ROAD SAFETY EVALUATION: AN ANALYTIC MODEL PROPOSAL FOR THE ROAD SAFETY AUDIT AND REVIEW

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SYNOPSIS

The analysis of road safety, seen as the procedure which is to be implemented in order to reduce or completely eliminate road accidents should be performed with a high level of efficacy, as for all the other disciplines where man's safety in general is involved.
For this reason several models and analysis were developed in the last years on this matter, as well as the standards and the guidelines issued by the National Government and the European Community.
By means of a unique model, this paper links road safety to the geometrical, functional and subsidiary parameters of a road infrastructure.
The diagnostic process is based on the general guidelines of the Road Safety Audit and Review, and consists of different macro-stages, all of them enabling the user to get also to the intermediate results.
In the first stage, in particular, the geometrical elements which are to be taken into account and the corresponding characteristic parameters are detected.
The elaboration of the data collected is performed during the second phase by means of the identification of the route anomalies from the viewpoint of planimetric and altimetric defects, with special interest for the plano-altimetric coordination.
The last part of the analysis, through accidents surveying, discovers the critical points (black-spots) of the track, so as to find their correlations with the route defects belonging to the geometrical conditions of the infrastructure.
In order to consider the different surroundings, the implementation of the proposed model makes a difference between the urban scenario and the outer environment, all the different resolutory approaches being as a matter of fact considered.
Apart from the user friendliness, the Authors highlight the fact that this model is an efficient tool for the planning interventions of the road infrastructures safety, thanks to its analytical validation.

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INTRODUCTION

The road accidents phenomenon is a problem that significantly increased in the last years; as a matter of fact strong is the technical an political effort for the reduction of the negative consequences for the users.
The traffic increase, furthermore, generated the need for new professionals and research fields.
The old standards referred to as the best solution for the cars design have been nowadays superseded by new technologies, and the same phenomenon occurred for the road construction technique.
In early 1960s the main objective of car designers were the achievement of power, speed and performances, while the most important issues are currently concentrated on both active and passive safety.
As for infrastructures, before the DM 5/11/01 Standards came into force, the road design was used to following the CNR prescriptions, the heterogeneity of the roads typologies nationwide being therefore obvious.

ROAD SAFETY IN EUROPE IN THE LAST 50 YEARS

In 50s and 60s in Italy and in Europe, more in general, the increased vehicles traffic caused a number of accidents greater than before, because of the poor roads regulations. From 70s to the first part of 80s, new laws became effective and a general improvement of the infrastructures network was experienced, thanks to new vehicles standards also.
Afterwards, the number of car accidents increased again because of the lack of severe laws and management regulations.
Eventually, in 90s a further reduction in the number of car accidents was observed everywhere in Europe but in Italy.
In the last decade 72.000 people died in car accidents and 2.400.000 were injured, 1/3 of them being young (15-29 years old).

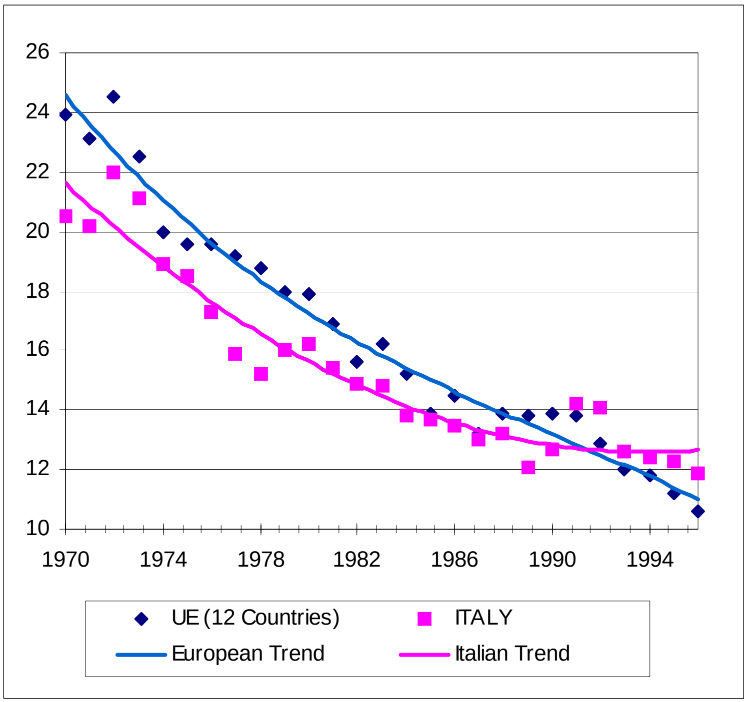

Figure 1 – Death index evolution: Italy/UE 1970-1996[1] comparison

The loss of human beings should be seriously considered by users, administrators, road networks managers and, more in general, by the all population.
The death index is the parameter that more than the others, can express the seriousness of car accidents: it represents the number of dead people every 100 crashes (Figure 1).
In the period within 1972 and 1988, the number of people killed was reduced from 12.000 to 7.500 per year, with a mean annual reduction equal to 2,2%, which was the same value experienced for the other European countries. In the last decade, unfortunately, this reduction was lowered to 1,0% while for the other countries it went up to 2,4%: because of this trend, Italy is classified as a medium-low safety level country.
Due to the annual increase of 2.900 deaths, compared to the mean value of the other UE countries, Italy risks becoming one of the worst nations in this poorly enviable list.
The social and economical costs of this situation should not be neglected, because of the loss of professionals, of temporary and permanent unfitness and of the severe costs for the casualties' families: in addition, enterprises pay their duty also, as 1/3 of accidents usually occurs during the house-working place journey.
The overall cost of the just mentioned issues in 2002 was equal to 34.108 million euros
In Italy everyday18 people die and 926 are injured because of car accidents.
In 2002 there were 237.812 crashes which involved 6.736 casualties, while 337.878 people were injured; this year, compared to the previous one (Table 1), experienced a slight increase in the number of accidents (+1.1%), and in the number of both victims (+0.8%) and injured (+1.0%).

Table 1 – Road accidents, casualties and injured people: year 2001-2002 (Source ISTAT)

	Absolute values		Variations%
	2001	2002	2002/2001
Accidents	235.142	237.812	+ 1,1
Casualties	6.682	6.736	+ 0,8
Injured	334.679	337.878	+ 1,0

The analysis of car crashes between 1991 and 2002 (Table 2) states that both the number of accidents and of injured people is increasing, the number of victims being, on the contrary, reduced (Figure 2) for all years but the last two-year period.
Indeed, the number of crashes experienced a 39,3% increase, 40% for the injured one: on the contrary, the casualties were reduced (-10,2%).
The death index moved from 4,4 (1991) to 2,8 (2002), as indicated in Figure 3, which means that the use of safety devices such as airbags, ABS and others play a fundamental role; in addition the safety Standards and the health structures are definitely better than before.
Most of car accidents are experienced in urban areas, no matter the nation; in particular, in Italy in 2002 the following data were collected (Table 3 and Figure 4):

- 6.2% accidents on motorways, with 11.3% casualties;
- 10.8% accidents on state highways with 25.3% casualties;
- 9.5% accidents on country roads with 20.3% casualties;
- 73.6%accidents on urban roads with 43.1% casualties;

Table 2 – Accidents from 1991 to 2002 (Source ISTAT)

Year	Accidents	Injured	Victims	Death Index
1991	170.702	240.688	7.498	4,4
1992	170.814	241.094	7.434	4,4
1993	153.393	216.100	6.645	4,3
1994	170.679	239.184	6.578	3,9
1995	182.761	259.571	6.512	3,6
1996	190.068	272.115	6.193	3,3
1997	190.031	270.962	6.226	3,3
1998	204.615	293.842	6.342	3,1
1999	225.646	322.999	6.688	3,0
2000	229.034	321.796	6.649	2,9
2001	235.142	334.679	6.682	2,8
2002	237.812	337.878	6.736	2,8

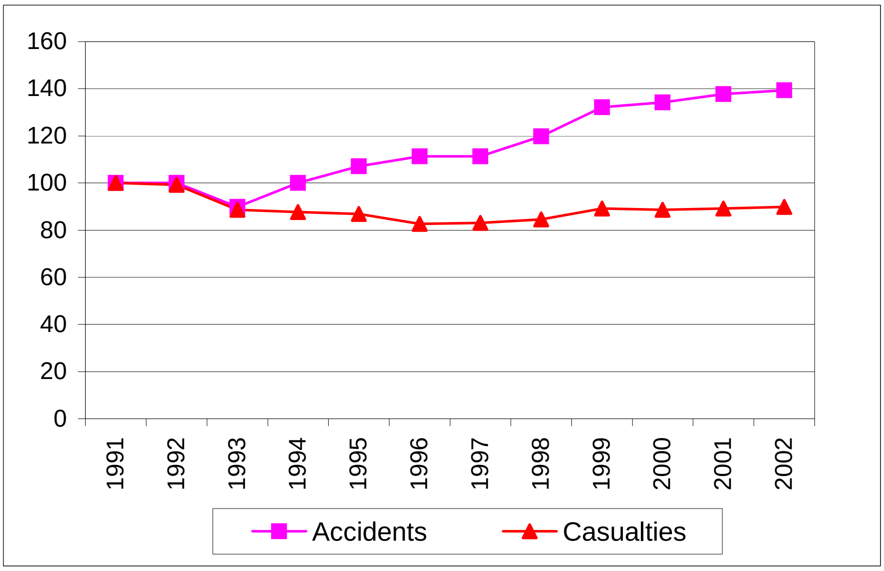

Figure 2 – Car accidents and casualties in the period 1991-2002 (base 1991=100)

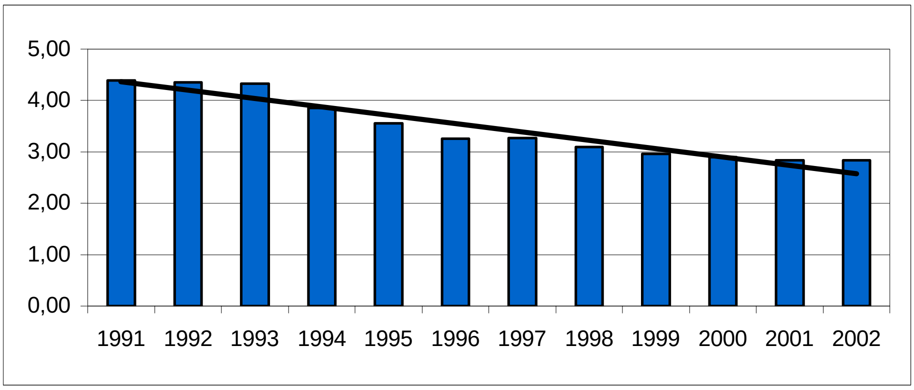

Figure 3 – Death index in the period 1991-2002

As a consequence, in urban surroundings the percentage of accidents is higher than in outer environments, the casualties and injured percentage being, in any case, lower. Every 100 crashes 1,7 people die in town, 5,1 on motorways and 6,7 on state highways; the reason for that resides in the reduced danger of the accidents in urban conditions.
The analysis of these data, filed by road typology, is included in Table 4.
Table 5 reports the crashes as function of the geometric track of the road infrastructure where they occurred, clearly highlighting that the higher number of crashes is experienced at junctions, straight roads and bends following them in this not enviable list.

Table 3 – Road accidents, victims and death index for each road typology - Year 2002 (Source ISTAT)

Road typology	Accidents		Casualties		Injured	
	Number	%	Number	%	Number	%
Urban roads	175.000	73.6	2.901	43.1	236.342	69.9
Outer roads	62.812	26.4	3.835	56.9	101.536	30.1
Totale	237.812	100	6.736	100	337.878	100

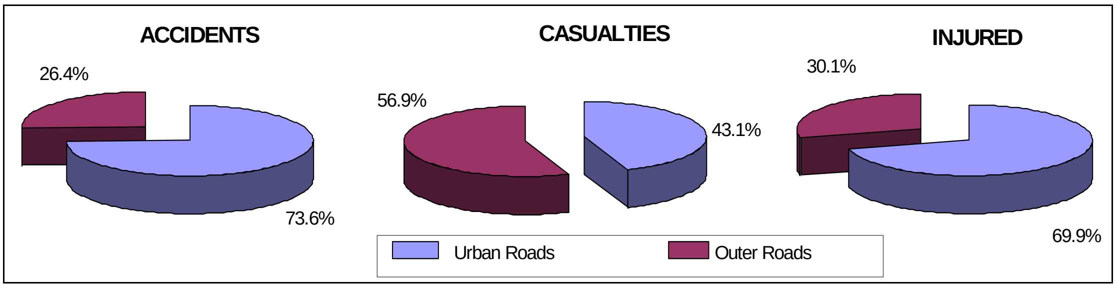

Figure 4 – Data comparison between urban and outer roads: accidents, casualties and injured

Table 4 - Road accidents, victims and death index for each outer road typology Year 2002 (Source ISTAT)

Outer road typology	Accident		Casualties		Death index
	Number	%	Number	%	
Motorways	14.761	6,2	758	11,3	5,1
State highway	25.598	10,8	1.706	25,3	6,7
Country Road	15.139	6,4	1.052	15,6	6,9
Outer town ways	7.314	3,1	2.901	43,1	1,7
Total outer roads	62.812	26,5	3.835	56,9	6,1

Table 5 – Accidents, casualties and injured according to road characteristics classification – Year 2002 (Source ISTAT)

Track sector	Accidents	Casualties	Injured	%Accidents	%Casualties	%Injured
Straight parts	96.197	3.374	133.051	40,5%	50,1%	39,4%
Bends	26.014	1.343	38.789	10,9%	19,9%	11,5%
Junctions	113.162	1.901	162.434	47,6%	28,2%	48,1%
Other (PL, etc.)	2.439	118	3.604	1,0%	1,8%	1,1%
Total	**237.812**	**6.736**	**337.878**	**100,0%**	**100,0%**	**100,0%**

THE POLITICAL CONTRAST ACTIONS

The severity of the problem met also the European politic class. Indeed, in 1994 the European Community established the first road safety European program with the indications of the fist strategies and advices which were to be followed in Europe, which are better defined in the following paragraphs.
In 1997 the second program “Promote the road safety inside the European community: 1997-2001 program” was drew up with the intention of reducing the road accidents casualties number, fixed at 40% by 2010.
Furthermore a stimulus for higher expenses for road safety was given, together with an economic comparative evaluation of the advantages in saving lives, called “one million ecu test”.
In this program a particular attention was paid for weak users (pedestrians, cyclists, motorcyclists, etc.), suggesting the creation of a government instrument which would evaluate the efficacy of the interventions through a local monitoring centre common language based. Hence, the EURO NCAP project started with the purpose of evaluating the passive safety of the vehicles on market, by means of adequate crash tests for different accident situations.
In 2000 the national data for a further program were verified and the UE produced the third program named “Halve the number of road accidents victims in the European Union by 2010: a shared responsibility”.
All the countries but Italy experienced a reduction in the accidents and, because of the positive results achieved, the program fixed the diminution of victims up to 50% by 2010.
Additionally, this document defined new risk factors belonging to cars and infrastructures, suggesting a series of partnerships between public and private Institutions and defining the general guidelines for the creation of an European monitoring centre.
Furthermore, the new European project EURO RAP started, with the purpose of evaluating the safety level of the European road infrastructures.
With the 144/99 Law, Art.32, Italy acknowledged the European Commission guidelines establishing the “National Plan of Road Safety” (PNSS), whose aim was the reduction of road accidents victims by 40%, subsequently updated to 50%.

Unfortunately, our country was at a disadvantage, compared to other European countries, because of the already mentioned increase of both casualties and injured people in the last period.
So as to allow the PNSS to start, in 2000 a first document was arranged, called "General guidelines for the plan actuation", which was followed by a series of publications, guidelines and funding through two implementing programs.
In November 2002 the "First annual program of the plan implementation" was approved, with a financial support of 130 million euros, and in September 2003, by means of the "Second annual program of implementation", 230 million euros were spent.
The PNSS identified the "first level" actions, which basically tended to determine the number of victims belonging to road accidents, and the "second level" ones, aiming at the strengthening and at the organisation of the instruments and the structures for the road safety administration. The actions management were arranged by National Government, Regional Government, Provinces and Municipalities all together .

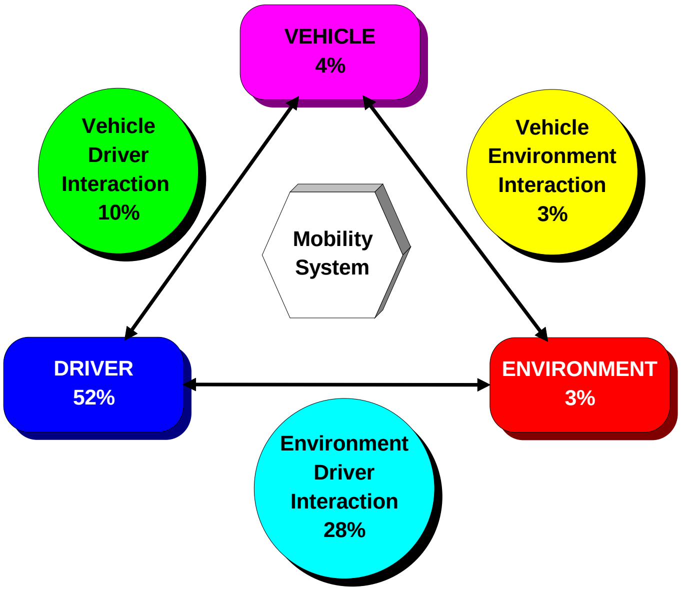

Figure 5 – Road accidents phenomenon factors interaction

ROAD ACCIDENTS FACTORS, PILOT PROJECTS AND RSA

The main factors causing car accidents are:
- driver: driving ability, psycho-physical conditions, driving behaviour, use of safety devices (seat belts, helmet, etc.);
- vehicle: performances, maintenance, working order, safety devices installed, etc.;
- environment, more in general:
  - route kind, from the planimetric and altimetric point of view, type of road section, maintenance, presence of guard rails , visibility, night lighting, etc;
  - traffic flows, number of heavy vehicles, traffic jams, etc;
  - climatic conditions (rain, fog, snow, etc.).

These factors interact with each other according to the scheme of Figure 5 and need appropriate strategies and contrast methodologies.
The PNSS acted acquiring operative methodologies through Pilot Projects (Figures 6 and 7).
Most of the pilot projects approached the problem of road safety through the following common operative stages: first of all the car crashes and the infrastructure were surveyed, identifying the so-called "critical accidents" (the recurring crashes) and then the intervention was proposed and executed, with a following monitoring phase.
Some pilot projects implemented the guidelines regardless of the road accident phenomenon knowledge.
The procedure proposed by the "Guidelines for the road safety analysis" was born in the United Kingdom with the name ROAD SAFETY AUDIT E REVIEW.
The safety analysis, internationally known as ROAD SAFETY AUDIT if referred to projects and ROAD SAFETY REVIEW if referred to roads in use, aims at the assessment of the potential risk situations in a road track.
The analysis is carried out through a system of judgements expressed by experts. The international success of the RSA&R is mainly due to its ease of application, but the results obtained, even though they are

positive, do not consider the trickiest problems of the infrastructures, which are hardly detectable through a qualitative description; in addition, the analysis process is completely transferred to the subjectivity of the Auditors.

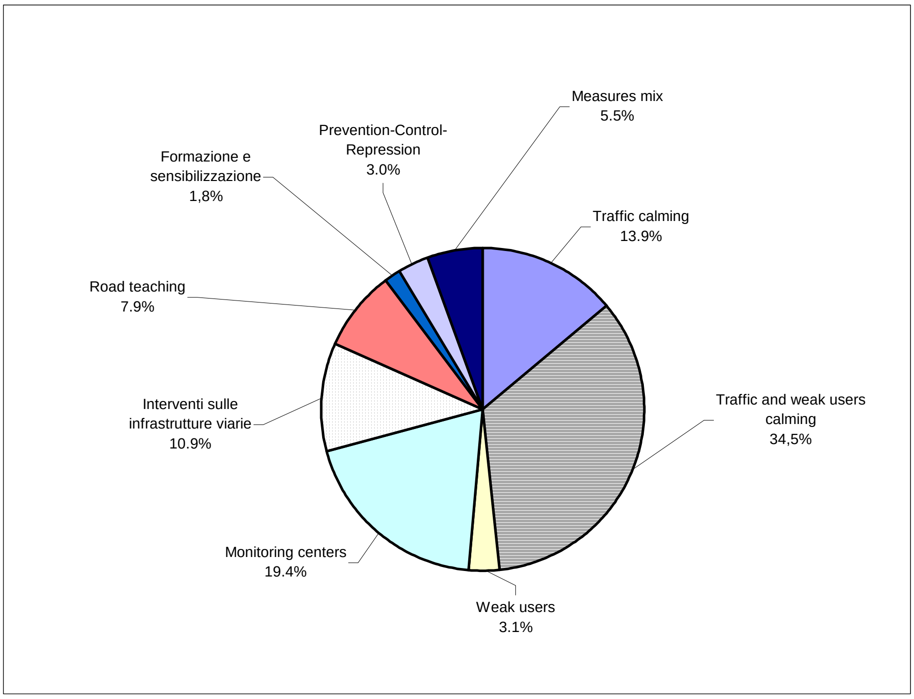

Figure 6 – Pilot project: number of proposals for each intervention typology

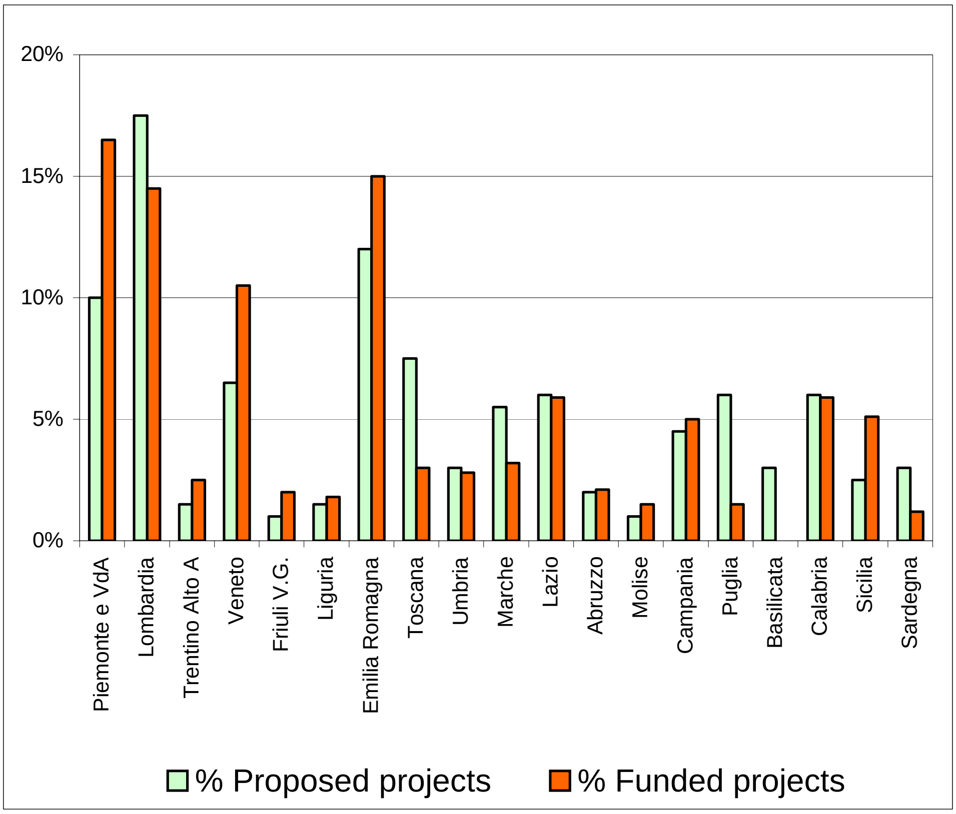

Figure 7 – Land distribution of the pilot projects

Some check lists, also prescribed by the guidelines, are to be compiled for the purpose during the site analysis; they are split up in the following categories:

- general aspects;
- geometry;

- junctions;
- signals;
- margins;
- pavements;
- weak users;
- parking;
- traffic calming means.

Every check list is composed of questions which are to be answered by the professionals during and after a site visit, the overall number of questions being 269.
The weakness point of the RSA&R procedure resides in the synthesis of the result, which gives only a technical, functional and qualitative description of the route, the evaluation of the defects which would potentially cause car accidents being therefore hidden.

SUPPORT MODEL TO RSA&R

The road construction technicians study the road accident phenomenon from the standpoint of both causes, analysing the human being-road-environment interactions, and effects, correlating the different factors.
Amongst all the road accident phenomenon prediction models found in literature, none of them was used in its original formulation for the pilot projects and for the PNSS funded projects.
In other words, no Administration intended to apply the models as the Authors proposed, probably because of the inherent operative difficulties of the models themselves.
The analysis procedure proposed in this paper wants to reduce these operative difficulties.
Moving from the operative planning out of the RSA&R, the Authors' methodology proposes the individuation of the geometrical deficiencies of the road track, by referring to the Standards in force (DM 05/11/01).
Practically, the safety level connected with the functional and geometrical parameters is detected by computing the divergences between these parameters and the Standards.
The methodology is made of two main stages: the first defines the existing infrastructure defects, while the second discovers the critical accident by means of the analysis of the car crashes that occurred during the last five years.
The first stage requires the recording of every single change from the technical Norms of the considered kind of road, whilst the second phase is based on a detailed analysis of the accidents in order to single out which kind of crash occurs with the highest frequency in the same spot.
Afterwards, the characterisation of the possible existing correlations is performed, referring to two extreme situations:

- presence of a precise correspondence, in the same point, between defects and critical accident: in this case, the safety intervention on the route will be performed by means on a geometrical improvement;
- lack of correlation between defects and critical accident for the above mentioned spot: in this situation the accidents belong to the trinomial vehicle-user-environment (functional aspect), rather than to the geometrical conditions of the route..

The first step for a concrete safety intervention lies in the achievement of geometrical and functional homogeneity of the route, as there is a strong tie between user's memory and expectations: indeed, the driver remembers the characteristics of the route he is driving along, and therefore he expects to come across the same route elements.
Thus, this methodology aims at the characterisation of the critical elements (geometrical and functional) which are to be considered by the Manager Board in order to guarantee higher safety standards.

Geometrical analysis

The operative stages of the proposed methodology are included in this paragraph: the start up is different, according to the urban or outer environment, as indicated in Figure 8.
The operative path for the outer conditions is the following:

1) geometrical data survey;
2) determination of the homogeneous sections;
3) individuation of singular or heterogeneous spots;
4) determination of the geometrical points which do not meet Standards, inside the homogeneous section, according to an assessment based on:

- straight parts length;
- length of bends;
- bends radii value;
- etc.

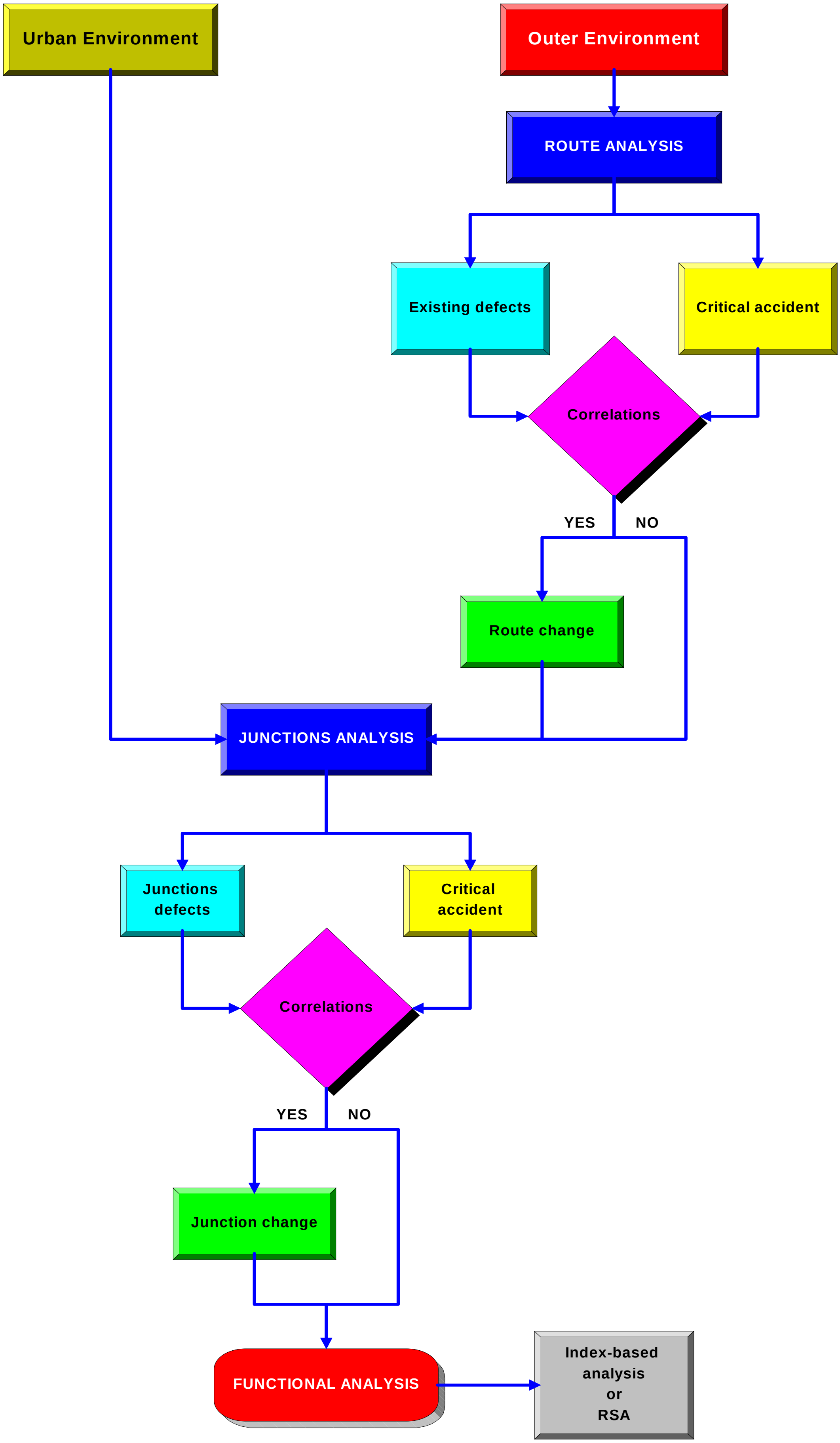

Figure 8 – Flow chart of the proposed methodology

The survey of the geometrical data can be performed by means of traditional instruments and/or with high performance apparatus, and it allows the determination of the plano-altimetric state of the route from the viewpoint of:

- bends radii;
- length of bends;
- straight parts length;
- longitudinal slope;
- vertical junctions;
- width of hard shoulders, lanes, etc.

Starting from the data collected, the route is divided into homogeneous sectors and the singular points which have completely different characteristics are highlighted.

The bends radius is the parameter considered for the identification of the homogeneous parts, which are basically made of a series of bends and straight parts, where the single radius value is not particularly different from the mean value (variance) calculated along the homogeneous sector itself.

The determination of the heterogeneous elements which are not consistent with the DM 5/11/01 Standards, along the homogeneous part, is performed by referring to prescriptions, as follows:

- once the operative speed of the element is assessed, the maximum and minimum length of the straight parts can be found from the formula L_{max} = 22 x V[m], where V is the speed (km/h) and from Table 6. The parts whose lengths are not within the prescribed values will be labelled as defective.

Table 6 – Minimum length of straight parts, according to DM 5/11/01

Speed [km/h]	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**
L min [m]	30	40	50	65	90	115	150	190	250	300	360

- as for the bends length, Standards require a correct perception of the element minimum length corresponding to a driving time of at least 2,5 seconds. The bends whose driving time is shorter than this value will be labelled as defective.

One should notice that the above cited Standards can be calibrated with appropriate tolerance margins, according to the purpose.

In addition, the car accidents are to be located on the track, in order to discover a possible correlation between spot and defect, an intervention being therefore necessary.

For example, if the accidents usually happen on the sector connecting two homogeneous curvature parts, the intervention will consider the connection of the above mentioned parts by means of an appropriate new bend, whose radius will be taken from the DM 5/11/01 Standards (Figure 9).

The same procedure will be adopted if the accidents occur inside the homogeneous sector: in this case also the characteristics of the route are to be improved through the indications included in the above mentioned prescriptions.

If the accidents are experienced in parts of the track were there is no existing defect, the analysis will follow the flow chart of Figure 8 up to the evaluation of the functional elements, the geometrical characteristics being not blamed.

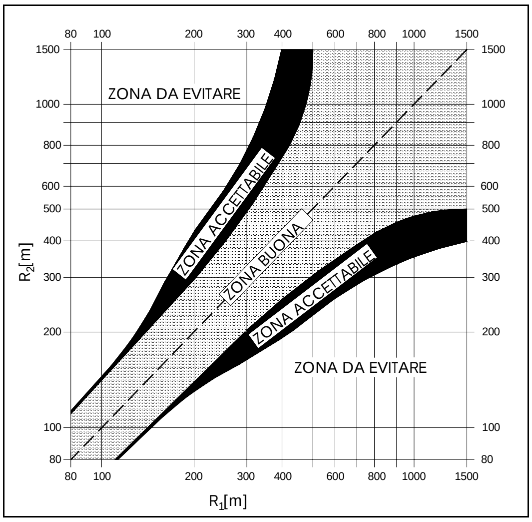

Figure 9: Correlation between the radii of two consecutive bends along the route (RAS-L/95)

This approach allows the user to find the sectors of the route were no accident occurred and which, in any case, do not follow the prescriptions. In this situation a planning procedure is to be considered for further interventions
Junctions are other elements deserving a special attention: they can be faced in the same way, no matter the surrounding environment. (Figure 8).
Obviously the junction which is to be studied should be analysed from the geometrical point of view, as well as from the standpoint of traffic flows and paths, so as to characterise the possible deficits.
Is this case also, the support of technical standards is fundamental for the sake of users safety.

Functional analysis

After completing the investigation of the route and of the junctions, if there is no connection between defects and critical accidents (Figure 8), the analysis will study the functional aspects.
The Road Safety Audit e Review (RSA&R) method is a quick mean for the evaluation of all the parameters involved in a car crash, where the functional elements are to be considered by beans of appropriate check lists. The efficacy of this method depends upon the subjectivity of the operator, but it is, in any case, sufficient for the detection of anomalous punctual situations.
The investigations of each functional aspect (signals, margins, pavement, weak users, parking, etc.) are to be performed along the whole route in a punctual and continuous manner, and the professional will express an evaluation by means of a percentage index representing the performance level as function of the efficacy from the standpoint of safety.
So as to better define the limits of this index, the operator survey is to be compared to the standards, connecting every functional aspect of the road to an index representative of the deviation from the optimal value suggested by the standards for the specific functional aspect itself.
The overall results of the survey can be included in appropriate diagrams where the progressive kilometric value is reported on the X-coordinates and the index on the Y-coordinates; furthermore, the number of accidents measured for every progressive value is reported in this diagram as well.
As a matter of fact, in total, the number of diagrams will be equal to the number of functional aspects considered.

CONCLUSIONS

The methodology proposed as integration for the typical RSA&R procedures intends to be an instrument for the analysis of road safety for the independent evaluation of the infrastructures deficiencies from both a track geometrical-building and functional point of view: this methodology tends to discover, in the first case, the correlations between infrastructures deficits and accidents and, in the second, the dependence of the road accident phenomenon on functional factors.
The procedure found its expression in the application for the SP80 road in the Potenza district, the results being impressive.
Anyway, the operative application highlighted the need for a deeper study of the index-linked functional analysis, so as to get to more objective results.
In conclusion, the Authors believe this instrument is a starting point for further improvements for the sake of a rational management of road safety.

NOTES

(1) The European Union data refer to twelve nations, excluding Greece, Spain and Portugal: this fact belongs to the fact that, for these countries, the evolution of both infrastructures and accidents are not directly linkable with the other EU countries (see the “2nd Parliament Report on the Road Safety Situation, 1999”, paragraph 1.2, “The European Situation”, point 1.2.2, “Mobility and death indices across UE”).

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