A DECISION SUPPORTING SYSTEM FOR HIGHWAY SAFETY MANAGEMENT

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ABSTRACT

In this study, a decision supporting system based on the identification and quantitative evaluation of the crash scenarios in the road network in order to implement the most cost effective safety measures is presented. In the paper, a concise description of the organization of the database, the formulation of the assumptions underlying the procedure, and the application of the procedure to a case study in Italy are described. Crash cases which, even if dispersed over a network or road section, present similarities in their process can lead to similar preventive measures. These crashes can then be aggregated around a crash scenario. That is, crashes at different sites which present similarities and belong to the same scenarios can be treated as unique entity. Crash scenarios are ranked according to their hazard level, and it is assumed that all the vehicles travelling the highway under the same scenario have the same crash probability. As a consequence, the benefits arising from the transformation of one scenario into another one depend on the hazard level of the two scenarios (before and after the implementation of the safety countermeasures). On this basis, if a certain financial resource is available, the choice of the scenario conversion group on a certain road network can be done searching among groups having a total cost equal to the available resources the group in which the total benefit is maximum.

Keywords: road safety management, crash scenarios, decision supporting systems.

INTRODUCTION

Traditionally, the first step in the highway safety management process is the identification of crash hotspots, also referred to as hazardous road locations, high-risk locations, crash-prone locations, black spots, or priority investigation locations (AASHTO, 2010; Austroads, 2009; Elvik, 2007; European Parliament, 2008; Tarko and Kanodia, 2004). Crash hotspot identification results in a list of sites that are prioritized for detailed engineering studies that can identify crash patterns, contributing factors, and potential countermeasures (Hauer et al., 2002, 2004). The most cost effective projects are selected to ensure that the best use is made of the limited funds available (Montella, 2001, 2005, 2010).

An alternative approach, which is presented in this study, consists in a decision supporting system based on the identification and quantitative evaluation of the crash scenarios in the road network in order to implement the most cost effective safety measures.

A crash can be defined as a rare, random, multi-factor event preceded by a situation in which one or more road users fail to cope with the road environment. Each crash is the result of a chain of events which is, in its entirety, unique, but some factors are common to several crash circumstances and the identification of these factors can be the basis for the the development of effective countermeasures (Montella, 2011; Montella et al., 2011a, 2011b). The combination of the crash circumstances makes up the crash scenario. The word scenario has been observed in the road safety diagnoses, i.e. the safety studies preliminary to the definition of engineering safety measures. These diagnoses aim at a sufficient understanding of the phenomena, thus making it possible to define appropriate measures, such as modifications in road layout, installing safety devices, etc. This generally implies the use of detailed analyses of police reports. This type of study was initially applied to the hotspots treatment. But diagnostic studies are also applied to wider areas to prepare more general safety measures. It is then important to be able to gather crash cases which, even if dispersed over a network or road section, present similarities in their process, and can lead to similar preventive measures. These crashes can then be aggregated around a crash scenario (Fleury and Brenac, 2001; Grossi and de Riso, 2005). That is, crashes at different sites which presents similarities and belong to the same scenarios can be treated as unique entity.

Different scenarios can be compared assuming that the change from one scenario to the other because of the implemented safety measures gives rise to a reduction in crash frequency related to the difference in the crash risk of the two scenarios. Thus, the identification of the risk of the different crash scenarios leads towards the selection of the countermeasures. In this paper, a Decision Supporting System (DSS) for road safety management based on the crash scenarios methodology is presented. The remainder of the paper presents a concise description of the organization of the database, the formulation of the assumptions underlying the procedure, and the application of the procedure to a case study in Italy.

DATA COLLECTING AND STORAGE

The database is formed by four sections (Grossi et al., 2009, 2010): (1) highway geometry, (2) traffic, (3) environmental conditions, and (4) crashes. Sections 1 and 2 were compiled using data provided by the Italian National Roads Institute (ANAS). Sections 3 data were supplied by the weather offices. Finally, crash data were obtained by the analysis of the original crash reports provided by the police offices (Traffic Police and Carabinieri).

Section 1 Highway Geometry

Section 1 contains the following information: horizontal and vertical elements of the axis, lane and shoulder widths, intersection location and configuration, and all the available items to characterize the entire roadway. Table 1 shows an extract of horizontal alignment data provided by ANAS along the axis of two roads SS 7 and SS 372 belonging to the network under study.

Table 1 Extract of the database, section 1: horizontal alignment

Road (1)	Direction (2)	Start (3)	End (4)	Type (5)	Radius (6)
SS7	NA-RM	160,006	160,128	0	10
SS7	NA-RM	160,128	160,195	1	2
SS7	NA-RM	160,195	160,292	0	10
SS7	NA-RM	160,292	160,450	1	4
SS7	NA-RM	160,450	160,700	0	10
SS7	NA-RM	160,700	160,971	1	10
SS372	NA-RM	-93	0,113	1	2
SS372	NA-RM	0,113	0,196	0	10
SS372	NA-RM	0,196	0,652	1	9
SS372	NA-RM	0,652	4,017	0	10
SS372	NA-RM	4,017	4,188	1	10
SS372	NA-RM	4,188	9,854	0	10

Column (5): 0 = tangent; 1 = curve.
Column (6): 0= curve radius < 50 m; 1= curve radius between 50 and 100 m; … ; 10 = curve radius > 1,000 m.

Section 2 Traffic

The section contains all the traffic information recorded by ANAS (Table 2). Traffic was classified in 9 categories. Hourly traffic volumes were recorded.

Table 2 Extract of the database, section 2: traffic

SS 372 - km 19,050 - Wednesday - 04/06/2003

Hour	Motorbikes	Cars	Vans	Trucks A	Trucks B	Trucks C	Buses	Special vehicles	Agric. vehicles	Total cars	Total HV	Total
7- 8	0	567	56	29	34	37	5	0	0	595	133	728
8- 9	6	513	32	55	26	55	11	0	0	529	163	692
9-10	2	460	229	171	110	152	31	0	0	575	578	1,153
10-11	4	530	87	75	43	39	13	0	0	573	214	787
11-12	8	678	76	62	35	46	7	0	0	716	188	904
12-13	4	647	64	47	41	52	5	0	0	679	177	856
13-14	8	620	30	38	35	52	1	0	0	635	141	776
14-15	7	670	52	108	26	66	6	0	0	696	232	928
15-16	2	617	35	55	33	59	8	0	1	635	173	808
16-17	7	723	69	105	54	91	9	0	0	757	294	1,051
17-18	8	653	112	106	62	87	6	0	0	709	317	1,026
18-19	11	718	111	104	90	108	12	0	0	774	369	1,143
Totals	67	7,396	953	955	589	844	114	0	1	7,873	2,979	10,852

The periods from 7 AM to 7 PM were classified as daytime, while those from 7 PM to 7 AM were classified as nighttime. The observations carried out in specific days of the year allowed to estimate the seasonal and annual average daily traffic (AADT), both in daytime and in nighttime. Estimations were performed using the formula of Geneva.

Section 3 Environmental Conditions

Rain heights recorded by rain gauges located close to the study road network are available (Table 3). These data, after processing, can be used to estimate how much rain falls at the time and site of the crash. In this stage of the research data were only used to confirm or correct information provided by the police officers about the pavement condition.

Furthermore, sunrise and sunset times in the different days of the year and in the different reference sites were recorded.

Table 3 Extract of the database, section 3: rain height in mm/h

Rain gauge name	County	Year	Month	Day	01:00	02:00	03:00	04:00	05:00
Grazzanise	CE	1996	12	31	13.4	22.2	0.2	0	0
Grazzanise	CE	1997	1	1	0	0	0	0	0
Grazzanise	CE	1997	1	2	0	0	0	0	0
Grazzanise	CE	1997	1	3	0.2	1.2	2	1.2	1.2
Grazzanise	CE	1997	1	4	0	0	0	0	0
Grazzanise	CE	1997	1	5	0.2	0.8	0	0.2	2
Grazzanise	CE	1997	1	6	0	0	0	0	0
Grazzanise	CE	1997	1	7	0.8	3	2.6	0.2	0
Grazzanise	CE	1997	1	8	0	0	0	0	0
Grazzanise	CE	1997	1	9	0	0	0	0	0.8
Grazzanise	CE	1997	1	10	2.6	4.2	3.6	5.6	4.8

Section 4 Crashes

For each crash, a report form was filled (Figure 1). The form contains only data that are considered necessary for a proper assessment of the crash risk and contributory factors. More specifically, the crash event is described by the precipitating factor (skidding, overtaking, etc.), the outcome of the event (run-off, head-on collision, etc.), and the consequences (people injuries and vehicle damages, etc.). If it is not possible to characterize the event, the crash is marked with the only outcome. It often happens that two events occur together, e.g. a vehicle "turns left" in a T-junction, and, simultaneously, the trailing vehicle overtakes on the left. In this case, both events are reported regardless of any possible judgment on responsibility.

The crash information are reported in the section 4 in tabular form (Table 4).

Figure 1 Database section, section 4: crash report form

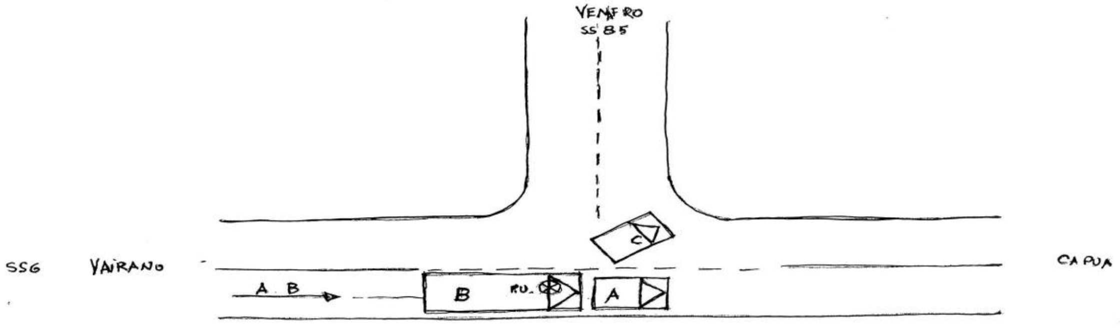
Protocol number				Crash:						Series:		
Taken by:		**Road: SS 6**		**Weather cond.**		**Pavement cond.**				**Light cond.**		
Traffic Police	X	Km		Clear	X	Dry			X	Natural		X
Carabinieri		Loc.		Rain		Ice				Artificial		
Others		Date: 04.05.1999		Cloudy		Pothole						
		Time: 11.15 PM		Fog		Wet						
Roadway		**Infrastruct. Char.**		**Road width**						**Intersection**		
2 lanes		Tangent	X	Lane						Roundabout		
3 lanes		Curve		Road						At grade		X
4 lanes		Grade		Shoulder						Acc. lane		
6 lanes		Crest/sag								Dec. lane		
		Tunnel										
Event		**Outcome**		**Vehicles involved**		**A**	**B**	**C**	**D**	**E**	**F**	**G**
Skidding		Run-off		Car		X		X				
Overtake		Head on collision		Truck			X					
Left turn		Side collision		Heavy truck								
Right turn		Rear end collision		Bus								
		Fence crash		Motorbike								
Loss of load		Tunnel crash										
Obstacle on the roadway				**Traffic**		**Work in progress**						
Tyre burst				Low volume		In the roadway						
Pedestrian				Normal		Outside the roadway						
Animal				Heavy volume								
Damage to people				**Driver's residence**								
Injured:	Dead:											
Sketch of the crash												
 C E' CADUTO DALLA BISARCA B												
Notes:												

Table 4 Extract of the database, section 4: crash data

(1)	(2)	Prot. (3)	Date (4)	Time (5)	Pav. (6)	Int (7)	Road (8)	Km (9)	C/T (10)	L (m) (11)	Event (12)	Dir (13)	Fat (14)	Inj (15)	Veh (16)
128	P	1	01.01.1996	7:30	W		SS7	173.120	C	7.40	Skid	R		2	1
129	P	3	13.01.1996	14:30	Dy		SS6	182.400	C		Skid	V			4
130	P	4	15.01.1996	11:15	Dy		SS7	189.030	T	7.10	U-turn	C	4	2	3
131	P	3	15.01.1996	19:45	Dy		SS372	24.500	T	7.00	U-turn	B			2
132	P	30	09.02.1996	11:30	Dy	X	SS372	23.400	C		U-turn	C		1	2
133	P	12	11.02.1996	11:55	W	T	SS6	192.100	T		L-turn	V		2	2
134	C	7/21	18.02.1996	23:10	Dy	X	SS372	10.900	C		L-turn	C			2
135	P	15	21.02.1996	11:30	Dy		SS6	177.500	C		Skid	C			1
136	C	20	22.02.1996	8:00	W	T	SS6	190.000	T	7.30	Overt.	V		1	2
137	C	22	01.03.1996	5:30	D		SS7	195.600	T		R-end	R			2
138	P	19	11.03.1996	18:30	W		SS7	183.400	C	9.75	Skid	R		1	2
139	P	20	15.03.1996	11:40	W		SS7	183.400	C	9.75	Skid	R		4	3
140	C	7/29	15.03.1996	13:10	W		SS6	187.000	C		Skid	C			2
141	C	90/24	18.03.1996	15:00	W		SS372	19.800	C	10.40	Skid	B		2	1
142	P		27.03.1996	15:45	W	X	SS6	177.700	C		Skid	C		2	3
143	P	60	27.03.1996	20:15	W	X	SS372	42.200	T		Entry	B	-	-	2
144	C	1/18	02.04.1996	5:00	W		SS7	183.400	C		Skid	R			1
145	C	7/35	02.04.1996	19:50	Dy		SS7	197.000	T	8.30	Overt.			2	1
146	P	94	03.04.1996	21:30	W	T	SS7	163.700	T		R-turn	C			1
147	P	68	05.04.1996	1:35	Dy		SS372	59.700	T	8.00	Overt.	C	-	-	2

Column (2): P means Traffic Police, C means Carabinieri.
Column (3): protocol number.
Columns (4) and (5): date and time of the crash.
Column (6): pavement conditions; Dy = dry, W = wet.
Column (7): intersection type (if any).
Column (8): road designation number.
Column (9): location.
Column (10): curve (C) or tangent (T).
Column (11): roadway width (m).
Column (12): event occurred.
Column (13): travel direction of the vehicle(s) involved in the crash (B-Benevento; C-Capua; R-Rome; V-Vairano).
Columns (14), (15) and (16): number of fatalities, injuries and involved vehicles.

DATA ANALYSIS

To show the data analysis process, a case study is presented. Data refer to the nine-year period from 1996 to 2004. Three two-lane rural highways managed by ANAS were studied. The network includes 18 km of the SS 6 “Casilina”, 30 km of the SS7 “Appia”, and 60 km of the SS 372 “Telesina”. Main difference between the highways relates to the access management: (a) controlled access on the SS 372, and (b) uncontrolled access on SS 6 and SS 7.

User Matrix

The user matrix contains 20 columns extracted from the database where the main information related to each crash are reported (Table 5).

Table 5 Extract of the User Matrix

Date (1)	Time (2)	Road (3)	Km (4)	D/N (5)	Pav (6)	Int (7)	C/T (8)	R (9)	L (10)
29.12.01	14.45	SS6	171.000	D	W	TLeft	T	∞	329
15.12.02	18.00	SS6	171.350	N	D	TRight	C	125	103
17.11.04	15.25	SS6	171.500	D	D		T	∞	2,466
03.05.96	12.50	SS6	171.750	D	D	TLeft	T	∞	2,466
10.10.03	19.50	SS6	171.750	N	D	TLeft	T	∞	2,466
08.04.96	0.30	SS6	172.000	N	D	X	T	∞	2,466
30.05.99	20.30	SS6	172.000	N	D	X	T	∞	2,466
06.06.00	15.30	SS6	172.000	D	D	X	T	∞	2,466
15.08.97	10.20	SS7	160.100	D	D		C	125	67
25.12.04	2.40	SS7	160.100	N	W		C	125	67
29.07.01	14.30	SS7	160.300	D	D		C	225	158
17.07.97	17.35	SS7	160.600	D	W		C	225	158
14.09.00	18.30	SS372	0.000	D	D		C	125	206
29.04.03	14.05	SS372	0.034	D	D		C	750	456
08.12.03	16.20	SS372	0.250	D	D		C	750	456

G (11)	S/C (12)	Rv (13)	Δi (14)	Pc/h (15)	Event (16)	Dir (17)	Fat (18)	Inj (19)	Veh (20)
1				300	Entry	V			2
-3				100	R-Turn	C		4	2
	S	5,000	4.0	400	Overt.	C			2
0				600	L-Turn	C			2
0				500	L-Turn	C			2
0				300	Pothole				1
0				400	L-Turn	C		1	2
0				400	Overt.	C		1	3
-1				400	Skid	R		1	1
-1				100	Skid	R			1
-1				300	Skid	R		1	1
0				800	Skid	C		3	1
-1				700	L-Turn	C			2
-1				1,100	Skid	B		1	2
-1				700	Head-on	C			2

Column (5): light conditions at the moment of the crash, D = day, N = night;
Column (9): horizontal radius (m);
Column (10): length of the horizontal element (m);
Column (11): longitudinal grade (%);
Column (12): S = sag, D = crest;
Column (13): vertical radius (m);
Column (14): absolute value of the difference in grade (%);
Column (15): passenger car equivalent volume per hour.

Crash Index

The crash rate (AASHTO, 2011) normalizes the frequency of crashes with exposure (measured by traffic volume). Roadway segment traffic volume is measured as vehicle-kilometers traveled for the study period. In the intersections, volumes are reported as entering vehicles per intersection. This method reflects crash risk for the individual road user.

Similarly, the crash index I_i normalizes the frequency of the number of vehicles involved in the crashes with exposure. It is defined as:

$$I_i = \frac{n_i \times 10^8}{V_i \times L_i} = \frac{n_i}{\frac{V_i \times L_i}{10^8}} \tag{1}$$

where n_i is the total number of vehicles involved in the crashes, V_i is the total volume in the analysis period, and L_i is the length of the segment i (km).

In a network, the crash index is assessed as:

$$I = \frac{\sum_i n_i}{\sum_i V_i L_i} \times 10^8 \tag{2}$$

In the intersections, the crash index is calculated as:

$$I_i = \frac{n_i \times 10^8}{V_i} = \frac{n_i}{\frac{V_i}{10^8}} \tag{3}$$

Crash Index as a Function of the Traffic

The crash index varies with traffic volume. Generally, a greater crash risk is observed with low traffic, because of the higher speeds and the lower drivers' workload. With the increase in the traffic volume, crash risk tends to decrease because of the lower speeds and the greater drivers' attention. Beyond certain traffic volumes, crash risk increases because of the interference between vehicles and too high drivers' workload.

This trend does not change from a qualitative point of view but presents different values on roads with different infrastructural characteristics. Specifically, it is worthwhile to observe the relationship between the crash index and the volume/capacity ratio. Table 6 shows the relationship for the highway SS 372 (two lane rural highway with controlled access). The lowest value of the crash index was observed for a volume/capacity ratio equal to 0.51. The higher value was observed for the lowest class of the volume/capacity ratio.

Table 6 SS372: relationship between crash risk and traffic

T eq. veh./h	Q/C (*)	Exp/10^8 vehic x km	Crashes x 10^8/Exp.	Fat. x 10^8/Exp.	Inj. x 10^8/Exp.	Veh. Inv. x 10^8/Exp.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
50/449	0,12	4,199	14,77	1,91	19,77	26,44
450/749	0,29	6,512	13,21	1,23	12,13	25,34
750/849	0,39	4,027	11,92	0,50	11,18	22,85
850/949	0,44	5,231	7,84	0,38	9,18	17,78
950/1.149	0,51	5.122	6,44	0,78	5,86	11,52
1.150/1.549	0,66	1,677	9,54	0,60	9,54	17,89

(*) Q = middle value of the class; C = 2,050 Pc/h.

CRASH SCENARIOS AND THEIR HAZARD

Scenario is the set of conditions within which a vehicle moves along a road network. Two different data sets having the same scenario components identifying two different roads and located in different places can be considered as two achievements of the same scenario. If one or more crash happen, we have a crash scenario. If we associate to a certain scenario all crashes belonging to the scenario, it is possible to evaluate the scenario hazard. The hypothesis is that the different realizations of a scenario on different parts of the road network have the same hazard level. For instance, all vehicles travels belonging to the same scenario (e.g., all tangents in daylight with no rain and no intersections) have the same hazard level. In other words, the calculated hazard levels are determinations of the same random variable.

Crash scenario hazards were calculated on SS 6 and SS 7. Scenario components were: (1) light conditions (day/night), (2) pavement conditions (wet/dry), (3) intersection presence (yes/no), and (4) horizontal alignment (curve/tangent). In table 7, all 2^4 scenario results are reported. Crashes belonging to the the first scenario (day, dry, no intersection, tangent) are showed in table 8.

Considering the scenario components indicated in table 7, traffic in the following environmental conditions was calculated: (1) daytime and dry, (2) daytime and wet, (3) nighttime and dry, and (4) nighttime and wet.

Daytime and nighttime AADTs were estimated basing on traffic observations carried out by ANAS in 2005. Considering a yearly growing rate equal to 1,5%, traffic in 2000 was estimated. Traffic in the 9 years study period (1996-2004) was assumed equal to the traffic in 2000.

Daytime and nighttime AADTs were split in traffic on dry pavement and traffic on wet pavement. In 2000, the Grazzanise rain gauge (located in the middle of the study area) measured 447 hours of rain occurred in 100 days. To calculate wet pavement conditions, the rain time was increased to consider the drying time. Overall, a wet pavement time equal to 10% in each year under observation was estimated.

The AADTs were calculated as follows:

$$\text{AADT}_{\text{DAYTIME, DRY}} = \text{AADT}_{\text{DAYTIME}} \text{ x Dry time} = 5{,}955 \text{ x } 0{,}9 = 5{,}359 \text{ Pc/day}$$
$$\text{AADT}_{\text{DAYTIME, WET}} = \text{AADT}_{\text{DAYTIME}} \text{ x Wet time} = 5{,}955 \text{ x } 0{,}1 = 596 \text{ Pc/day}$$
$$\text{AADT}_{\text{NIGHTTIME, DRY}} = \text{AADT}_{\text{NIGHTTIME}} \text{ x Dry time} = 2{,}491 \text{ x } 0{,}9 = 2{,}242 \text{ Pc/day}$$
$$\text{AADT}_{\text{NIGHTTIME, WET}} = \text{AADT}_{\text{NIGHTTIME}} \text{ x Wet time} = 2{,}491 \text{ x } 0{,}1 = 249 \text{ Pc/day}$$

Basing on these values of AADTs, the total traffic volume in the nine years under observation (V) in the 4 different environmental conditions was calculated.

Table 7 Scenarios

Scenario	Components				Realizations	Crashes	Fat	Inj	Veh
I	D	Dy	No	T	17	27	6	36	60
II	D	Dy	No	C	26	41	8	47	73
III	D	Dy	Yes	T	62	100	4	125	224
IV	D	Dy	Yes	C	17	20	2	21	40
V	D	W	No	T	5	8	0	12	16
VI	D	W	No	C	19	71	9	113	140
VII	D	W	Yes	T	13	18	0	16	37
VIII	D	W	Yes	C	13	22	2	34	38
IX	N	Dy	No	T	7	15	4	27	29
X	N	Dy	No	C	8	22	0	4	13
XI	N	Dy	Yes	T	21	27	0	45	53
XII	N	Dy	Yes	C	5	12	0	18	24
XIII	N	W	No	T	7	8	1	4	12
XIV	N	W	No	C	16	23	4	20	35
XV	N	W	Yes	T	17	18	0	31	32
XVI	N	W	Yes	C	8	8	0	10	14

Table 8 Crashes belonging to scenario I

SCENARIO I												
Date, time and location				Components				L	Event	Fat	Inj	Veh
17.11.2004	15.25	S.S.6	171.500	D	Dy	No	T	2,466	Overt.			2
10.03.2002	17.00	S.S.6	174.400	D	Dy	No	T	762	Overt.			3
02.10.2000	12.00	S.S.6	176.000	D	Dy	No	T	1,696	Entry		1	2
07.05.2004	16.40	S.S.6	176.100	D	Dy	No	T	1,696	Overt.	1	2	3
25.08.1997	16.15	S.S.6	176.500	D	Dy	No	T	1,696	Head-on			2
01.07.2001	12.30	S.S.6	176.700	D	Dy	No	T	1,696	Obst.		5	2
31.10.2002	10.15	S.S.6	180.000	D	Dy	No	T	703	Skid		1	1
20.07.1997	10.00	S.S.6	180.300	D	Dy	No	T	298	R-End		2	2
13.11.1998	15.15	S.S.6	180.350	D	Dy	No	T	298	R-End			3
10.11.2003	14.50	S.S.6	184.000	D	Dy	No	T	239	R-End		3	3
06.08.1996	9.00	S.S.7	161.000	D	Dy	No	T	504	Overt.		3	2
31.07.2003	9.45	S.S.7	166.300	D	Dy	No	T	109	Works			3
27.07.2003	17.45	S.S.7	170.200	D	Dy	No	T	149	R-End			2
01.04.2002	17.45	S.S.7	171.070	D	Dy	No	T	46	Dog		2	1
17.08.2003	18.10	S.S.7	172.400	D	Dy	No	T	490	R-End			3
18.06.2004	15.30	S.S.7	175.600	D	Dy	No	T	1,021	Skid		1	1
18.07.1999	9.30	S.S.7	179.000	D	Dy	No	T	766	R-End		9	4
16.07.1999	6.00	S.S.7	179.900	D	Dy	No	T	1,083	Overt.		1	3
02.06.1996	19.30	S.S.7	184.400	D	Dy	No	T	518	Overt.			3
01.03.2001	12.40	S.S.7	186.600	D	Dy	No	T	1,716	Skid		1	1
03.02.1997	10.00	S.S.7	188.100	D	Dy	No	T	2,355	Overt.			3
04.06.2000	13.45	S.S.7	188.350	D	Dy	No	T	2,355	U-Turn	1	1	2
21.07.2000	14.45	S.S.7	188.400	D	Dy	No	T	2,355	Overt.			2
21.04.2003	17.45	S.S.7	188.500	D	Dy	No	T	2,355	Overt.			2
20.09.2001	15.50	S.S.7	188.600	D	Dy	No	T	2,355	Skid		1	1
15.01.1996	11.15	S.S.7	189.030	D	Dy	No	T	2,355	U-Turn	4	2	3

Assuming the ratio between the number of vehicles involved in crashes and the total volume as a hazard measure, the crash scenarios were ranked as shown in table 9.

Table 9 Scenarios in hazard order

Scenario	Components (lighting, pavement, intersection, alignment)	Vehicles involved	V	Veh x 10^8/V
VI	D, W, No, C	140	1,957,860	7,150
XIV	N, W, No, C	35	817,965	4,279
XV	N, W, Yes, T	31	817,965	3,790
VIII	D, W, Yes, C	38	1,957,860	1,941
VII	D, W, Yes, T	37	1,957,860	1,890
XVI	N, W, Yes, C	13	817,965	1,589
XIII	N, W, No, T	12	817,965	1,467
III	D, Dr, Yes, T	212	17,604,315	1,204
V	D, W, No, T	16	1,957,860	817
XI	N, Dr, Yes, T	53	7,364,970	720
X	N, Dr, No, C	32	7,364,970	434
II	D, Dr, No, C	73	17,604,315	415
IX	N, Dr, No, T	29	7,364,970	394
I	D, Dr, No, T	60	17,604,315	341
XII	N, Dr, Yes, C	24	7,364,970	326
IV	D, Dr, Yes, C	38	17,604,315	216

Half of the vehicles involved in crossing crashes at four leg intersections were considered as running on the road under observation (see scenarios XV, VIII, VII, XVI, III, XII, IV).

The most dangerous was scenario VI: daytime, wet pavement, no intersections, curve.

The largest number of vehicles involved in crashes was in the scenario III, whose realizations were in tangent intersections in daylight conditions and dry road. Scenario III was also the most dangerous in dry pavement.

These results confirm that two-lane rural highways are particularly hazardous in the curves with wet pavement and at the intersections when crossing speeds are high (daytime and dry pavement).

If we consider scenario VI, it can be observed that the crash risk varies depending on the curve radius. It is possible to obtain more accurate results by replacing the simple component C, Curve, with more components including different ranges of the curve radii.

CONSIDERATIONS ON THE MOST HAZARDOUS SCENARIO

Scenario VI occurred along about 9 km of curves present on SS6 and SS7 and was characterized by 71 crashes, with the involvement of 140 vehicles, producing 113 injuries and 9 fatalities. In most of these crashes, the precipitating event was the vehicle skidding.

Crashes belonging to the scenario VI were grouped according to the following radius classes (Table 10 and Figure 2): (1) scenario $VI_1 = R \leq 75$ m, (2) scenario $VI_2 = 75 < R \leq 125$ m, (3) scenario $VI_3 = 125 < R \leq 175$ m, (4) scenario $VI_4 = 175 < R \leq 225$ m, (5) scenario $VI_5 = 225 < R \leq 275$ m, (6) scenario $VI_6 = 275 < R \leq 400$ m, (7) scenario $VI_7 = 400 < R \leq 750$ m, and (8) scenario $VI_8 = R \geq 750$ m.

In figure 2, each class of radius was characterized by his middle value. A great increase in the crash rate was observed when the radius is lower than 300 m. This result is consistent with several literature findings (e.g., Bonneson et al., 2005; Brenac, 1996; Lamm et al. 1999).

Table 10 Partition of scenario VI in 8 scenarios having different values of the radius component

Scenario	Components	Total vehicles	Fat	Inj	Veh.	Veh x 10^8/V	L (km)	I
VI_1	D, W, No, 75	1,957,860	1	23	37	1,890	0.212	8,914
VI_2	D, W, No, 125	1,957,860	5	48	48	2,451	0.885	2,770
VI_3	D, W, No, 175	1,957,860	1	13	10	511	0.401	1,274
VI_4	D, W, No, 225	1,957,860	2	11	11	562	0.725	775
VI_5	D, W, No, 275	1,957,860		11	15	766	1.147	668
VI_6	D, W, No, 400	1,957,860		4	8	409	1.618	253
VI_7	D, W, No, 750	1,957,860		8	8	409	1.828	224
VI_8	D, W, No, 1,250	1,957,860		3	3	153	2.280	67

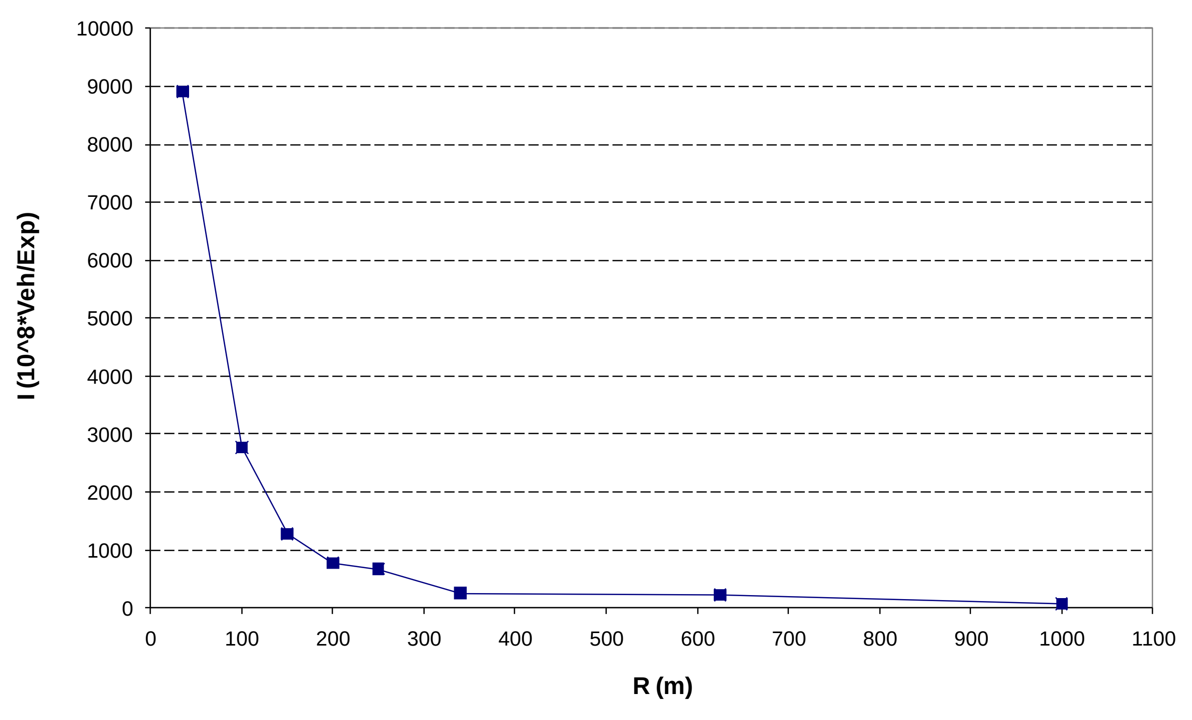


Figure 2 Relationship between crash index and radius (Scenario VI)

Looking closer at figure 2, it is possible to note that the hazard can be considered very high if radius is lower than 150 m, high if radius varies from 150 m to 300 m, low if radius is higher than 300 m. To simplify the characterization of high risk scenarios, scenario VI was split in just 3 components (Table 12).

Table 12 Partition of scenario VI in 3 scenarios

Scenario	Components	Total vehicles	Fat	Inj	Veh.	Veh x 10^8/V	L (km)	I
VI_1	D, W, No, $0<R\leq 150$	1,957,860	6	71	85	4,341	1.097	3,958
VI_2	D, W, No, $150<R\leq 300$	1,957,860	3	35	36	1,839	2.273	809
VI_3	D, W, No, $300<R\leq 1.500$	1,957,860		15	19	970	5.726	169

EVALAUTION OF THE SAFETY COUNTERMEASURES EFFECTIVENESS

To improve scenario VI, three different safety measures can be compared:

1) Increase the radius of the curves with R < 150 m (scenario VI_1) to values between 150 and 300 m (scenario VI_2). As a result, the crash index in daylight and wet pavement (outside the intersections) should be reduced from 3,958 to 809 involved vehicles/10^8 vehic x km.

2) Increase the radius of the curves with R < 150 m (scenario VI_1) to values greater than 300 m (scenario VI_3). As a result, the crash index in daylight and wet pavement (outside the intersections) should be reduced from 3,958 to 169 involved vehicles/10^8 vehic x km.

3) Increase the radius of the curves with radius between 150 and 300 m (scenario VI_2). to values greater than 300 m (scenario VI_3). As a result, the crash index in daylight and wet pavement (outside the intersections) should be reduced from 809 to 169 involved vehicles/10^8 vehic x km.

Benefits of the safety measure 1 are the economic benefits associated with the reduction in fatalities, injuries, and damaged vehicles and can be estimated with the equation:

$$\begin{aligned}(\Delta C_{1,2})_{VI} = {} & [C_{fat} x6/(1{,}957{,}860x1.097)+C_{inj}x71/(1{,}957{,}860x1.097)+C_v x85/(1{,}957{,}860x1.097)]xV_1x1.097 \\ & - [C_{fat}x3/(1{,}957{,}860x2.273)+ C_{inj}\ x35/(1{,}957{,}860x2.273)+ C_v x36/(1{,}957{,}860x2.273)]xV_1xL_1 \end{aligned} \tag{4}$$

where $(\Delta C_{1,2})_{VI}$ is the cost difference between the social cost of the scenario VI_1 and the scenario VI_2 social cost in the time period where total traffic is V_1; C_{fat}, C_{inj}, C_v are respectively the social cost of a fatality, an injury, and a damaged vehicle; L_1 is the total length of scenario VI_1 after the conversion (R < 150 to 150 < R < 300). It must be taken into account that the curve lengths change between the scenarios. The social cost of fatalities and injuries were defined in the Italian National Road Safety Plan, with the cost of a fatality equal to 1,394,000 € and the cost of an injury equal to 73,600 €. The cost of a damaged vehicle was drawn from the UK estimates (DfT, 2007) and is equal to about 3,000 € per vehicle involved in the crash. The total benefit estimated with the formula 4 $(\Delta C_{1,2})_{VI}$ is equal to 9,702,782 €. Benefits of the safety measure in daylight conditions and wet pavement $(\Delta C_{1,2})_{VI}$ must be increased to take into account the benefits resulting in other environmental scenarios: II, X and XIV. These can be evaluated and estimated with a similar procedure. Finally, we shall obtain a total $(\Delta C_{1,2})$.

$$\Delta C_{1,2} = (\Delta C_{1,2})_{VI} + (\Delta C_{1,2})_{II} + (\Delta C_{1,2})_{X} + (\Delta C_{1,2})_{XIV} \tag{5}$$

Night scenario contribution was not considered due to the low number of vehicles involved. The total benefit was estimated equal to 18,758,166 €.

The cost evaluation was carried out with reference to works similar to those hypothesized: cost I equal to 130,650 €, cost II equal to 261,000 €, and Cost III equal to 225,700 €. The total cost to convert the scenario VI_1 in VI_2 is the cost of the measure I in 15 curves (1,959,750 €). The cost of the other safety measures can be estimated with the same procedure.

SELECTION OF THE SAFETY COUNTERMEASURES

Defined the crash scenarios in a road network, the average hazard of different realizations in a single scenario calculated with (1) or (3) can be regarded as the probability for a vehicle to be involved in an crash.
To generalize the equations and formulas derived in the previous paragraphs, let's consider the most dangerous scenario in a road network. Be I_1 the crash index (eq. 3). Let's suppose that scenario components are: daylight conditions, dry pavement, at grade intersections, and horizontal tangent. Let's also assume that no auxiliary turn lane are provided and intersection sight distance is not adequate. The flow on the minor roadway be Q_2. Let's assume that we add turn lanes or remove the obstacles limiting the sight distance. As a result, the starting scenario will be modified into a less hazardous one, characterized by the crash index I_2.

Let's assume that the relationship between crash and traffic volume is linear (which is a rough approximation). If V_1 is the total traffic volume and L_1 is the length of the segment, the transformation of the scenario 1 in the scenario 2 will give rise to a change in the number of vehicles involved in crashes equal to (eq. 6a for road segments and eq. 6b for intersections):

$$\Delta N_{1,2} = V_1 \times (I_1 - I_2) \times L_1 \qquad (6a)$$

$$\Delta N_{1,2} = V_1 \times (I_1 - I_2) \qquad (6b)$$

After the evaluation of the ratios between the number of fatalities and the involved vehicles (f) and between the number of injuries and the involved vehicles (i), the change in the crash social cost $\Delta C_{1,2}$ is equal to (eq. 7a for road segment and eq. 6b for intersections):

$$\Delta C_{1,2} = V_1 \times [(I_1 - I_2) \times C_v + (I_1 i_1 - I_2 i_2) \times C_{inj} + (I_1 f_1 - I_2 f_2) \times C_{fat}] \times L_1 \qquad (7a)$$

$$\Delta C_{1,2} = V_1 \times [(I_1 - I_2) \times C_v + (I_1 i_1 - I_2 i_2) \times C_{inj} + (I_1 f_1 - I_2 f_2) \times C_{fat}] \qquad (7b)$$

In an extended road network, road safety improvement is rarely consistent with available budget. To optimize safety benefits, it is possible to characterize all the crash scenarios and sort them in hazard order (Table 9). The i_{th} scenario can be converted in one or more less hazardous scenario, j_{th}, with j > i. Each scenario conversion can be carried out with one or more safety measures and it is possible to evaluate the cost $S_{i,j}$. The total benefit ($\Delta C_{i,j}$) can be estimated with equation 7a or 7b. If a certain financial resource *F* is available, the choice of the scenario conversion group on a certain road network can be done searching among groups having a total cost ($\Sigma\ S_{i,j} = F$) the group in which the total benefit G is maximum ($\Sigma\ (\Delta C_{i,j}) = G_{max}$).

CONCLUSIONS

In this study, a decision supporting system based on the identification and quantitative evaluation of the crash scenarios in the road network in order to implement the most cost effective safety measures is presented. The base element of the decision supporting system is a database containing the main information related to highway geometry, traffic, environmental conditions, and crashes. Crash cases which, even if dispersed over a network or road section, present similarities in their process can lead to similar preventive measures. These crashes can then be aggregated around a crash scenario. That is, crashes at different sites which presents similarities and belong to the same scenarios can be treated as unique entity. Crash scenarios are ranked according to their hazard level, and it can be assumed that all the vehicles travelling the highway under the same scenario (e.g., daylight, wet pavement, no intersection, tangent alignment) have the same crash probability. As a consequence, the benefits arising from the transformation of one scenario into another one depend on the hazard level of the two scenarios (before and after the implementation of the safety countermeasure). On this basis, if a certain financial resource is available, the choice of the scenario conversion group on a certain road network can be done searching among groups having a total cost equal to the available resources the group in which the total benefit is maximum.

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