Control of an Experimental Model for Accident Management by Means of an Investigation Carried out on the A3 Freeway prior to and after modernisation works.

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Synopsis

In the this study a procedure is presented by which permits the construction of a model to manage the phenomenon of accidents. In particular, with the proposed model it is possible to establish the dangerousness of a road, in terms of accidents, knowing only the geometrical characteristics.
The model in question was obtained taking accident rates and other measurements connected to it, on a stretch of the A3 freeway prior to and after modernisation works. On the basis of the data captured, with the auxiliary of classical statistics and innovative operative research techniques, an expression of the model was obtained. Then, the model was applied to an unmodernised stretch of the A3 freeway and some high risk accident situations were identified, as well as the interventions which indicated the best benefit in terms of road safety.
On the same stretch, after a short period of time, modernisation works were carried out and finished in 2002. Following the aforementioned works, after about 2 years of opening to traffic, a comparison was carried out between the benefits estimated by the model and those observed following the modernisation. The result of the comparison was very positive in that the maximum error come across with the model is within 15%.

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Introduction

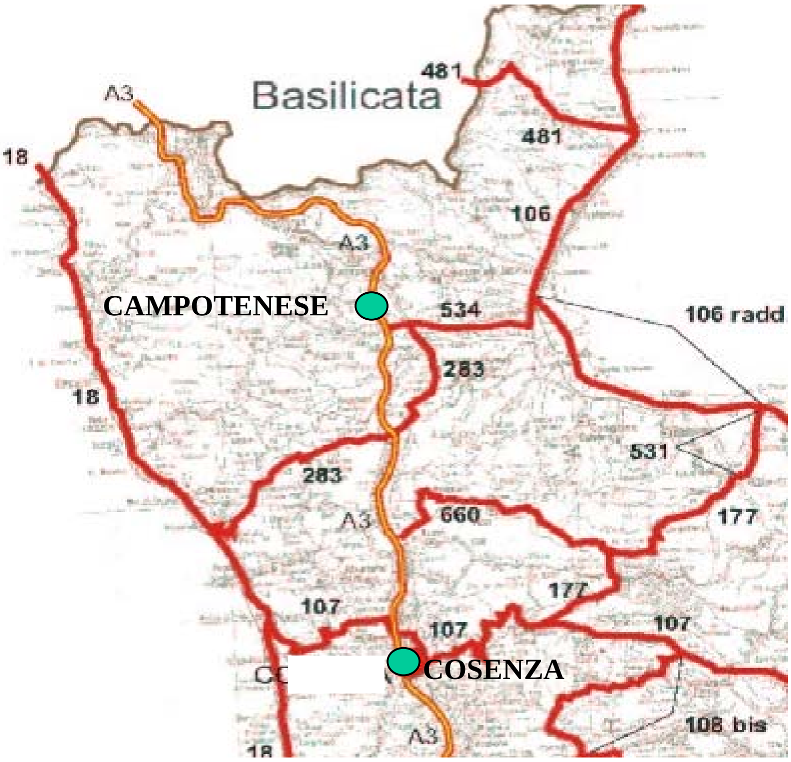
The planning of infrastructural works always presents a difficult choice for the managing organisation of roads. The topic is further complicated when, along with simple maintenance works it is also necessary to plan works aimed at controlling road safety. As is well known in Italy, the problem of road accidents has become extremely serious, so serious that in the fields of the National road safety plan, one of the primary objectives foreseen is the reduction of the accident level by 40% [2].
It is evident that such an objective could be met only if all the components which constitute the "man – road – vehicle" system are committed to finding new strategies which can improve the entire system.
In particular, the "road" component requires the road engineer to propose strategies and instruments which can help in the checking and improvement of accident levels due to anomalies linked to the road section.
In this work a procedure is proposed, through which it is possible to obtain an instrument which permits the planning of infrastructural interventions, which, under all the same conditions permit the achievement of the best objective in terms of road safety.

1. PROCEDURE FOLLOWED FOR MODEL CONSTRUCTION

1.1 Description of the stretch of road used in the study

The stretch used for the construction of the accident interpretative model, is from Campotenese at km 177+000, and North Cosenza at km 251+000 (figure 1).

Figure 1



All the information obtained on the stretch concern a period prior to the modernisation works, from 31/10/98 and 31/10/99 inclusive.
The stretch in question presents a "CNR III" type assimilable transversal section.

From a planimetrical viewpoint, the stretch presents a straight development for about 65% and curves for about 35%. The curvature radii are between about 350 and 2000 metres. From an altimetrical viewpoint the stretch is characterised by almost level segments, with slopes close to 1%, and undulated section whose slope is about 4%.
Furthermore, all the stretch is surfaced with a flexible type road surface with a closed type non draining layer.

1.2 Data used in the study

The data used in the study are the following:
1) data regarding geometry axis and the transversal section;
2) data regarding accident rates;
3) traffic data;
Data regarding geometry and the transversal section were obtained from map sources scale 1:5000 and 1:10000. Information about accidents was obtained from statements from the relevant police authorities. Data regarding traffic was taken from ANAS archives which permitted, in particular, the obtainment of T.G.M. relating to the study period, as well as the variation on an annual basis which was about 2.5%.

1.3 Organization of Data

The data listed in the previous paragraph were organised according to the logic in table 1. In the first columns the progressive, data and time of accidents are reported. In the following columns the environmental conditions, the geometrical conditions and the traffic conditions in which the accident is controlled.

Table 1

Accidents numeber	Progressive	Date	hour	Protocol Numeber	Direction	slope [%]	Planimetric element	Radius [m]	Paving state	Light condition	Wounded numeber	Type accident	particularitity	Driver	T.G.M. [veh./day]
1	226,000	05/11/98	21.30	513 /98	S	0,50	Curve	900	dry	night	2	Sideslip	svincolo	residents	15000
2	226,000	30/12/98	14.30	695 /98	S	0,40	Curve	900	dry	day	0	Sideslip	galleria	Not residents	15000
3	226,000	07/03/99	17.30	151 /99	S	0,40	Curve	900	dry	day	0	Sideslip	Area di servizio	Not residents	15000
4	226,000	26/03/99	7.45	186 /99	N	-0,40	Curve	900	dry	day	0	Collision with obstacle	assente	Not residents	15000
5	226,000	14/04/99	3.35	263 /99	N	-0,40	curve	900	dry	night	0	hole	assente	Not residents	15000

1.4 Technique used for data analysis

The data contained in the data matrix were analysed by means of hard c-means binary partition. Such a technique which has been used in studies which regard accident rates is valid for the identification of accident scenes [18]. For detailed information regarding this technique refer to the original publication [20]; in this area, the basic principles upon which the technique is founded are reported.

Hard c-means technique.

The H-c-m technique, as already mentioned, is a binary partition technique which permits the subdivision of m-accidents, which represent the sample space, c-groupings. Each accident in the sample space represents a point in which the coordinates are represented by the measurements associated with the accidents (progressive, curvature, state of road surfacing, slope etc.).
The grouping of accidents is carried out according to the level of affinity of the accidents. A criteria for measuring the affinity between the elements of the sample space is represented by the Euclideo type distance for example.
Once the criteria for measuring the affinity of the sample space elements has been chosen, by means of any repetitive type optimisation algorithym, it is possible to classify and subdivide the accidents in c-groupings.
In particular it has been seen that to the groupings identified with this technique, it is possible to associate the significance of the accident scene.

1.5 Characterising variables of the observed phenomenon

The variables used in the analysis were identified by mean of an iterative process. Initially, all the variables reported in table 1 were inserted. Then, some of them were removed and reintroduced on rotation until the analysis resulted significant. In table 2 the variables whose analysis produced the best result are reported. Furthermore, in the same table the codes assigned to non-numerical variables are reported.

Table 2

	Variable	**Variable denomination**	**Type of variable**	**Variable codifies**	**range**
1	*Curving (1/R)*	**Crv**	numerical		[0,00÷0,0028]
2	*Longitudinal slope [%]*	**PL**	numerical		[-2,5 ÷; 2,5]
3	*Freeway exit*	**SVI**	Not numerical	1,0 = absence 1,25= presence of "freeway exit" with acceleration and deceleration lane planned correctly. 1,5 = presence of "freeway exit" with acceleration and deceleration lane not planned correctly	[1÷1,5]
4	*Light condition (luminosity)*	**LC**	Not numerical	1,0 = night 2,0 = day	[1,00÷2,00]
5	*State of paving*	**Pav**	Not numerical	1,0 = dry 2,0 = wet	[1,00÷2,00]
6	*Tunnel*	**Gal**	Not numerical	1,0 = absence 1,5 = in the tunnel 2,0 = exit tunnel	[1,00÷2,00]

1.6 Results obtained from data analysis

The analysis technique described in paragraph 1.4. was applied to the data matrix, transformed according to the codes reported in table 2. The obtained results are reported in table 3.

Table 3

	scenes	Progressive	Light condition	Curving [1/m]	Radius [m]	Longitudinal slope [%]	tunnel	Freeway exit	State of paving	severity	Number og vehicles	Lenght of the scene [km]	T.G.M [Veh./day]	Dangerousness index
1	f	243,502	1,00	0,0003	1050	1,17	1,00	1,50	2,00	1,14	27	1,8	15000	**1879**
2	n	241,703	1,00	0,0025	400	2,18	1,00	1,00	1,86	1,27	51	3,6	15000	**1531**
3	q	200,345	2,00	0,0009	915	-2,89	1,05	1,00	2,00	1,45	10	2,4	15000	**1324**
4	k	229,566	2,00	0,0005	950	0,56	1,00	1,50	1,83	1,08	11	1,5	15000	**1306**
5	b	192,124	1,00	0,001	964	-3,41	1,00	1,00	2,00	1,33	21	2,4	15000	**1279**
6	d	226,193	2,00	0,0026	392	2,02	1,00	1,00	1,63	1,13	13	1,5	15000	**1221**
7	h	247,071	1,00	0,0007	1090	0,65	1,00	1,50	1,00	1,18	35	1,8	15000	**841**
8	a	238,998	2,00	0,0003	1025	0,72	1,00	1,00	1,24	1,31	59	8,1	15000	**833**
9	o	227,914	1,00	0,0002	1087	1,21	1,00	1,00	2,00	1,21	47	7,5	15000	**828**
10	c	195,271	2,00	0,0007	999	-2,97	1,08	1,00	1,00	1,19	38	4,8	15000	**691**
11	m	234,992	1,00	2E-05	2800	0,31	1,00	1,00	1,00	1,23	99	9,9	15000	**451**
12	p	191,398	1,00	0,0005	696	-2,62	1,53	1,00	1,18	1,32	22	3	15000	**402**
13	g	232,487	1,00	0,0017	669	-0,53	1,00	1,00	1,00	1,18	31	3,6	15000	**372**
14	i	196,450	1,00	0,0005	1111	-3,41	1,00	1,00	1,00	1,34	62	8,4	15000	**361**

Each line in table 4, which was obtained by calculating the average value of the measurements present in the different groupings, represents an accident scene. If, for example, we analyse the first line, remembering that the code assigned to the different measurements in table 3, one can state that the scenes are characterised by:

scene "**f**"

- Nocturnal light conditions;
- Low curvature;
- Low longitudinal slope;
- Absence of tunnels;
- Presence of freeway exit;
- Wet road paving;

such a procedure can clearly be extended to all other scenes in table 3. in order to calculate the distance in each of the scenes, it was necessary to define the spatial and temporal development of the scene. The temporal development coincides precisely with the observation period which, in the case in question, is 9 months. The spatial development was determined in the following way: for each accident, or accidents that occurred at the same progressive an influence area was assumed based on different situations (curve, tunnel entrance, tunnel exit etc.) which assumed different values comprising, in each case, between 100 and 300 metres, the sum of the different influence areas was assumed as spatial development of the scene. Then, the accident rate index was calculated in each scene, as the relationship between the number of vehicles (in the scene) and the distance in the section and period (each hundred thousand vehicles kilometre), taking into consideration different light conditions (day and night), and the different conditions deriving from the state of the road surface (dry, wet).

Such an index, multiplied by the severity variable, whose code is reported in table 5, gave a new index (dangerousness index) which takes into account, not only the number of vehicles involved in accidents, but also the seriousness.

Table 5

Severity Variable	
	Codifies
Without wounded	**1,0**
From 1 to 4 wounded	**1,5**
From 5 to 10 wounded	**2,5**
With dead men	**5,0**

The relation used for calculating the dangerousness index was the following:

$$Ip = \frac{(10^8 * Nv * Sev)}{(365 * L * k1 * k2 * T.G.M.)}$$

Where:

Nv, is the number of accidents;
L, is the length of the scene;
K1, is a coefficient that takes into account the road surface conditions and has a value of 0.75 for a dry road surface, and 0.25 for a wet road surface;
K2, is a coefficient that takes into account light conditions and has a value of 0.67 for daylight and 0.33 for nocturnal light;
Sev, is the severity codified according to the logic in table 5;
T.G.M., is the average daytime traffic.

Finally, to have confirmation of the significance of the groupings, in terms of accident rates, the determination index was calculated considering the measurements reported in table 2, as independent variables, and the dangerousness index reported in table 4 as dependent variable. ρ^2 determination index calculated resulted as being equal to 0.85, which amply confirms the significance of the groupings.

1.7 Expression of the interpretive model

The analytical expression of the interpretive model was obtained by means of a multiple linear regression carried out along the measurements indicated in table 3. The variables, which resulted as being significant in the regression are the following:

- ✓ **Luminosity** (Independent variable);
- ✓ **Curvature** (Independent variable);
- ✓ **Freeway exit** (Independent variable);
- ✓ **Paving** (Independent variable);
- ✓ **Longitudinal slope** (Independent variable)
- ✓ **Dangerousness index** (dependent variable)

The expression obtained for the interpretative model is the following:

$$\mathbf{Ip=-1520+109*LC+140771*Crv+962*SVI++743*Pav+7,13*PL^2} \quad \mathbf{(1)}$$

The level of correlation, between the various measurements used in the regression, resulted as being very high. In fact, the ρ^2 determination coefficient resulted as being equal to 0,86.

Furthermore, the ***"t student"*** test carried out in order to establish the significance level of the model coefficient (1), results reported in table 5, further confirmed the statistical validity of the model.

Table 5

	Coefficients of the model	t-student	significance
(Constant)	-1520,00	-3,1	0,012
LC	109,00	0,8	0,420
Crv	140771,00	1,7	0,124
SVI	961,00	2,7	0,027
Pav	743,00	4,9	0,000
PEND	7,13	0,4	0,670

In figure 2 the results of the comparison between the dangerousness index values determined by means of the procedure described in paragraph 1.6, on the basis of which the accidents observed and the accident rate index calculated by means of the model (1) are reported.

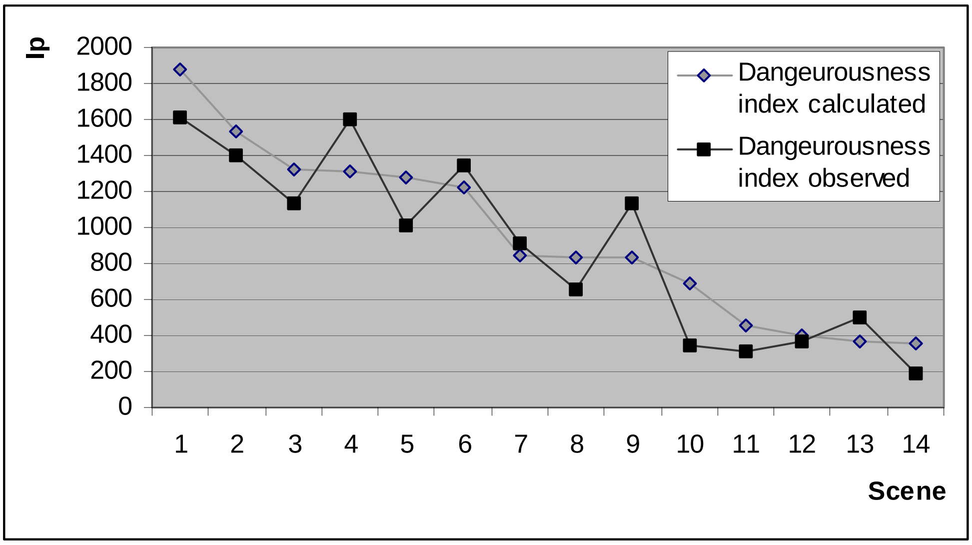


Figure 2

2. EXPERIMENTATION OF THE MODEL ON A FREEWAY STRETCH UNDERGOING MODERNISATION WORK

In order to establish the validity of the model, an experimentation was carried out on a stretch of freeway undergoing modernisation works. The section examined was from 240+000 km and 251+500 km and it contained the trunk from which the model was obtained (1). This section was chosen as it included the first two most dangerous scenes reported in table 3.

2.1 Accident scenes identified by the model

In order to analyse the aforementioned section, and to identify the accident scenes knowing only the tract geometry, it was necessary to identify all the plane – altimetric elements constituting the tract and present in the expression of the model (1). In table 6 a vertical section of the matrix used is reported.
The codes reported in table 2 were assigned to the variables present in the model (1). In particular the maximum values in the aforementioned table were assigned to the road surface variable and lighting variable.

Table 6

Progressive	Planimetric element	Curving [1/m]	Radius [m]	Freeway exit	Longitudinal slope [%]	State of paving	Light condition	Dangerousness index calculated with the model (1)
241,102	rettifilo	0,0000	Infinito	1	1	2	2	1045
241,437	curva	0,0031	320	1	1	2	2	1484
241,844	rettifilo	0,0000	Infinito	1	1	2	2	1045
241,944	rettifilo	0,0000	Infinito	1	1	2	2	1045
242,044	rettifilo	0,0000	Infinito	1	1	2	2	1045
242,144	rettifilo	0,0000	Infinito	1	1	2	2	1045
242,232	rettifilo	0,0000	Infinito	1	1	2	2	1045
242,232	rettifilo	0,0000	Infinito	1	1	2	2	1045
242,314	curva	0,0010	970	1	1	2	2	1190
242,414	curva	0,0010	970	1	1	2	2	1190

The scenes identified with the model, in an increasing order with respect to the dangerousness index, are reported in table 7.

Table 7

scene	Average progressive	Planimetric elemet	Curving [1m]	Radius [m]	Freeway exit	Longitudinal slope [%]	State of paving	Light condition	Dangerousness index
1	245,146	Curve	0,0013	800	1,5	0,5	2,0	2,0	**1806**
2	241,753	Curve	0,0031	320	1,0	1,0	2,0	2,0	**1594**
3	249,323	Curve	0,0018	Infinite	1,0	1,0	2,0	2,0	**1401**
4	245,106	Curve	0,0013	Infinite	1,0	0,5	2,0	2,0	**1337**
5	245,799	Curve	0,0012	840	1,0	0,5	2,0	2,0	**1316**
6	243,24	Curve	0,0012	Infinite	1,0	0,5	2,0	2,0	**1313**
7	240,37	Curve	0,0011	Infinite	1,0	0,5	2,0	2,0	**1305**
8	242,519	Curve	0,0010	970	1,0	1,0	2,0	2,0	**1299**
9	242,619	Curve	0,0010	970	1,0	1,0	2,0	2,0	**1299**
10	248,868	Curve	0,0010	Infinite	1,0	1,0	2,0	2,0	**1295**
11	244,007	Curve	0,0006	Infinite	1,0	0,5	2,0	2,0	**1232**
12	241,102	Straight	0,0000	Infinite	1,0	1,0	2,0	2,0	**1154**
13	242,77	Straight	0,0000	Infinite	1,0	1,0	2,0	2,0	**1154**

Each line reported in table 8 represents an accident scene identified in correspondence with determined geometric situations and in certain prefixed environmental situations. It can be observed that, for example, scene 1, taking environmental conditions into consideration, the accident occurs in relation to the "freeway-exit", on a bend (R=800m) and a low longitudinal slope. Scene 2, always taking environmental conditions into consideration, is characterised by high curvature (radius=320m), absence of "freeway-exit" and low longitudinal slope. Therefore, once the most dangerous accident scenes are identified, on the basis of the sole geometrical characteristics of the tract, it is possible to plan infrastructural works in order to remove the highest accident risk situations.

2.2 Planning of infrastructural works aimed at reducing accident rates

The section examined, following modernisation works, has undergone different changes. In particular, the most relevant changes can be summarised by the following points:

- Increase in curve radium in which the value resulted as being less than 800m;
- Use of draining road paving;
- Adaptation of the "CNR II" type transversal section.

These works have clearly brought about an improvement on the viability which has produced a reduction in the accident rate.
Starting from this data, directly verified during the study development, it was possible to further evaluate the quality of model 1. In fact simulating the same work carried out by ANAS on the first two most dangerous scenes reported in table 7, it was possible to evaluate the error made with the model in evaluating the benefits deriving from the aforementioned works.
In tables 8 and 9,besides the numerical values assumed by the different measurements modified following hypothesised infrastructural works, the results obtained from the simulation carried out with model 1 are reported. In the final column the benefit is reported, obtained as the relationship between the dangerousness index, estimated with model 1, prior to and after the introduction of infrastructural modifications.

Table 8

Scene	Description of the modification	Numerical variation of the variable	Dangerousness index after modernisation works	Dangerousness index before modernisation works	Benefit [%]
1	Freeway exit: adaptation of the acceleration and deceleration lane	Da 1,5 ad 1,25	**1194**	**1806**	**34%**
	paving: Use of draining road paving	Da 2 ad 1,5			

Table 9

Scene	Description of the modification	Numerical variation of the variable	Dangerousness index after modernisation works	Dangerousness index before modernisation works	Benefit [%]
2	Curvature: Increase in curve radium from 320 m to 800m	Da 1,5 ad 1,25	**959**	**1594**	**38%**
	paving: Use of draining road paving	Da 2 ad 1,5			

The results obtained from the comparison of the danger index determined, according to the procedures illustrated in paragraph 1.6, on the basis of observed accidents in the two modernised and unmodernised viability conditions, are reported in table 10. Finally, in table 11 the comparison of benefits estimated with the model (1) and those obtained based on observed accidents are reported. As can be observed, the error in estimation with the model is less than 15%.

Table 10

	Average progressive	Number of accidents before modernisation works	Number of accidents after modernisation works	Number of wounded before modernisation works	Number of wounded after modernisation works	**Dangerousness index before modernisation works**	**Dangerousness index after modernisation works**	**Benefit [%]**
1	245,146	8	4	8	0	**1677**	**1003**	**40%**
2	241,753	5	2	5	1	**1123**	**679**	**39%**

Table11

Benefit obtained with the accidents observed	**Benefit estimated with the model (1)**
40%	**34%**
39%	**38%**

CONCLUSIONS

The results given in the study highlight the validity of the proposed methodology for the construction of instruments aimed at planning and controlling road accidents.
In particular, the proposed model, even if in a limited field, has shown its potentiality for quickly identifying scenes that are at the highest risk of accidents, knowing only the geometrical characteristics of the road. In the control section, the model identified the same most dangerous accident scenes, previously determined based on observed accidents. In fact, with the model the two most dangerous scenes were localised, respectively in relation to the "freeway-exit", on a curve (R=800m) and low descent and following, for the second scene, in correspondence with a curve (R=320m), in absence of a "freeway-exit", and low slope.
In light of the results obtained, one can maintain that the methodology presented represents a highly useful instrument for constructing support models for the activation of correct intervention strategies in the field of road safety. Furthermore, in the future, the possibility of making the obtained model transferable in other areas thus avoiding the repetition of the procedure for every field of intervention has not been excluded.
With such an aim, the study is continuing with the experimentation of the protocol on other freeway stretches characterised by different geometric and traffic conditions.

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