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A Decision Support System for the safety evaluation of urban pedestrian crossings

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Abstract

This paper proposes an innovative methodology, based on a Decision Support Systems, for the safety evaluation of pedestrian crossings without traffic lights in urban neighborhood areas. It provides an on-site inspection performed using ad-hoc data check lists, and it allows to assign a safety rate to the pedestrian crossing, in order to define a priority list of interventions and to suggest which features need to be improved. This new approach can be useful and easy to use for public administration managers and local governances, when they need to allocate limited financial resources to several pedestrian crossings. It has been applied to 10 pedestrian crossings on two roads in the urban area of Bologna and the resulted ranking list has been used by the Municipality of Bologna in its Urban Road Safety Plan 2016-2019.

Keywords: pedestrian crossing; Decision Support System; road safety measures; safety evaluation

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1. Introduction

Road traffic crashes represent the eighth leading cause of death globally. Causing more than 1.35 million lives and 50 million injuries each year, they become the leading cause of death for children and young adults aged 5–29 years, and overall the eighth main cause of death for all age groups surpassing HIV/AIDS, tuberculosis and other diseases (WHO, 2018). More exposed are obviously the vulnerable road users, particularly the pedestrians, i.e. in 2019 the distribution of fatalities reported an incidence of 21% for pedestrian accidents, with 5 515 pedestrian fatalities in EU24 on 26 267 overall accidents and 602 in Italy on overall 3 428 (about 18%) (ERSO, 2019). Pedestrian accidents are more frequent in urban than in rural areas, because in the densely populated urban zones walking is a daily routine for most people generally as argued by some authors (Fontaine, (1997); Baltes, (1998); Clifton et al., (2009); Elvik,

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(2010); Islam et al., (2014)). The safety level of a pedestrian crossing can be assessed in different ways. One of the most used in Italy is the Road Safety Review (RSR), that is a formal examination of the road element, in which an independent and qualified team reports on the road's crash potential and safety performance. It has been based upon the selection of a qualified review team, that it must be independent from the designers, maintenance and operation actors (Directive 2008/96/EC, 2008). Cafiso et al. (2008) proposed a procedure based on the site inspections, conducted by independent and qualified review teams, in different conditions of lightning, traffic and climate. The inspections are conducted through the use of check lists specialized on pedestrian crosswalk, that permits to reduce the risk that relevant safety parameters may be missed. The main RSR limit is the subjectivity of the review team members, that depends on their experience and up-to-date expertise in road safety engineering and crash investigation and prevention, linked to an understanding of traffic management and highway design. To overcome this limitation, a solution can be the use of the Decision Support Systems, that are computer and internet-based information systems that can assess management alternatives, as well as facilitate knowledge communication between stakeholders as indicated by Carmona et al. (2013).

In this paper a new methodology for the safety evaluation of pedestrian crossings without traffic lights in urban neighborhood roads has been proposed. It provides an on-site inspection performed using ad-hoc data check lists, defined in order to decrease the subjectivity of the road safety review analysis, considering only quantitative parameters. This new evaluation methodology has been tested in real urban contexts, applying to 10 pedestrian crossings on two roads in the urban area of Bologna. The paper proceeds as follows: Section 2 explains the methodology, Section 3 illustrates the site object of study, and Section 4 shows the obtained results.

2. Methods

The proposed methodology evaluated a Risk Index (RI), that allows to create a priority list that may be used as a Decision Support System for Road safety governance. RI is structured on the multiple product between variables related to pedestrian crossing structure, traffic condition, pedestrian risk exposure and urban context predictors. RI is calculated as:

$$RI = V * M * E \qquad (1)$$

where:

V the Vulnerability of pedestrian crossing, that describe its technical quality in terms of objective parameters organized in 3 categories (visibility items, signals and accessibility, geometry).

M the Magnitude, that describe the severity of pedestrian physical damages in case of accident occurring in the pedestrian crossing and it takes in account the connection between pedestrian physical damages and average impacting car speed defined by multiplier factor.

E the overall Exposure of pedestrian crossing to accidents, in terms of vehicle exposure and pedestrian exposure.

RI presents a value scale variable from 0 to 10, where 10 is the less safe pedestrian crossing. This methodology uses check lists that allocate score for any items, using 1 or 0 value, as existing or not factor. Only in specific case some items require numerical value, i.e. pedestrian crossing length parameter. In the following sections any variables have been examined in details.

2.1. Vulnerability

Vulnerability (V), related to quality parameters within the pedestrian crossing, has been calculated on several technical items aggregated in 3 categories: visibility, signals and accessibility, and geometry. It is expressed as:

$$V_k = \frac{\sum_{i=1}^{n} f_{i,fav} * P_{ik,fav}}{\sum P_{ik,fav}} \qquad (2)$$

where:

Vk the Vulnerability for K categories (in which k may assume V as Visibility, S as Signals and Accessibility, G as Geometry).

Pi the Weight for the i-esime sub-items.
n the Number of sub-items for each category.
fi the Multiplier factor of the i-esime sub-items.

The value obtained for Vk has been normalized to 0-100 span. In details, a significant variable in Visibility is the distance light pole -crossing, that it has been easier to measure than the level of single lightening in lux and it represents a general standard in urban context wherein public lightening is commonly present and widespread. Furthermore, disturbing visibility factors as presence of parking lots beside the lane and green furniture, have been considered.

Signals and accessibility category is defined by technical features as zebra crossing dimension, presence of horizontal and vertical signals and architectural barriers.

Geometry is defined by technical variables as lane length, number of lanes per road, pedestrian island, etc.

Overall Pedestrian crossing Vulnerability (VAP) has been then calculated through:

$$V_{AP} = \frac{\left[(V_v * P_v) + (V_s * P_s) + (V_g * P_g)\right]}{(P_v + P_l + P_g)} \tag{3}$$

where:
Vv the Vulnerability for Visibility category.
Pv the Weight for visibility category.
Vs the Vulnerability of the Signals and accessibility category.
Ps the Weight for the Signals and accessibility category.
Vg the Vulnerability of Geometry category.
Pg the Weight for geometry category.

Vulnerability with 0 value explains an acceptable level of safety, while 100 is a critical level of safety.

In order to evaluate the weights for any single items, the approaches of Cafiso et al. (2008) and Basile et al. (2010), and the scientific literature have been deeply analyzed.

The criteria adopted to allocate the weights is based on accounting higher score to most relevant items in terms of road safety impact.

Basile et al. (2010) has defined a first weights list using AHP methodology and the general category of Night-time visibility and Day-time Visibility have the highest weights. In particular Night-time Visibility accounts for over 40%. It has been also observed that increased intensity of road lighting decreases the number of accidents with pedestrian of 59%. Similarly, increased intensity of roadway lightning and installation of flashing warning signs acts with a reduction of pedestrian crashes of 57% in nighttime and a significant decrease in daytime, about 21% (Zgeer et al., (2006); Nassar et al., (2011); Scott et al., (2012); Bassani et al., (2012); Niaki et al., (2014); Bichicchi et al., (2017); Gibbons at al., (2015); Wei et al., (2016); Bullough et al., (2017), (2021); Wang et al., (2018); Gbologah et al., (2019); Bhagavathula et al., (2019), (2020); Costa et al., (2017), (2018), (2020)). Even bus stop relocating, as measure aimed to remove obstacles, induces a significant decrease exposition of pedestrian to accidents as indicated by Pegrum, (1972) and Polus et al., (1978).

The remaining items are focused on signals presence related to roadway width, that for similitude is aggregated into the Category of this research “Signals and accessibility”, and in Basile approach accounts for 19-20%. Furthermore, in pavement flashing light able to warn drivers when pedestrians are present, have a positive effect on reducing vehicles-pedestrian conflict, with a rate about 17% on the basis of the study of Lantieri et al., (2021).

Other evidence concerning impact of Signals and Accessibility as secondary items if compared with Visibility is demonstrated by Traffic Calming measures, i.e. expressed in Table 2 as Optical or acoustics speed warning elements, or Pavement variations, that are able to reduce pedestrian-Vehicles crashes of 25% after tested by Brilon et al., (1993).

It is necessary to finally highlight that in Basile analysis some items related to horizontal signals dimension (i.e. pedestrian crossing width) acts strongly to increase visibility and are enlisted in Day-Time Visibility, as indicated above with a high percentage of impact (22-24%). On that basis, it is possible to confirm the impact of Signal and accessibility as secondary for safety.

The third category in Basile analysis is Accessibility, characterized by a weight of 19-20%, evaluates variables such as “Presence of Obstacles” and “Pedestrian Island”. Those items are located in the present research in the Category Geometry, that also enlist some items present in Basile upper category “Spatial and Temporal design”, as roadway width. It has been also demonstrated that measure for remove obstacle as bus stop relocation may act positively in reducing the risk of fatalities, also due to the decrease of pedestrian movements around the area and due to the presence of pedestrian refuge island that decreases also the risk of pedestrian-vehicles conflict as argued by some authors (Berger et al., (1975); Ghasemi et al., (2002); Garder er al., (2004); Vignali et al., (2019), (2020)). In table 1, 2 it is illustrated the maximum weight for each category.

Table 1. Items and weights for each category

Items in Visibility category	Weights
Presence of Bilateral lightening	0
Presence of unilateral lightening	0.5
Presence of public light pole at < 3 m distance from pedestrian crossing	1
Presence of public light pole at distance between 3 and 5 m from pedestrian crossing	1.5
Presence of public light pole at distance > 3 5 m from pedestrian crossing	2
Presence of motorcycle parking lots	1
Presence of car parking lots	2
Presence of single spot obstacles (i.e. advertising panels)	1
Presence of green furniture in the nearest zone of the pedestrian crossing	2
Presence of parking lot in the nearest zone of the pedestrian crossing	2
Presence of garbage containers in the nearest zone of the pedestrian crossing	2
Presence of walls or barriers in the nearest zone of the pedestrian crossing	2
Maximum value of Weight for Visibility category	3

Sub categories	Items in Signals and Accessibility Category	Weights
Vertical sign	Compliant with standards	0
	Incomplete / ineffective	1
	Lacking of signals	2
	Flashing lights	- 0.5
	Presence of advertising panels	1
Horizontal sign transversal to the road	Zebra crossing lenght > = 4 m	0
	Zebra crossing lenght < 4 m	1
	Presence of Pavement variations	-0.25
Horizontal signals parallel to the road	Continuous Centerline marking (or not needed)	0
	Lack of Centerline marking	1
	Discontinuos Centerline marking	0.5
Accessibility	Presence of architectural barriers on one side of the road	2
	Presence of architectural barriers on both side of the road	1
	Absence of logos	0.5
	Maximum value for Weight in Signals and Accessibility Category	2.5

Items in Geometry Category	Weights
Pedestrian crossing length < 7 m	0
Pedestrian crossing length between 7 and 10 m	0.75
Pedestrian crossing length > 10 m	1.5
One way road	0

Bi directional road	0.5
Presence of Chockers or lateral gulfs	-0.5
Altimetric variation	-1
Presence of Pedestrian Island	-1
Overall Weight for Geometry Category	2

2.2. Magnitude

Magnitude (M) is connected to the consequences and the severity of injures for pedestrians. It has been associated to speed range variability, through the use of a multiplier factor that explain how speed increasing induces worst injures to pedestrians. Speed range and related Magnitude factors (Mf) are: Speed less than 30 km/h (1), Speed between 30-50 km/h (1.5), Speed higher than 50 km/h (2).

The numerical values of Magnitude have been attributed in comparison with speed range on the basis of the correlation existing between consistency of physical damage and increasing of speed. In particular in literature has been underlined how the probability of pedestrian death is of 5% if speed car is 39 km/h, while it became 40% if speed car is 50 Km/h till about 90% in presence of speed car more or equal than 70km/h (Wegman et al., 2008).

2.3. Exposure

The Exposure Factor (E) takes in account contextual conditions, and is expressed by both vehicle and pedestrian traffic conditions and related variables:

$$\boldsymbol{E = E_v * E_p} \qquad (4)$$

Where:
Ev the Exposure of vehicle.
EP the Exposure of pedestrian.

Exposure of vehicle (Ev) has been constructed upon Average Daily traffic (ADT), and exposure of pedestrian (Ep) is related to specific factors conditioning Pedestrian Impact (PI) around a radius about 50 m.

Exposure of vehicle and related ADT are categorized in the following lapse: ADT≤ 15000 (1), ADT15000 ÷ 25000 (2), ADT≥ 25000 (4). The Exposure of pedestrian and related PI is enlisted as: PI < = 2 (1), 2 < PI<= 4 (2), 4 < PI <= 6 (3), PI > 6 (4).

A specific statistical analysis has been conducted to find these independent variables and their related weights. In general terms the PI is expressed as:

$$\boldsymbol{PI = \sum Pi * fi} \qquad (5)$$

Where:
Pi Weight associated to contextual impact factors.
Fi coefficient of existing factor.

The coefficient of existing factor assumes value of 0 if variable not present or 1 in case of variable present.

The research has been oriented to reach out new variables not only site-related, but common in the urban neighborhood contexts, with the aim to define which external parameters may be added in the methodology, it has been takes in account data availability of all pedestrian accidents occurred in all pedestrian crossing in Bologna from 2014 to 2019. The data set included 120 urban intersections and the number of accidents per intersection. In particular the overall number of accidents involving pedestrian was 44. It has been used a statistic analysis through a multiple regression model on the data provided by Municipality of Bologna. The analysis has been conducted through SPSS software to find correlations among data set variables, structuring a correlation matrix. From the first step the recurring variables has been: pedestrian crossing length, bilateral lightning, speed, obstacles presence, Average Daily traffic > 25.000, school presence in the neighborhood, hospital presence in the neighborhood. The second step has been to evaluate co-linearity, removing any cases in which the predictors are correlated each other.The results show that most relevant predictor is the variable "hospital presence in the neighborhood", followed in order of importance by "school presence", "Daily Average traffic > 25.000", "Speed comprehended between 30-50km/h".

On the basis of the most relevant variables deduced by the statistical analysis and the correlations found, it has been possible associate weights on a progressive scale with the aim to identify a simple and clear numerical hierarchy, for any new contextual variables. Contextual attractor by the contextual impact factor and related weights are: Bus Stop presence (2), School presence (3), Hospital and Health institution presence (3), Commercial/Productive facilities (2), Entertainment, sportive or high social value point presence (2).

The weights have been applied in the calculation of PI (equation 4), useful to define the Pedestrian Exposure.

3. The site object of the study

The methodology has been applied to 10 pedestrians crossing in the urban area of Bologna without traffic lights regulation. It has been considered 5 pedestrian crossing located along via Saragozza and 5 in Via Zanardi. The two roads have one lane for each direction and connects the historical city center to outskirts. Roads info are reported in Table 2.

Table 2. Pedestrian crossing locations and info (S: Saragozza, Z: Zanardi)

Intersection number	Width lane (m)	Average daily traffic	Pedestrian per day	Pedestrian accidents (2018)
1S	12	12610	290	1
2S	10	13271	110	0
3S	7,5	11592	170	
4S	10	13271	100	0
5S	9,5	13271	120	1
6Z	11,5	7018	140	0
7Z	14	7018	30	0
8Z	9,5	7018	50	0
9Z	9,5	7018	200	0
10Z	9,5	13271	120	0

4. Results

It has been applied the Risk Index calculation to pedestrian crossing in Via Saragozza and in Via Zanardi, through the use of Check list system where it has been filled the value 1 for existing variable or 0 for not existing. The check list has been filled by a team of 3 experts. The RI has been established for any of 10 pedestrians crossing in Saragozza and Zanardi roads, defining a final list of priorities from less safe to the safest. The results have been validated by using the Cafiso method (Cafiso et al., (2008)) on the same pedestrian crossing in Bologna. In Table 3 has been reported the comparison between the two different methods.

Table 3. Comparison between the proposed method and the Cafiso method (via Saragozza)

Pedestrian crossing - Via Saragozza (in order of more safety pedestrian crossing)	Risk Index	Safety Index (Cafiso et al., 2008)
1S	9.17	61865
3S	4.7	46217

2S	4.47	44532
5S	4.38	41672
4S	4.22	38320

Pedestrian crossing - Via Zanardi (in order of more safety pedestrian crossing)	Risk Index	Safety Index (Cafiso et al., 2008)
10Z	4.39	61865
9Z	4.05	46217
8Z	3.03	44532
6Z	2.19	41672
7Z	1.93	38320

The obtained results show the same list in terms of priorities ranking obtained by the two procedures, allowing the validation of the proposed methodology.

The validation has consequently permitted to insert the results within the Urban Road Safety Plan 2016-2019 (PSSU) – Annex A of Municipality of Bologna. The list has been illustrated as a driving score for Municipality's road interventions and financial orientation to Road Safety.

5. Conclusions

Pedestrian crossings safety engages different variables, most of them typical onsite items and others influenced by urban context. The paper presents a new methodology that provides an evaluation of pedestrian crossing safety level and related list of priorities of intervention, on the basis of detected objective factors, and that represents an economic and easy to implement Decision Support System for local governance. The methodology has been only defined for pedestrian crossing without traffic lights in urban neighborhood areas. The specificity of the methodology is that requires not wide resources by local governance to be implemented and it has been able to work on objective factors, freeing the results from subjective perspective of the single review team member. The research demonstrates also the relevant impact of context conditions on the safety level of pedestrian crossing, defining as statistical relevant safety predictors the variables pedestrian crossing length, presence of bilateral lightening, speed, ADT> 25000, schools, hospitals.

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