. It should be noted, though, that part of these results may reflect particularities of the specific network (few traffic signals, low traffic volumes etc.).

# Acknowledgements

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