MODELS FOR THE SAFETY ASSESMENT IN ROAD INTERSECTIONS FOR FOOTPATHS IN URBAN CONTEXT

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ABSTRACT. Analyzing the activities of the urban population, it can be noted that great part of the daily movements within the residential area is done on foot, and, as a matter of fact, the kilometres covered on foot are consistent and indispensable part of the city mobility.

Walking by foot represents the necessary conjunction link between the places of departure and arrival and the bus stops or the public car parks.

Therefore, it is essential, in the process of transport planning, at the different levels of competence, to shed a particular attention to the assessment of the safety standards of the pedestrian routes, especially in correspondence of the intersections with the great city roads.

In fact, referring to the most recent surveys, fatal accidents involving pedestrians in urban environment represent almost 14% of the total amount of road accident casualties.

The main strategies of action for the reduction of such typology of accidents are essentially finalized to obtain on one side a better protection of the weaker part, the pedestrian, and on the other side to modify the ways of use of the automobile, in particular regarding:

- modifications to the order and the regulation of the roads that contribute to communicate and, where necessary, to impose behavioural models which better adapt to the surrounding context;
- actions of redesign, where technically possible, of the dangerous nodes;
- development of specific procedures of moderation of the traffic with the application of techniques of traffic calming;
- specific participations of protection of particularly vulnerable places - schools, hospitals, churches, etc. - where not already inserted in wider plans of the area or axis.

The primary objective of this study is to develop a safety index to allow engineers and planners to proactively prioritize intersection crosswalks and intersection approaches with respect to pedestrian safety. We analyse the interaction between vehicles and pedestrians traffic flows, with the intention to calculate an Intersection Safety Index which would assess the pedestrian crossing risk, acting also as a support for the definition of the most appropriate design solutions.

Keywords: *intersection, safety, pedestrian, risk, model.*

INTRODUCTION

The pedestrian accident rate in Italy represents a national emergency, in fact, the last statistical data shows how the number of casualties among pedestrians has risen, in countertrend compared to the number of deaths on the total of road incidents [ASAPS (2007)]. In particular, there are in average sixty pedestrian victims daily, and in the 51% of the cases the responsibility is not ascribable on the pedestrian. (Figure 1 and Figure 2).

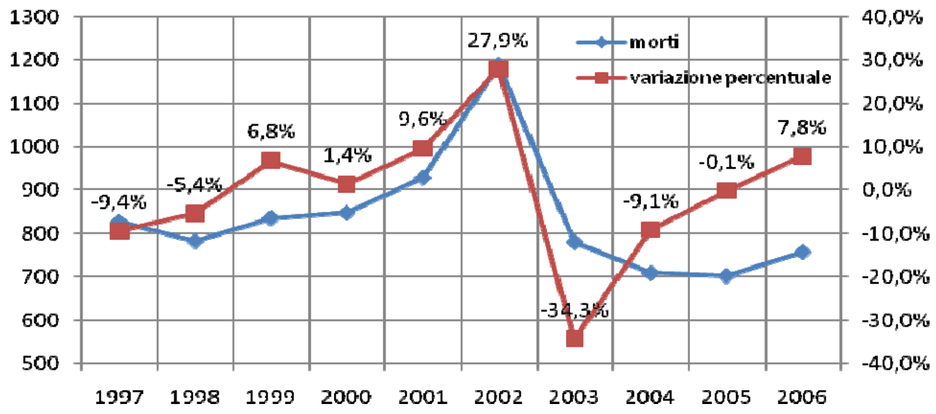

Figure 1 – Trend of casualties among pedestrians (1997-2006).

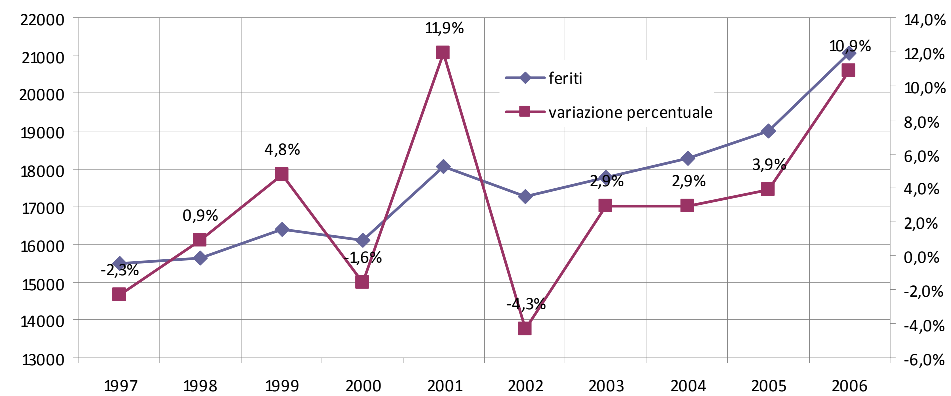

Figure 2 – Trend of the number of injured among pedestrians (1997-2006).

In the year 2000 pedestrians represented 12.7% of road accident casualties, in 2006 13.4 %. In 2006 there were 758 casualties among pedestrians, 55 more than the previous year, with an increase equal to 7.8 %. Another aspect is that the victims are manly elderly and children. A true national emergency, as the total data of 8000 dead pedestrians and 170 thousand injured in the last ten years has to be compared with the total of the deaths and the wounded caused from street incidents that in the same decade have decreased respectively of 4.7% and of 2.7%, (Figure 3).

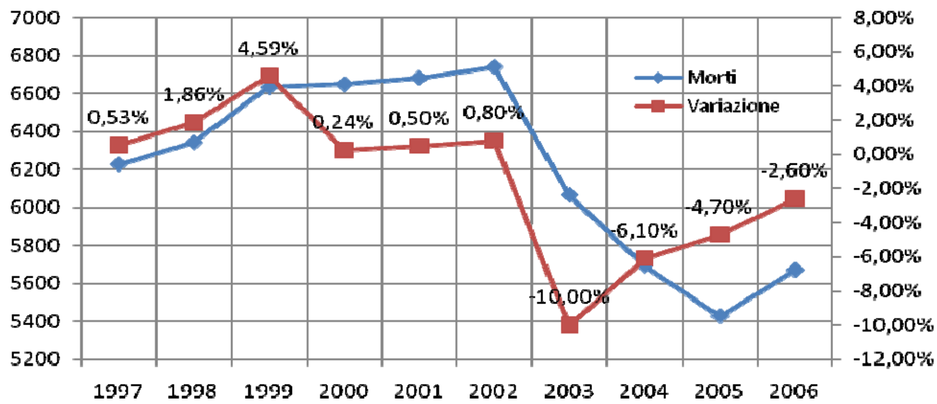

Figure 3 – Accidents in the last 10 years (1997-2006).

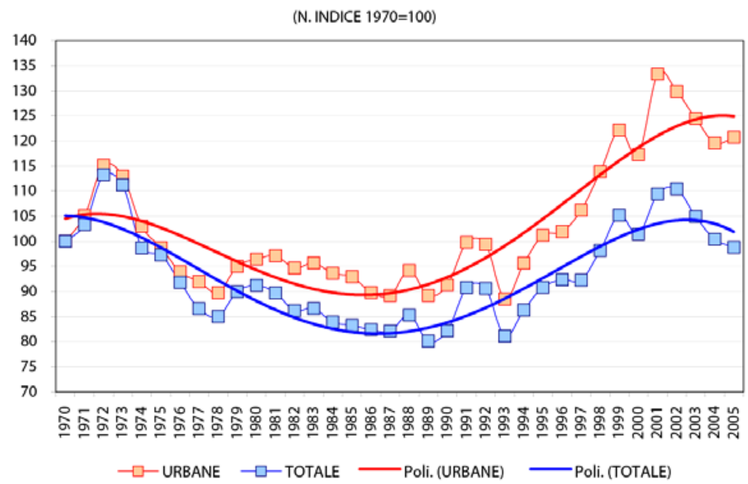

Figure 4 – Trend of the social cost for accident related damage.

The number of victims of road accidents in urban area is extraordinarily high and shows how the level of road safety in Italian cities is low [Consulta Nazionale sulla Sicurezza Stradale (2007)]. It can be observed, furthermore, than the relative deterioration of road safety has not developed in recent years, but it has been following a growing trend since 1970 (Figure 4).

Analysing these numbers it can be observed how the pedestrians are the weakest link of the urban transport system, a component often neglected and not adequately considered in the processes of transport planning and in the design process of motor vehicles, as it is only quite recent that the crash tests with the so-called "pedestrian collision" have been introduced. However, speed remains the main variable of the system "vehicle-safety-infrastructure-user". As a fact, a pedestrian hit by a vehicle that proceeds with a speed of 70 km/h has only a 10% rate of survival.

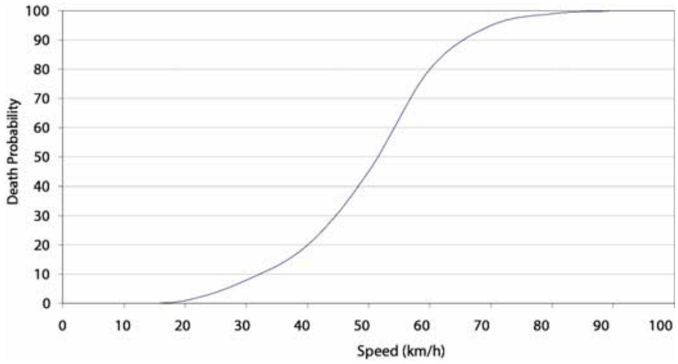

Figure 5 – Death risk for pedestrians in function of impact speed.

A vehicle that travels at a speed of 50 km/hour covers, during the reaction time of the driver (in the best case, estimated in a second), little less than 14 metres, which goes from the moment of the perception of the danger to the moment in which he/she starts to break, and covers a similar space before that the vehicle stops. Therefore, a person who finds himself within 14 metres is hit at a speed of 50 km/hour, with an impact equivalent to that of a falling man from a three story building, with a very high probability of death, or at the least with serious invalidity.

Instead, at a speed of 30 km/hour, in normal conditions it is possible to arrest the vehicle within 14 metres. Also in the case in which a person is hit from the vehicle, the collision has, lower probability of causing serious consequences, as a speed of collision of 30 km/h is equivalent to falling from a height of 3.5 mt, a collision speed of 20 km/h is equivalent to falling from a height of 1.5 m, therefore with a high probability of remaining unharmed, or with little injuries (Figure 5).

These numbers explain the reasons which push in favour of the moderation of traffic in urban areas, and explain the reasons for which the 30 km/h speed limit is set for safety's sake on roads in residential areas.

THE LEGISLATION BACKGROUND

The Italian legislation on the planning of road infrastructures and, in particular, on street safety was until the beginning of the 90's lacking in specifications, if not absent. And all the existing legislation tends to privilege the point of view of the motorist and, only recently, in the road code an attention to the needs of pedestrians seems to have been taken in consideration.

However the only real step ahead is represented from the Urban Traffic Plans (PUT) in which concepts as that one of the pedestrian zones, of continuity of the pedestrian network and 30 km/h speed limits (zones 30) were introduced for the first time in an holistic manner. The Urban Traffic Plan is, therefore, the first instrument in the Italian code that considers the pedestrian as a priority component of the traffic system.

Zone 30

The concept of *traffic calming* represents the synthesis of the different functions that are required on roads in residential areas, and with and adequate design phase the speed of motorized vehicles is limited.

In the different European experiences , the polices have taken different names, “zone 30” in Italy and France, “20 mph zones” in the United Kingdom, “tempo 30 zonen” in Germany, but substantially the concept is equal in all countries.

The road concept is maintained, as sidewalks are for pedestrians and roads are for the cars, where pedestrians do not have right of way if not on crossings (zebra crossings signalled with paint or elevated as continuation of the sidewalk). But the success, in terms of road safety is the reduction of peak speed.

Some European countries has gone as far as bringing the prescriptions into Legislation: in the United Kingdom they were introduced by the Traffic Calming Act in 1992, while in France they were introduced by the decree 29/11/1990 n. 90/1060 “Modifications and integrations to the Road Code”.

One of the strong points of the project for zone 30 is in the idea of continuity of the pedestrian network, in the zone 30 the concept of “pedestrian crossing of the road” is substituted by the “vehicle crossing of the sidewalk”.

In each intersection, raising the road platform, the motor vehicles have “to go up on the sidewalk”, invading an area in which the pedestrian has priority. Such actions concur in giving continuity to the network of pedestrian footpaths, and at the same time abolishing also the architectural features which denies access to the disabled users [Regione Piemonte (2007)].

The constituent elements of the road safety

Road safety can be seen as a complex system characterized from different variables. The elements that characterize road safety system, are:

- vehicle;
- infrastructure;
- user.

When the administrators and the institutions think in terms of pedestrian safety, often and quite simply it results in spot located developments, introducing road signalling and/or through the realization of footpaths, but it is quite seldom that these realizations are part of a more general scheme, or a there is a great attention to the pedestrian continuity and the maintenance of the infrastructures.

To be effective, form a road safety point of view all the actions must be part of a more general strategy for pedestrian mobility.

Safety actions

The actions finalized to the pedestrian protection in transport systems can be subdivided in actions for safety, for infrastructure, for vehicles and for users.

To be able to define the eventual infrastructural actions and/or of planning, finalized to the improvement of the safety standards of exercise of a road network it is indispensable to characterize the role that every arc of the net and, therefore, every road has in the network. The aim of identifying a road hierarchy is to distinguish the role each road plays in the movement of vehicles, the movement of people on foot or in wheelchairs, and as part of the local urban environment.

One of the fundamental processes is to define and establish a road hierarchy so that motor traffic can be concentrated onto the roads appropriate to its journey purpose. Improvement proposals, maintenance allocations and environmental standards all relate to the different tiers of the hierarchy, so that the character of each road is developed to best suit the functions that it has to fulfil.

The hierarchy described here represents an ideal which is very unlikely to exist in practice. But it is valuable to understand what the ideal represents when trying to establish a realistic hierarchy for an urban area.

In an ideal situation roads can be categorised into five tiers and complemented by additional routes for walking and cycling. However, in a real network, roads may not be identified with one tier and compromises have to be made. In particular, many urban roads form "mixed priority routes" where several functions have to co-exist on the road and alongside the road. In deciding the functions of a road it is important to take into account the requirements of public transport users and the size and routes of public transport vehicles and the priority given to them. Figure 6 describes an ideal hierarchy.

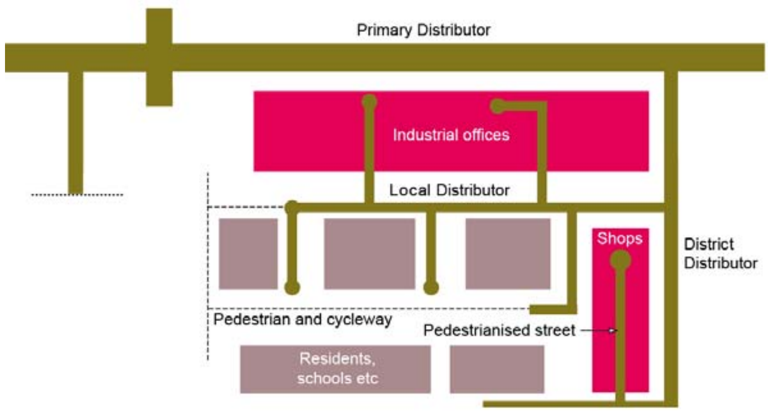

Figure 6 - Ideal schematic hierarchy of urban roads (Dep. for Transport, 2003).

While the ideal hierarchy is a useful starting point, the real roads may not fall easily into these tiers. However, it is important to identify how the local network can most appropriately perform the functions required by the area.

Discrepancies between the engineering characteristics of the roads and the functional road hierarchy are almost inevitable, but the starting point is to identify the functions currently being performed by each road.

Diversity of activity on a road and discrepancies between its engineering characteristics and the mix of functions it is performing are often associated with unusually high levels of accident occurrence. This may be because of an initial unclear definition of function or because the road and its use have been allowed to develop without adequate management. Where a road has more than one function it is important to ensure that particular attention is paid to pedestrian traffic and more priority given to pedestrian movements, especially around residential and shopping areas. It is imperative to establish at an early stage whether there are conflicts between the existing functional road hierarchy and local land use, and to establish priorities. A common problem is the barrier effect created by distributor roads. These may cut between residential areas and shops or schools, and may, therefore, have a requirement for significant pedestrian crossing movements. It is important to recognise that roads are not just arteries for movement but are also used as public spaces and can have a significant effect on community activity and quality of life.

But traffic flows are an important consideration and should be taken into account, and should be studied in detail in establishing the ideal road hierarchy. In many towns main roads may serve multiple functions and there will be a need to balance very carefully the provision for heavy vehicle flows whilst catering for vulnerable road users who are currently at great risk. Each road in the network needs to be examined in terms of its current function and its observed performance of that role. If there are problems on a route in terms of the level of traffic, traffic mix, poor accident history or environmental quality, there are really only two options to consider:

- alter its role by transferring all or some of its functions to other roads;
- retain its role, and introduce specific measures to improve its performance at the chosen level.

Local area schemes will be needed to modify the road network to achieve the overall objectives of safety whilst not inhibiting the movement of vehicles and people to any significant extent. In many cases this will inevitably take a long time but the existence of an overall strategy will assist in enabling the problems to be tackled in a logical order and in seizing every opportunity to make progress.

In an urban context *Zone 30* should not be the exception, but standard. It isn’t often that in cities the average speed is higher than 15 kmph: it is therefore quite clear that the advantage, in terms of capacity, given by peak speed limits of 50 or 70 kmph are reduced to nothing on those roads where intersections, and built up environments which require stop and go every so often. A policy to reduce peack speed has to be accompanied by infrastructural changes producing:

- restructuring ad redesign of the roads;
- introduction of pedestrian precincts, with eventual access for bicycles;

- parking dissuasion with tariff policies for the areas with higher attraction capacity (city centre, central business district).

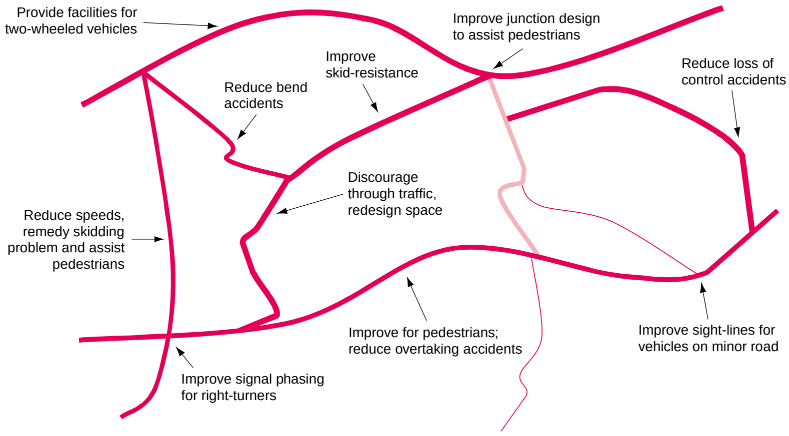

Figure 7 - Typical objective setting for sections of a network [Dep. for Transport (2003)].

In the areas of grater risk of conflict with motorized vehicles it is also useful the use of coloured pavements for cycling paths.
An important aspect for the success of actions of road safety is the use of clear, maintained and consistent road signalling.
Ambiguity on the indications and prescriptions for driving behaviour, do not help to promote safety on the roads, so it is necessary that panels should be always maintained, and when surplus to requirement should be removed, avoiding, as sometimes happen, that old and new cohabit contributing to uncertainty and potential risk exposure.

ASSESSMENT OF PEDESTRIAN SAFETY AT INTERSECTIONS

Recently studies and researches on road safety in urban environment have been addressed to the development of models for the previsional assessment of accidents in correspondence of intersections [Carter, et al. (2006), Cirianni and Luongo (2005)]. However, often these studies do not consider adequately the pedestrian who is the most vulnerable components in the transport system.

Recently a simple model for the definition of a *Safety Index* (Ped ISI) has been proposed, to allow engineers, planners, and other practitioners to proactively prioritize intersection crosswalks and intersection approaches with respect to pedestrian safety, each intersection will receive a Safety Index [Carter et al. (2007)] value between 1 (safest) and 6 (least safe). All significant variables in the proposed ratings model (signal and stop control, number of through lanes, vehicle speed, and commercial area type) were retained and included in the Ped ISI model, as shown in the following table:

Variable Name	Variable Description	Values
ISI	*Safety index value (pedestrian)*	*Dependent variable*
SIGNAL	Traffic signal-controlled crossing	0 = no 1 = yes
STOP	Stop sign-controlled crossing	0 = no 1 = yes
LNS	Number of through lanes on street being crossed (both directions)	1, 2, 3, …
SPEED	85th percentile speed of street being crossed	Speed in km/h
MAINADT	Traffic volume on street being crossed	ADT in thousands
COMM	Predominant land use on surrounding area is commercial development (i.e., retail, restaurants, etc.).	0 = not predominantly commercial area 1 = predominantly commercial area

Table 1 - Variables considered in the proposed model [Carter *et al.* (2007)].

Model Description

The model consists of one equation that determines the safety index score for a single pedestrian crossing. In particular, the equation used in the Ped ISI model has been recalibrated to better represent Italian cities; therefore the new model of assessment of the safety index has been expressed by the relation:

Pedestrian intersection safety index (Ped ISI)

$$\mathbf{ISI} = a_1 - a_2 \cdot \mathbf{SIGNAL} - a_3 \cdot \mathbf{STOP} + a_4 \cdot \mathbf{LNS} + a_5 \cdot \mathbf{SPEED} + a_6 \cdot (\mathbf{MAINADT} \cdot \mathbf{STOP}) + a_7 \cdot \mathbf{COMM}$$

The variables considered are:

- *Presence of traffic signals or stop signs.* Few, if any, formal studies have been conducted to quantify the effect of adding traffic signals or stop signs on pedestrian crash rates. However, traffic signals definitely change the interaction between motorists and pedestrians at intersections by creating gaps that allow for pedestrians to cross. Therefore, including information on such traffic controls at intersections would logically be an important factor in a pedestrian safety index. The fact that both signals and stop signs have the effect of reducing the crosswalk rating (indicating a safer crosswalk) is reasonable, since pedestrians would generally be safer in situations where traffic is controlled.
- *Number of through lanes on the street being crossed.* Recent research for FHWA found that pedestrian crash risk increases significantly as the number of travel lanes increases [Zegeer *et al.* (2001)]. This is a logical relationship, since an increase in travel lanes at pedestrian crossings corresponds to an increase in the exposure distance and time that a pedestrian is in the street interacting with oncoming motor vehicles.

- *Vehicle speed (85th percentile speed).* The stopping distance for motor vehicles increases dramatically as a function of increased vehicle speed. In addition, the likelihood of a fatal injury to a pedestrian also increases greatly in a pedestrian collision with a motor vehicle for higher vehicle speed. Therefore, including vehicle speed in the pedestrian safety index model is logical and appropriate. One disadvantage to using speed limit is that it is difficult to obtain from maps or speed limit signs. However, it was also thought that speed limit (which is easier to obtain) is often not a very good representation of actual vehicle speed at many locations. Therefore, it was decided to collect speed data on each of the approaches used in the pedestrian model development to more accurately represent the speed characteristics at each site. It is recognized that agencies that ultimately apply the pedestrian model will need to collect or obtain all of the input variables, including 85th percentile speed. However, if agencies do not have such data for certain sites, they have the option of adjusting the value of the speed limit by some amount (e.g., increasing by 14 km/h (9 mi/h)) to estimate 85th percentile speed value.
- *Main street traffic volume.* Increases in motor vehicle volume have been found to have a significant relationship with increased likelihood of pedestrian crashes [Zegeer *et al.* (1985)]. In both studies, increased traffic volume was one of the roadway factors that was most highly correlated with an increase in pedestrian crash frequency.
- *Commercial development.* The use of commercial area type in the model is possibly related to an increase in pedestrian exposure resulting from higher pedestrian volume and fewer pedestrian facilities. Past research has also found that commercial area was related to an increase in pedestrian crash risk [Zegeer *et al.* (1985)].

All of the factors included in the Ped ISI have been found in other studies to be related to pedestrian safety and/or have a logical association with safety.

The coefficients a_i of the equation have been calibrated using data from a study led in the city of Villa San Giovanni, where, analysing the behaviour of pedestrians in the phase of crossing, it was possible to score the safety conditions on a scale form 1 to 6. Subsequently the correlations between the considered variables and the desired safety index were analyzed. Results of these model developments are shown in following Tables:

Variable No.	Variable Name	Estimate
0	Constant	2.385
1	Signal on main street	−2.000
2	Stop sign on main street	−1.807
3	Number of through lanes	0.335
4	85th percentile speed	0.028
5	Commercial area	0.315

Table 2 –Estimated Values of the coefficients.

Model	R^2
MED_ISI = 2.385 – 2.000 · **SIGNAL** – 1.807 · **STOP** + 0.335 · **LNS** + 0.02 · **SPEED** + 0.06 · (**MAINADT** · **STOP**) + 0.315**COMM**	$R^2 = 0.843$

Table 3 – Proposed Model.

Application of the Proposed Model

The proposed model allows to determine a representative synthetic index of the safety condition of an intersection to pedestrian crossing, which allows to estimate the effectiveness of the infrastructural works and/or of transport planning finalized to the improvement of the safety standards.

As an example it is shown an application, and the results, on an intersection of the city of Villa S. Giovanni.

Figure 8 – intersection is between the via Marconi and the via Riviera (Villa S. Giovanni).

The analyzed intersection is between the via Marconi and the via Riviera, where a traffic light system has been introduced

(Figure 8).

Through the application of the proposed model it has been possible to estimate in numerical terms the increase of the safety levels for the pedestrian crossing, due to the adoption of the traffic lights system and to the application of a strategy of traffic calming (zones 30):

MED_ISI = 3.448 (without Signal)
MED_ISI = 2,155 (with Signal)

With speed limitation:

MED_ISI = 3,168 (without Signal)
MED_ISI = 1,875 (with Signal)

It can be observed as with the proposed modifications (lights system and speed limitation) allow a remarkable elevation of the safety standards for pedestrians.

CONCLUSIONS

In the present paper the problem relative to road safety in urban context has been analyzed, with a particular attention on pedestrian accidents. It was shown how it is necessary in the planning process to focus on the assessment of safety standards for pedestrian footpaths, especially in correspondence, with intersections on urban roadways. Therefore, a numerical model for the esteem of a safety index of the intersections has been proposed, to help planners and designers to estimate the priorities for the road crossings and the approach to the intersections, in respect of pedestrian safety. The proposed index, representative of the safety condition of an intersection to the pedestrian crossing, allows to estimate the effectiveness of infrastructural and/or planning actions, as illustrated in the case of an intersection in the city of Villa San Giovanni.

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