ASSESSMENT OF THE PEDESTRIAN CROSSING RISK: PROCESSING OF A NUMERICAL MODEL

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ABSTRACT

Referring to the most recent surveys, the pernicious accidents involving pedestrians in urban environment represent almost 14% of the total amount of road crashes victims.

Moving from these assumption, this study is focused on the interaction between vehicles and pedestrians traffic flows, with the intention to process a numerical model which would assess the pedestrian crossing risk, acting also as a support for the definition of the most appropriate design solutions.

More specifically, the starting point of the research was based on an on-site survey of the most critical urban trunks of the city of Potenza (Italy) by means of the "*traffic conflicts technique*"; afterwards, both the geometric and functional (*legal and illegal streams, number and severity of conflicts*, etc.) conditions were analysed, all of them being the starting point for the arrangement of a mathematical model for the assessment of the pedestrian crossing risk.

So as to characterise such model, a specific formula was calibrated, which takes into account the relative weight of each single characteristic and whose application allows to determine the risk level for each crossing, having a clear understanding of the real safety conditions of pedestrians.

Afterwards, in order to divide the hazard conditions into homogeneous classes, an indicator called *"risk rate"* was introduced, and on the basis of such parameter, some different intervention scenarios were suggested for the most critical crossings.

In addition, some adjustments of the infrastructure were proposed for the sake of both pedestrian safety and comfort, pointing out, were necessary, the materials to be used for the pavements in order to highlight the conflict points.

In conclusion, the suggested model is a useful support instrument for the *safety review* process since, taking all the variables and boundary conditions into account, it brings to an objective improvement of the pedestrian safety in urban environment.
Keywords: *pedestrian crossing risk, road safety, risk rate, safety review.*

1 SYNOPSIS

Facing the concern of the interaction between vehicles and non-motorized traffic in urban environment means that two fundamental aspects of mobility are to be taken into account: accessibility and safety.

The motorized component is most of the times predominant in urban areas, thus being a threat for weak users: referring to the ISTAT annual survey data, it is evident that the town is the place where the highest number of casualties happens, this number being 75% of total accidents. In addition, in the last ten years 14% of the fatalities involved pedestrians.

In Italy, the Standards face the traffic quandaries from the driver point of view, trying to minimize the running times and to achieve the desired speed, both in the case of the Nuovo Codice della Strada (NCDS) and of the 5/11/2001 decree "*Norme funzionali e geometriche per la costruzione delle strade*".

The last adjournment D.L. 121/2002 -"*Disposizioni urgenti per garantire la sicurezza nella circolazione stradale*" - and D.L. *n. 151* del 27/06/2003, eventually tried to give importance to pedestrian traffic, although they are much more concentrated on increasing the sanctions and the repressive aspects of the Norm.

Actually, the Urban Traffic Plan (PUT) is the very step forward, which proposes some new concepts as the environmental isle, the pedestrian network continuity and the 30 km/h speed limits in residential areas. Thus, the PUT is the first Italian instrument which considers pedestrians as a pivotal traffic component, therefore overturning the usual idea for which all the norms framework was basically focused onto vehicles.

However the law on PUT lacks of practical accomplishment indications, hence not acting as the real traffic calming instrument it is intended to be.

2 DETAILS ON THE INVESTIGATION CARRIED OUT

Having stated this, the experimental investigation proposed in this paper was concentrated on the interaction between the flows of vehicles and pedestrians, aiming at the elaboration of a mathematical model which would assess the risk of street crossings and support the spotting of the crossovers which need to be improved from the safety point of view.

An on-site survey of the most critical areas of the city of Potenza (Italy) from the standpoint of pedestrians safety, based on the statistical data of the last decade, was the starting point of the research.

By means of the *traffic flows conflicts technique* a large number of pedestrian crossings were catalogued on the basis of the hazard level, as function of the interaction between pedestrians and vehicles traffic flows.

In addition, the assessment of road geometry where the crossings are located was carried out, along with the definition of the characteristics of the vehicles flow itself (average speed, traffic components, etc.).

At the end of the survey stage, such geometrical and functional characteristics were employed, together with the "*traffic conflicts*" variables (*legal and illegal pedestrian rate of flow, number and severity of conflicts, etc.*), for the definition of a mathematical model for the assessment of the crossings risk assessment.

The proper calibration of all the parameters, along with the data of the on-site survey which are actually the input for the model, allowed both the determination of such risk and the identification of the techniques and the interventions which are to be considered so as to reduce the hazard within the desired values.

Hence, each pedestrian crossing investigated during the research, was assessed in terms of safety by means of an indicator, which clusters them in homogeneous hazard classes, before and after the intervention.

2.1 State of the art

The potential risk for weak users has been largely faced by several people and Institutions; more specifically, some researchers focused their efforts on both the interaction pedestrians- traffic flow and the traffic calming measures (Busi R, Tiboni M. (2003), Busi R., Zavanella L. (2003), Cappelli A. et al. (2000), Festa D., Nuzzolo A. (1990), Maternini G., Zavanella L. (2001)).

Some others investigated on the boundary conditions for the increase of pedestrian safety, as Mc. Mahon P.J. (2002) and, more recently, Ranzo A. et al. (2004).

A much wider interest in road safety, hence including also pedestrian, is the essence of the European Community action in recent years, with the aim to dramaticaly reduce the number of fatalities across Europe by 2010 (Commissione della Comunità Europea (2001) (2003).

2.2 Data collection

The investigation started with the statistical data acquisition of all the crashes in town involving pedestrians in the period 1996-2004, which were provided by the Municipal Police of the city of Potenza. These information are included in Table 1.

Table 1 Urban crashes involving pedestrians in the period 01/01/1996 – 31/12/2004

MUNICIPALITY OF POTENZA
MUNICIPAL POLICE
ROAD CRASHES DEPARTMENT

YEAR	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*TOT.*
CRASHES	179	147	127	189	194	203	318	296	284	1937
PEDESTRIAN CASUALTIES	6	7	8	13	10	6	6	5	5	66
INJURED	102	93	73	159	149	185	194	176	164	1295
PASSED AWAY	1	1	==	1	==	2	1	1	2	9

2.3 Investigation sites spotting

Three big rings with severe pedestrians hazard within the urban network of the city of Potenza were spotted from the analysis of the above mentioned data, their length being, respectively, 1.3, 2.7 and 3 kilometres.

The preliminary survey, apart from locating the investigation spots, was dedicated to the determination of the time of the day the pedestrian flow was predominant in each of the road sections (e.g. rush hours for schools and offices, opening time of shops, etc.).

Hence, the investigation on site involved the direct watching of every crossing, for each ring, for one hour a day, at rush hours, for five consecutive working days, without considering the closing days of school for bank holidays.

As a matter of fact, the following details were collected:

- ✓ Number and typology (mild, average, severe) of traffic conflicts;
- ✓ Number of pedestrians crossing on crossovers, thus “legal”;
- ✓ Number of “illegal” crossings with relative plots with the indications of position, direction and orientation;

Table 2 refers to on of the survey sites, with all the indication above mentioned; such outcomes were afterwards represented with some plan views, as illustrated in Figure 1.

Eventually, in Table 3 there are all the most important considerations on the case, after thorough analysis of the events which occurred at the intersection.

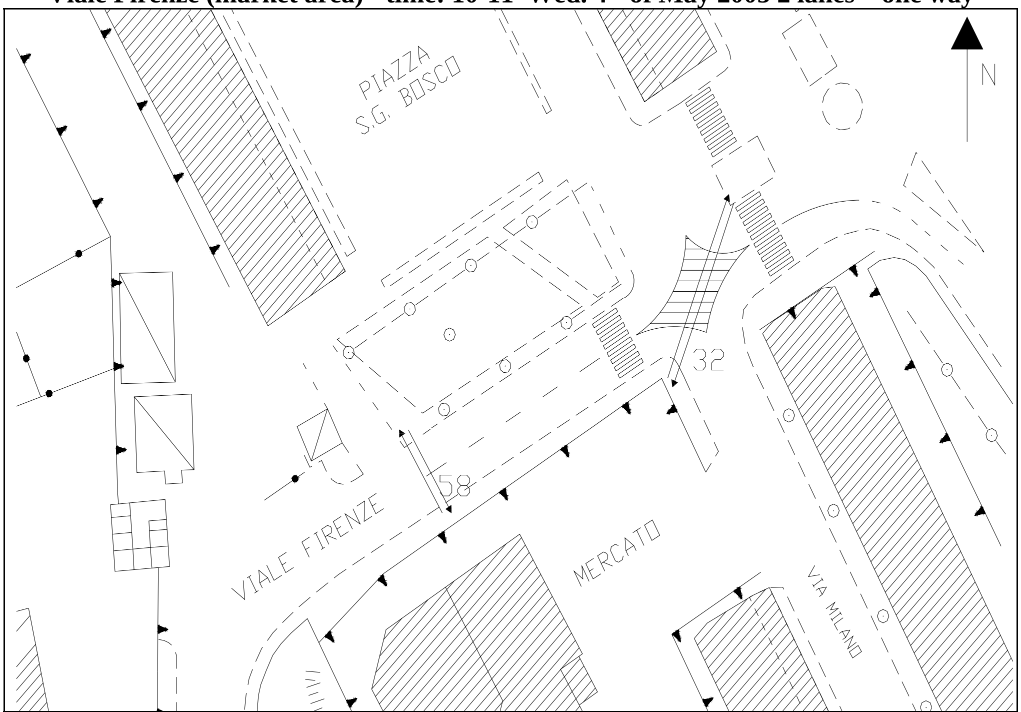
Table 2 Type file of the investigation on-site

LOCATION 1	DATE AND TIME	ILLEGAL CROSSINGS	LEGAL CROSSINGS	CONFLICTS			
				Mild	Avg	Sev	Total
RING 1							
Market surroundings	02-06/05/2005 h. 10-11	1113	243	22	7	-	29
Street number 36	09-13/05/2005 h. 10-11	220	90	6	1	-	7
Don Bosco Square	16-20/05/2005 h. 10-11	135	52	10	4	-	14
Intersection with Messina Street	23-27/05/2005 h. 8.30-9.30	245	91	16	6	-	22
Intersection with A.Vecchia Street	19-23/09/2005 h. 8.30-9.30	210	15	5	-	-	5
Intersection with Sabbioneta Street	26-30/09/2005 h. 13-14	910	325	20	5	2	27

Table 3 Type file with details and observations on the pedestrian crossing analysed

TRAFFIC CONFLICT N° 1	
Time	10.02
Traffic conditions	Mild
User A	Elderly pedestrian
User b	Passenger car
Conflict severity	AVERAGE
Detailed description	*An elderly pedestrian is walking on the crossing while an approaching car obliges him to push up his movements*

Viale Firenze (market area) - time: 10-11 Wed. 4th of May 2005 2 lanes – one way



Pedestrian crossings = 525		Traffic conflicts
Legal crossings	Illegal crossings	
435	91	9

Figure 1 Plan view representation of the outcomes of the investigation on-site

3 MODEL GENERATION

3.1 Characteristic parameters

Starting from the data collected for each of the situations analysed, a model for the hazard assessment of the pedestrian crossings was derived, taking into account all the variables involved in the process.

In particular, the analysis of traffic conflicts allowed the Author to spot the following variables; for the sake of understanding, variables 1,2,3,4,6,9,13 and 14 have been measured on site by the Author, while the remaining ones were calculated according to references and tables found in literature (Busi M., Tiboni M. (2003) and Cappelli A. et al (2000).

1. number of traffic conflicts:
   - n_l = number of mild conflicts
   - n_m = number of average conflicts
   - n_g = number of severe conflicts

2. pedestrians legal rate of flow: P_{leg} = *legal crossings / h*

3. pedestrians illegal rate of flow: P_{ill} = *illegal crossings/ h*

4. distance between the illegal crossover and the pedestrian crossing: d [m]

5. irregularity factor of the crossings:

$$I = \begin{cases} 0 & \text{if } 0 \le P_{ill} \le 25\%\ P_{leg} \\ 0.025 & \text{if } 25\%\ P_{leg} < P_{ill} \le 50\%\ P_{leg} \\ 0.05 & \text{if } 50\%\ P_{leg} < P_{ill} \le 75\%\ P_{leg} \\ 0.10 & \text{if } 75\%\ P_{leg} < P_{ill} \le 100\%\ P_{leg} \\ 1.1 - (P_{leg} / P_{ill}) & \text{if } P_{leg} < P_{ill} \end{cases}$$

Afterwards, by means of the graphical representation of the crossings, the following variables were determined:

6. distance between two consecutive crossings or between a crossing and an intersection: d_{att} [m]

7. length coefficient of the crossing:

$$L_A = \begin{cases} 1 & \text{if } l < 5\text{m} \\ l^{0.04} & \text{if } 5\text{m} \le l < 7\text{m} \\ l^{0.06} & \text{if } 7\text{m} \le l < 9\text{ m} \\ l^{0.08} & \text{if } 9\text{m} \le l < 11\text{m} \\ l^{0.1} & \text{if } l \ge 11\text{m} \end{cases}$$

(l = length of the pedestrian crossing)

8. saturation rate of flow of the crossing (maximum number of pedestrians which can regularly cross the street in one hour):

$$P_s = P_p \times t_v \times b \qquad \text{[pedestrians / h]}$$

where:

P_p = maximum pedestrian flow for the service level considered, which can be taken from Table 4;

t_v = time (fraction of hour) dedicated to crossings, based on traffic light signalling;

b = width of the pedestrian crossing.

Table 4 Pedestrian service levels

Service level	Characteristics of the flow	Pedestrian area [m^2 /ped]	Average speed [m/min]	Pedestrian flow [ped/min/m]	% Maximum capacity
A	Free	>12	>80	<7	8
B	Free with restrictions	>4	>75	<23	28
C	Stable	>2	>73	<33	40
D	Conditioned	>1.5	>70	<49	60
E	Congested	>0.5	>45	<82	100

9. visibility of the crossing:

$$Va = \begin{cases} 1 & \text{if stopping sight distance is assured} \\ D_A / D_A^{mis} & \text{if it is not} \end{cases}$$

where:

D_A = the stopping sight distance to be determined by the specific table in the Italian Standards D.M. 05/11/01;

D_A^{mis}=the free sight distance, or the part of the track from where the driver can catch sight of the pedestrian crossing, no matter the traffic, atmospheric and illumination conditions;

10. vehicles circulation direction:

$$s = \begin{cases} 1 & \text{if one-way street} \\ 0.94 & \text{if two-way street} \end{cases}$$

11. generalised vehicles rate of flow: $Q = Q_{cars}\ (\ 100 - P_t + E_t \times P_t\ )\ /\ 100$ [vehic / h]

where:

P_t = buses and heavy trucks;

E_t = equivalent coefficient of passenger cars, which can be inferred from literature.

12. saturation rate of flow of vehicles: $S = \quad S_0 \ x \ N \ x \ f_W \ x \ f_{HW} \ x \ f_G \ x \ f_P \ x \ f_B$ [vehic / h]

    where the coefficients (tabled in literature) are the following:
    S_0 = saturation flow, or the maximum hour flow which can be disposed of by a lane without circulation obstacles, generally assumed equal to 1900 vehic/h;
    N = number of lanes;
    f_W = correction factor which considers the width of the road;
    f_{HW}= correction factor which considers the percentage of heavy vehicles on the flow;
    f_G = correction factor which takes into account the slope of the road;
    f_P = correction factor considering the stopping possibility;
    f_B = correction factor which considers the presence of bus stops.

13. speed of the vechicles flow: $v^{85}\left[\frac{km}{h}\right]$ (85 percentile of vehicles speed)

14. speed limit of the road: $v^{\lim}\left[\frac{km}{h}\right]$

After detecting all the above mentioned variables, which were also calibrated as function of their relative weight in terms of hazard, and using as input the data learnt on-site, the Author derived the following mathematical model (Eq. 1) which defines the risk value of a pedestrian crossing:

Eq. 1

$$R = V_A \cdot L_A \cdot \left\{ 0.015 n_l + 0.03 n_m + 0.045 n_g + \frac{0.92}{P_S} \cdot \left[P_{leg} + 3.78 \sum_{i=1}^{n} \left(\frac{d_i}{\frac{d_{att}}{2} - d_i + 5.3} \right) \right] + \left[\sum_{j=1}^{m} \frac{1}{31.8} \left(\frac{Q_j}{S_j} + \frac{V_j^{85}}{V_j^{lim}} \right) \right]^s \right\} \cdot (1 + I)$$

where:
i= number of illegal crossings;
j= number of lanes.

3.2 Assessment of the risk rate of a pedestrian crossing

Three levels for the risk rate of the pedestrian crossings were thence defined, the consequent definition of the risk level of such crossovers being so defined:

$0 < R \leq 0.35$	→	Low risk rate
$0.35 < R \leq 0.70$	→	Average risk rate
$R \geq 0.70$	→	High risk rate

As a consequence, the model was applied onto all the pedestrian crossing of the chosen rings of the city; for the sake of brevity only a minor part of the outcomes is reported in Table 5

Table 5 Risk rate of some of the crossings, calculated with the proposed model

Location 1	**RISK LEVEL**	**RISK RATE**
Market surroundings	***0.478***	**AVERAGE**
Street Number 36	***0.115***	LOW
Don Bosco Square	***0.256***	LOW
Intersection with Messina Street	***0.452***	**AVERAGE**
Intersection with A. Vecchia Street	***0.232***	LOW
Intersection with Sabbioneta Street	***0.418***	**AVERAGE**
Anzio Street – Alberghiero School	***0.905***	**HIGH**

3.3 Interventions proposed for the most hazardous pedestrian crossings

The results obtained after the application of the model allowed the Author to highlight the pedestrian crossing which urgently need to be subjected to interventions for the reduction of the risk rate and, most of all, to identify which are the most effective actions to be undertaken.

For the sake of understanding, one of the situations faced during the investigation which showed as being critical from the standpoint of users safety is reported in this paper: it is a pedestrian crossing located nearby a 4-arms intersection on a three lane two-way urban road, one of them being the bus lane (Figure 2)..

So as to reduce the risk level, as illustrated in Figure 3, the Author proposed the re-arrangement of a "bayonet" crossing, by moving forward part of the sidewalk located on the left hand side of the road and by inserting a brand new safety island just in the central reserve of the carriageway.

In this way the protected area is increased and both pedestrians and cyclists have the chance to rest at mid-way of their crossover, the crossing length being thus almost halved.

The protection is achieved by employing rubber seams with prismatic reflecting surface.

In addition, since the speed of the vehicles coming from North was found to be the most critical component in the pedestrians hazard, the model suggested to put in place a speed-calming band, along with the appropriate traffic signals. Furthermore, the horizontal signals were found to be in need of replacement and the parking stalls were removed in order to increase the sight distance up to the required level.

Table 6 represents the comparison of results obtained by applying the model derived, before and after the suggested changes, so as to understand to what extent the improvement would reduce the pedestrians risks, all the other boundary conditions being unaltered.

Figure 2 One of the crossing before the intervention

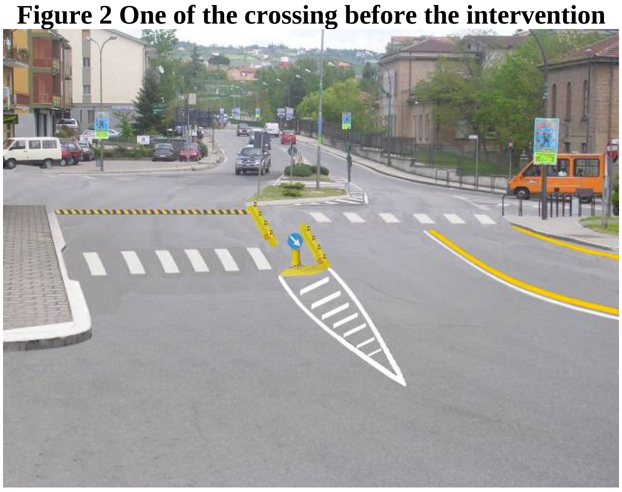


Figure 3 The same crossing after the intervention suggested

Table 6 Risk value and rate of one of the crossings before and after

	BEFORE	AFTER
Number of mild conflicts	2	2
Number of average conflicts	2	2
Number of severe conflicts	0	0
Legal rate of flow	49	49
Illegal rate of flow	18	18
Length coefficient of the crossing	1,2	1,113
Saturation rate of flow of the crossing	5760	5760
Maximum pedestrian flow for the considered pedestrian level	*32*	*32*
Crossing length	*4*	*4*
Crossing Time (part of one hour)	*45*	*45*
Distance of illegal crossings from the pedestrian crossing	11	11

(contined)	BEFORE	AFTER
Generalised vehicle rate of flow	1030	1030
Vehicles rate of flow	*1000*	*1000*
Buses and heavy vehicles percentage	*3*	*3*
Equivalent coefficient of passenger cars	*2*	*2*
Traffic flow speed	40	25
Speed limit	50	50
Saturation vehicle rate of flow	1402	1388
Saturation flow	*1900*	*1900*
Number of lanes	3	3
Correction factor which considers the width of the road	*0,909*	*0,9*
Correction factor which considers the percentage of heavy vehicles	*0,97*	*0,97*
Correction factor which takes into account the slope of the road	*1*	*1*
Correction factor considering the stopping possibility	*0,89*	*0,89*
Correction factor which considers the presence of bus stops	*0,94*	*0,94*
Traffic flow direction	0,94	0,94
Distance between two consecutive crossings	80	80
Pedestrian crossing visibility	1,6	1
RISK VALUE	**0,452**	**0.236**
RISK RATE	**AVERAGE**	**LOW**

4 CONCLUSIONS

This research intended to support the preventing analysis of pedestrian crossings by elaborating a mathematical model which would quantify the risk level for users.

The investigation was based on an experimental analysis carried out on the critical urban trunks of the city of Potenza (Italy), starting from the statistical data supplied by the Municipal Police.

The on-site survey provided for the direct and continuous watching of several pedestrian crossings by using the *traffic conflicts technique* and observing the interactions between vehicles and pedestrians which might have caused casualties.

At first instance, for each crossover the variables of the analysis of traffic flows were detected, such as number and severity of conflicts, number of both legal and illegal crossings, distance of the formers from the allowed crossover areas, etc.

In addition, the geometrical and functional characteristics of the trunk where each crossing is located were taken into account, which are mainly the traffic flow speed, the carriageway width, the generalised vehicles rate of flow, the stopping sight distance, etc.

By using these variables the mathematical model for the assessment of the risk rate of pedestrian crossings was elaborated and calibrated.

At the end of the formula implementation the Author labelled each crossover with a risk value, so as to get to a clear understanding of the overall situation for the viewpoint of pedestrians safety.

In order to file the hazard conditions into homogeneous categories, another indicator was defined, the so-called risk rate, its value being low, average and high, with respect to its magnitude.

On the basis of the outcomes of the model applied onto each crossing, the critical spots were highlighted and, so as to verify the effectiveness of the model itself, some intervention scenarios were proposed for the just mentioned pedestrian crossovers.

Amongst the different alternatives, the most suitable were chosen with respect to both model results and technical-economical issues, hence detecting the solutions with the lowest risk level for users.

The outcomes were comforting, since a reduction within 35 and 48% of the risk rate was achieved for the most hazardous crossings.

In conclusion, the Author strongly believes that the model elaborated in this research is able to assess the risk of a pedestrian crossing from both the qualitative and quantitative point of view, thus acting as an adequate instrument for the safety review processes in urban sites.

Starting from this investigation it would be surely useful to develop a further mathematical model which could be adopted also at design stage for pedestrians safety audit.

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