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Tools for Assessing the Safety Impact of Interventions on Road Safety

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Abstract

This paper is the result of a PhD in Transport Infrastructure, realized at CTL, aimed to investigate issues related to the evaluation of interventions producing changes in traffic configuration and to develop an information system (Road safety Impact Assessment - RIA Module) to be integrated in an existing Decision Support System on road safety.
The research created a library of SPF and developed an information system, called "RIA Module", updating the existing "DSS - ISIDE", developed by CTL.

Keywords: Road Safety Impact Assessment; Decision Support System; Safety Performance Functions

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1. Introduction

In 2010, in Italy, 211.4004 traffic accidents were reported, causing the death of 4.090 people, while 302.735 people were injured. The tribute that the nation is paying in term of human life lost or injured due to traffic accidents corresponds to about 28 billions of Euros each year (without accounting for the accidents with only damages). These results have been obtained considering the data of surveys of ISTAT/ACI[†] [1]about the traffic accidents.

The implementation of policies and measures that encourage the reduction of risk on the road network cannot ignore the knowledge of the phenomenon and must therefore start from information that is clear, complete and consistent.

In 2001 the European Commission has launched a program to reduce road accidents through a document called "Promoting road safety in the European Union: the 2001 program" (White Paper) which aims to halve the number of deaths since 2000 to 2010. In 2003 the EC published the document "Road Safety Action Programme" [2] with which actions to achieve the White Paper objectives are defined.

The growing awareness on the problem of traffic accidents, in addition with introducing specific tools (such as the Urban Road Safety Plans and safety checks), made sure that road safety often falls between the goal-will of the current planning instruments and planning traffic (such as Urban Traffic Plans). This prompts the need, in planning phase to an estimate of the effects on the safety of interventions designed to evaluate the possibility of intervention with respect to security.

In 2008 Directive No. 96 [3] has been issued requiring the establishment and implementation of procedures relating to:

- Impact on road safety for infrastructure projects (Road Safety Impact Assessment - RIA);
- Controls on the design of infrastructure (Road Safety Audit);
- Classification and management of road network safety open to traffic (Safety Ranking and Management);
- Safety inspections on the roads running (Road Safety Inspection).

In particular, the Directive introduces the road safety impact assessment for infrastructure projects (RIA) that can be done through the use of Safety Performance Functions (SPF), models predicting how, the number and severity of accidents change, according to the variation of elements such as traffic flows or speed on the network arcs.
This assessment appears to be important both during the design of interventions aimed at reducing accident rates (e.g. design of roundabouts), but above all in the planning stage of an intervention that will result in a change in traffic flows, not necessarily linked to road safety (e.g. Urban Traffic Plans, etc.).
The problems related to this evaluation process through the SPF are:

- the SPF models are dependent on different data (geometric-functional features of infrastructure, speed on the arches, geo-referenced data from accidents, etc ...) that are not easily available or can be of poor quality [4];
- the SPFs currently studied and calibrated (Safety Analyst) relate to the reality of the United States;
- in Italy, as in Europe, there is not a SPF library already calibrated and validated;
- in Italy the best functional form to fit the national context for these models has not yet been studied;
- it is difficult to work together with two types of models, those for the simulation of the traffic flows (which are needed to simulate the flow of traffic on a network) and those for the prediction of accidents.

These models (SPF) have been extensively studied in the United States and a library was created in the Safety Analyst software. In particular, these models have been calibrated and validated on the American context. In Europe, these models have been studied, but there is still not a library such that of United States. In Italy, SPF

[†] ISTAT: National Institute of Statistics
ACI: Automobile Club d'Italia

calibrated for the international context have been applied to the Italian one [5], but a library of models does not exist.

This paper summarizes the research realized during a Ph.D. in Transport Infrastructure, activated by the Department of Civil Engineering, Building and Environment of "Sapienza" University of Rome.

This research is part of a series of studies conducted by the group working on Road Safety at Research Centre for Transport and Logistics (CTL) of "Sapienza" University of Rome.

In particular, these studies were conducted as part of some European research projects, related with road safety (ROSEBUD, SafetyNET and Dacota). In the national context, in the framework of various projects (City of Perugia, City of Parma, Marche Region), the research group has developed a decision support system (DSS) for road safety, ISIDE (In-strumentation for Safety Improvement, Design and Evaluation). The DSS is a tool based on the computerization of the analysis and planning process. ISIDE seeks to improve decision-making skills of designers to identify possible accident causes and to select most effective interventions for a specific site, based on the lowest cost-benefit ratio.

The objective of this research was to develop an information tool, referred to as "Module RIA", updating the DSS ISIDE, allowing the impact assessment on road safety interventions that involve a modification of the conditions of traffic, through the creation of a library of SPF. These models were calibrated in an urban and extra-urban context using data collected in Italian cities participating in projects funded under the Program for Implementation of National Road Safety Plan, to which the research group is actively involved as CTL.

2. Methodological approach

The methodological approach used in the Ph.D. research is represented in Figure 1.

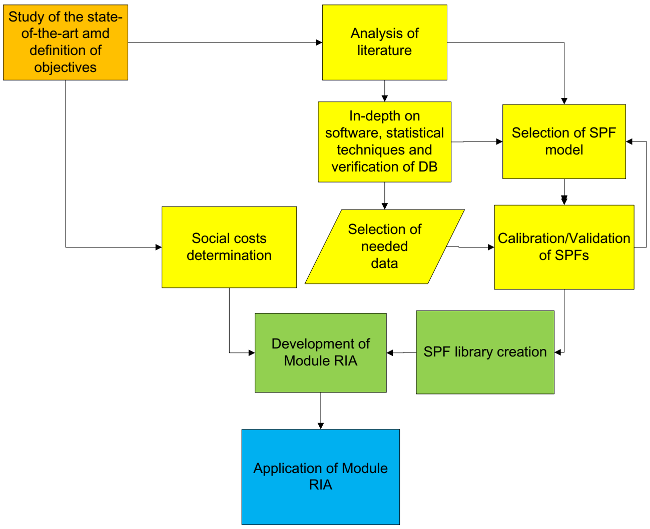

Figure 1 Methodological approach

After a first phase in which the State-of-the-Art was studied, the existing literature and in-depth statistical techniques were analyzed, before moving to the choice of model for the SPF. The study focused initially on the type of models, including linear models, evidencing several problems:

- a linear model cannot reproduce a not linear reality like that of accident [6], [7];

- the distribution of the response variable is only of normal type;
- models are additive that would lead to a prediction of accident even in the presence of zero flows of traffic.

Generalized linear models were then studied, including in particular counting models. In this case the family of functions that obey to re-sponsored variable is broader, as it also includes the Poisson, the Negative Binomial distribution, etc. (Figure 2).

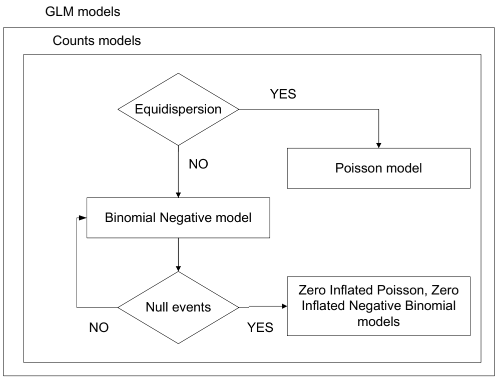

Figure 2 Family of generalized linear models for count

After choosing the type of model, the variables to be used for their calibration [8], [9], [10], [11], [12], [13], [14] according to available data, were selected. In particular the available data included:

- Road network with characteristics of the infrastructure, with road elements broken down according to: Area (urban / rural), Functional class / number of lanes, Traffic control system (type of intersection, rotated-tee), and Length of string.
- Traffic flows in terms of Average Daily Traffic (ADT).
- Geo-referenced accident data (number of accidents, severity, etc.).

Based on the data available and the type of model choice, SPF functions for urban and extra-urban areas were calibrated.

3. SPFs Calibration

3.1. Urban area

In urban area the following distinctions were made:

- two functional forms, calibrated for arcs and nodes;
- three types of models: Poisson, Negative Binomial, Zero Inflated;
- two calibration tests for the year 2006 and for the years 2005/2007.

It was then possible choosing among 12 possible models for arcs and nodes.

The available data included in particular:

- Geo-referenced road graph: 3,483 arcs[‡], 2,688 nodes[§], 521 km of network.
- Mobility: Origin / Destination matrix of 1996 and Traffic flows on 71 survey sections (year 2006), used to update the Origin / Destination matrix.
- Details of accidents: 6,742 accidents recorded (2003 to June 2011), 6,600 accidents geo-referenced (98%).

‡ Arc: stretch of road between two nodes

§ Node: intersection

The mobility data were also used to simulate, using the software TransCAD, the flows on urban and extra-urban networks considered, both in the actual scenario than in the project ones.

The functional form defined for the arcs is:

$$I = e^{(\beta_0+\beta_1\cdot lnADT+\beta_2\cdot lnLENGTH+\beta_3\cdot lnType6+\beta_4\cdot lnType7+\beta_5\cdot lnType8+\beta_6\cdot lnType9)} \quad (1)$$

where:

I= Incidents
ADT = Average Daily Traffic.
$LENGTH$ = the arc length (Km).
$Type6$ = one-way road with 1 lane.
$Type7$ = one-way road with two or more lanes.
$Type8$ = two-way road with one lane.
$Type9$ = two-way road with two lanes.
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ = parameters to be calibrated.

The functional form of the SPF defined for the nodes is:

$$I = e^{(\beta_0+\beta_1\cdot lnADTMAX+\beta_2\cdot lnADTMIN+\beta_3\cdot lnType10+\beta_4\cdot lnType11+\beta_5\cdot lnType12+\beta_6\cdot lnType13+\beta_7\cdot lnType14+\beta_8\cdot lnType15)} \quad (2)$$

where:

I= Incidents
$ADTMAX$ = Max ADT among all intersection approaches.
$ADTMIN$ = Min ADT among all intersection approaches.
$Type10$ = not signalized intersection with three arms.
$Type11$ = signalized intersection with three arms.
$Type12$ = not signalized intersection with four or more arms.
$Type13$ = signalized intersection with four or more arms.
$Type14$ = roundabout with three arms.
$Type15$ = roundabout with four or more arms.
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7, \beta_8$ = parameters to be calibrated.

The functional forms were calibrated using the maximum likelihood method.

The results of the calibrations were validated using statistical tests, described in Table 1 (the calibrations providing the better results are marked with *).

Table 1 Results of the calibration and validation tests in urban area

Year	Model	Element	EQM	Emax	Emean	Deviance
2006	Poisson	Arcs	0.48	18.82	0.23	-2.86%
2006	Binomial negative *	Arcs	0.48	19.23	0.23	0.27%
2006	Zero inflated	Arcs	0.41	17.88	0.17	66.00%
2005-2007	Poisson	Arcs	0.46	44.88	0.21	13.06%
2005-2007	Binomial negative	Arcs	0.46	44.13	0.21	0.69%
2005-2007	Zero inflated	Arcs	0.45	40.20	0.20	49.14%
2006	Poisson	Nodes	0.90	111.32	0.82	1.12%
2006	Binomial negative *	Nodes	0.91	113.06	0.82	1.40%
2006	Zero inflated	Nodes	1.10	196.00	1.21	66.00%
2005-2007	Poisson	Nodes	0.64	44.13	0.42	7.42%

2005-2007	Binomial negative	Nodes	0.65	45.50	0.42	7.90%
2005-2007	Zero inflated	Nodes	0.75	40.11	0.56	16.21%

EQM is mean square error:

$$EQM = \sqrt{\sum_N \frac{(C-R)^2}{N}} \tag{3}$$

Where:
C = Number of incidents calculated
R = Number of incidents reported
N = Sample size
Emax is maximum error:

$$E_{max} = max(C-R)^2 \tag{4}$$

Where:
C = Number of incidents calculated
R = Number of incidents reported
Emean is mean error:

$$E_{mean} = mean(C-R)^2 \tag{5}$$

Where:
C = Number of incidents calculated
R = Number of incidents reported
The values of the calibration coefficients for the urban area are shown in Table 2.

Table 2 Calibration coefficients of the SPF for urban area

Coefficients for arcs	Value	Coefficients for nodes	Value
β_0	-2.130	β_0	-1.772
β_1	0.276	β_1	0.037
β_2	0.632	β_2	0.006
β_3	-0.858	β_3	-2.535
β_4	0.326	β_4	-2.100
β_5	-0.949	β_5	-1.541
β_6	0	β_6	-0.229
		β_7	-0.900
		β_8	0

3.2. Extra - Urban area

For extra-urban road, a single functional form has been defined for the number of deaths per km and the number of injured per km and two models were calibrated (Poisson and Binomial negative).

It was then possible to choose between two possible models for the dead and injured. The data available were:

- Geo-referenced road graph: 5,206 arcs, 4,169 nodes and 7,768 km network.
- Mobility: traffic flows (by type of mode) simulated with TransCAD.
- Details of accidents: deaths and injured on the network (not geo-referenced).

The functional form, both for the number of deaths and for the number of injured, is:

$$I = e^{(\beta_0+\beta_1 \cdot lnADT+\beta_2 \cdot Type1+\beta_3 \cdot Type2+\beta_4 \cdot Type3+\beta_5 \cdot Type4+\beta_6 \cdot Type5)} \tag{6}$$

where:
I = Death or injured per Km.
ADT = Average Daily Traffic.
*Type*1 = motorways with two carriageway and three lanes per carriageway.
Type2 = motorways with two carriageway and two lanes per carriageway.
Type 3 = multi-lane roads in each direction with separator.
Type4 = multi-lane roads in each direction without separator.
Type5 = Two lanes roads (one in each direction).
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ = parameters to be calibrated.

The calibration results were validated using statistical tests, described in Table 3 (the calibrations providing the better results are marked with *).

Table 3 Results of the calibration and validation tests in extra-urban area

Model	Deaths/Injured	EQM	Emax	Emean	Deviance
Poisson	Deaths	0.55	17.82	0.31	5.30%
Binomial negative *	Deaths	0.55	17.88	0.30	4.92%
Poisson	Injured	2.80	231.95	7.86	3.35%
Binomial negative *	Injured	2.82	234.83	7.97	0.52%

The values of the calibration coefficients for the extra-urban area are shown in Table 4.

Table 4 Calibration coefficients of the SPF for extra-urban area

Coefficients for deaths	Value	Coefficients for injured	Value
β_0	-5.609	β_0	-2.640
β_1	0.525	β_1	0.377
β_2	-2.191	β_2	0.948
β_3	-2.351	β_3	0.387
β_4	-2.368	β_4	-0.526
β_5	-2.644	β_5	-0.794
β_6	0	β_6	0

4. Application the module RIA

In the process of reviewing and updating of the DSS ISIDE the "Module RIA" was developed that allows the evaluation of effects on road safety of interventions that determine changes in the configuration of traffic:

- Policies and large-scale interventions for the improvement of road safety.
- Interventions of variation in demand and / or supply of transport.

The module RIA allows for simulation of intervention scenarios and for evaluation of the scenarios simulated, as can be seen in Figure 3.

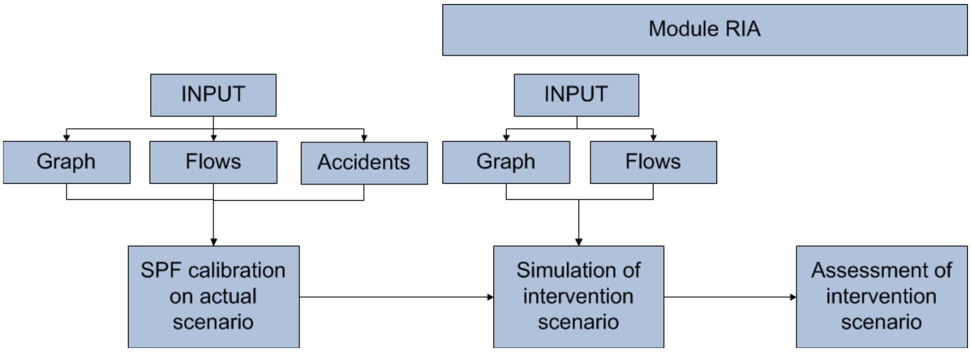

Figure 3 Block diagram of the Module RIA

In particular, the Module RIA, using input data such as road graph with intervention scenario, traffic flows for the intervention scenario, SPFs calibrated on the actual scenario, allows the calculation of accidents on the elements of the graph of the intervention scenario and then to obtain the impact on road safety in the intervention scenario in terms of frequency of accidents.

The Module RIA was applied to two real cases, both in urban area (city of Terni) and extra-urban area (Lazio Region).

In urban area, the test consisted in applying the Module RIA to the road network of Terni. Based on the collected data (traffic flows on 71 sections used to update the Origin / Destination matrix), the traffic flows on the entire network were simulated. This simulation, together with the collected accident data, constituted the so-called "Actual Scenario". A design hypothesis was done, consisting in making some road of the historical centre accessible only for pedestrians. Traffic flows simulations were realized also in this case and this constituted the so-called "Design Scenario".

The Table 5, Figure 4 and Figure 5 show the results obtained for the urban test. The difference in term of accidents between the Actual scenario and the Design scenario is of -223 accidents per Km for the arcs, and of -71 accidents for the nodes. While the accidents on the whole network has decreased, an increase of the number of elements on which the accidents happen was found. This is due to the fact that having made some roads available only to pedestrians, on some other roads the traffic flows have increased, and consequently also the number of accidents.

Table 5 Results of Module RIA application in urban area

Indicators	Arcs	Nodes
Accidents difference (design / actual)	-223 acc/km	-71 acc
% of element with increase of accidents	52%	32%
% of element with reduction of accidents	8%	9%
% of element without change of accidents	40%	59%
Average increase of accidents	1.73 acc/km	0.27 acc
Average reduction of accidents	-12.38 acc/km	-1.23 acc

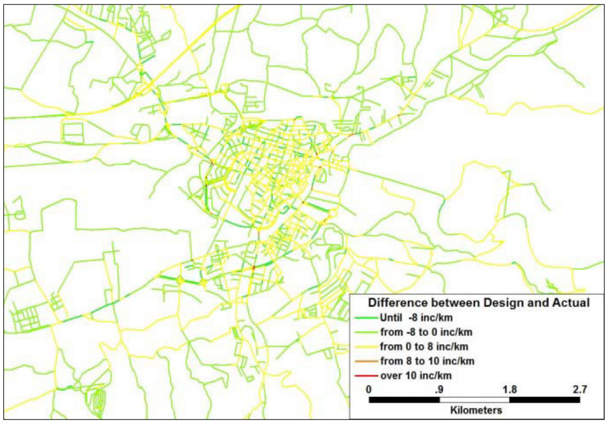

Figure 4 Difference of accidents per km between actual and design scenarios on arcs

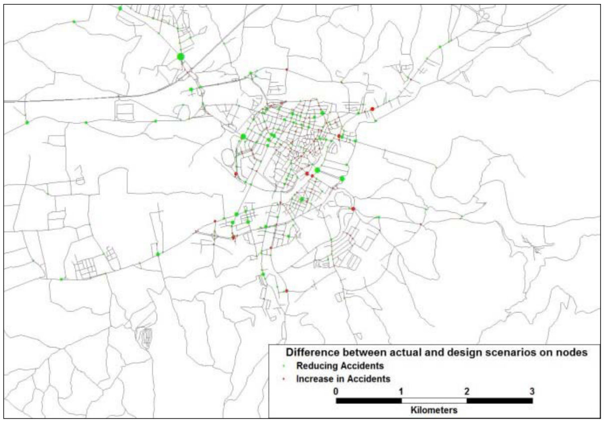

Figure 5 Difference between actual and design scenarios on nodes

5. Conclusions

In this paper the main aspects of the problem related with the impact assessment, on road safety, of interventions modifying the traffic flows have been highlighted. The problem of not having a methodology to be applied makes impossible to assess correctly the safety effects caused for modifications of the traffic flows, in addition to the impossibility of assessing a-priori a possible intervention scenario. The international panorama has evidenced a lack of system allowing to make these evaluations. The Ph.D. research has demonstrated other calibration and validation methodologies for the functions estimating the accidents and has reviewed and updated the DSS ISIDE with the Module RIA (Road safety Impact Assessment).

During the research problems related with the lack or incomplete data (traffic flows, geo-referenced accidents, etc.) have been found, limiting the possibility to calibrate very detailed functions. On another hand, it would not be useful to disaggregate too much the problem, adding other variables to the functions because the statistical reliability of the calibration could decrease.

Possible future developments of the research concern the increase of the SPF library trying, based on the data availability, for instance to distinguish between ADT classes, geographical area, etc. It will be possible to calibrate new functions using the data coming from the Monitoring Centers for Road Safety being realized in all the national territory.

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