A STUDY ON MOTORWAY SAFETY: EXOGENOUS VARIABLES AND PERCEPTION OF ON-BOARD TELEMATICS RELEVANCE

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SUMMARY

The first aim of this paper is to correlate motorway safety with the exogenous variables influencing it, mainly those that can be properly quantified, viz. those related to the environment and the infrastructure; an application to the Venice – Padova motorway case is carried out. The appraisal of the weights of mentioned variables allows us to deduce the relevance of human behaviour and, thereafter, the potential field of influence of on-board telematics when accidents occur or might happen.

POSSIBLE EFFECTS OF TELEMATICS ON MOTORWAY SAFETY

Many research projects are aimed at improving safety on roads and motorways by means of telematics systems and devices, frequently through those on-board. Usually, such technologies have two main purposes:

1. To allow communication among the organisations - collecting data on infrastructures - and vehicles, or among the vehicles themselves;
2. To assist the driver, in order to affront defective driving in situations of emergency, imprudence or insufficient attention level, possibly due to an imperfect psychophysical condition. Examples of proposed technologies are: anti-collision radar devices, rear-view cameras, sensorial systems for driving assistance in case of bad visibility (e.g., microwave radar, remote infrared cameras,…), and anti-drowsiness systems.

The first of the two purposes is strictly linked to vehicle flow conditions: one of its main outcomes is pre-trip or en route real-time information about infrastructure conditions, which may contribute to avoiding: useless loss of time, accident areas, and the rapid increase in traffic that, as highlighted later on, represents one of the main causes of accidents. As far as information transmitted by VMS or directly on-board is concerned, its efficiency has been examined in (1).

As for the second target, the systems designed to compensate for the driver's lack of attention and promptness mainly appear oriented to meet the endogenous accident causes,

linked to human behaviour. This is particularly true for some devices, such as anti-drowsiness systems, that mainly deal with keeping the driver under control (2, 3, 4).
As a matter of fact, all these automatic vehicle guidance systems based on monitoring external parameters (safety distance, wheel position in relation to road lines, etc.) may often prove useful in dangerous environmental conditions. For example, some systems for automatic speed control depending on safety distance are able to operate correctly even in bad visibility conditions, due to fog, mist or heavy rain (5).
At present, scientific literature is not yet able definitively to identify the effects of on-board ITS on traffic safety, as their application is not widespread. In this paper, in view of the role that the literature has assigned to exogenous factors and taking into account further, more in-depth analysis on this matter, the relevance of on-board telematics systems in motorway safety improvement may be deduced.

PREVIOUS RESEARCH

Motorway traffic safety, a subject of research for some decades (6, 7, 8, 9, 10, 11, 12), is usually interpreted based on two considerations: on one hand, emphasis is given to how dangerous the behaviour of some drivers is (13, 14, 15), on the other hand, the inadequacy of infrastructure or of services rendered by the organisations in charge is declared (16, 17).
Moreover, the issue of infrastructure inadequacy is often linked to other aspects, such as atmospheric or environmental factors (in Italy: 18; 19). Even the so-called "human factor" shows many facets: a road design methodology aimed at safety should prevent human errors as much as possible, by avoiding the improper use of roads, user uncertainty and sudden speed changes that are features of most accidents (10, 11, 20).
As a matter of fact, any road accident has as a basic feature an *excessively sudden variation* - not only of speed, but also of road width, twisting and turning, distance between vehicles, etc. - *compared to the driver reaction capability.* This idea of variation, in time and space, of the state of any vehicle, of the traffic flow, of the infrastructure or of the atmospheric conditions, may be usefully recalled in light of the conclusions.
Therefore, the objective to be pursued for increasing safety is related to the improvement of the infrastructure, of the use drivers make of it and therefore to the possibility of controlling traffic or each individual vehicle.
The threefold influence of *road*, *man* and *vehicle* on the risk of accidents occurring has also been a study topic for many years (7, 16, 20, 21). It is interesting to recall the Haddon matrix (21), concerning the interaction of the three above-mentioned factors with the three accident dynamics moments, defined as pre-crash, in-crash and after-crash.
In the mid-eighties, Stabey and Treat also tried to estimate the contribution of the three road safety macro variables (*Table 1*); they established how infrastructure – combined with the other two variables – contributes to 28-34% of the cases, man to 93-94% and vehicle only to 8-12% of accident cases. Actually, man may be assigned some responsibility in 100% of accidents, even if this statement is usually difficult to prove.

Contribution	***Sabey***	***Treat***
Road	2 %	3 %
Man	65 %	57 %
Vehicle	2 %	2 %
Road-man	24 %	27 %
Man-vehicle	4 %	6 %
Road-vehicle	1 %	1 %
All three variables	1 %	3 %

Table 1. Contribution of the three main variables on road safety according to Sabey and Treat (21)

Taking into account the situation in Italy, motorways, while representing approximately the 20% of total traffic, are just 10% of the national road network. Various improvements to them, including widening, have had a positive impact: less recent statistics (22), referring to a large network expansion period (1969-79), show a meaningful decrease in accidents and their seriousness (*Table 2*). Certainly, accidents must be related to the number of vehicles running on the motorway section and to the extension of it; the validity of the *accidents/vehicle·km* ratio is widely recognised, with denominator typically expressed in hundreds of millions or in billions.

Reference period	1969-1979
Development of the Italian motorway network extension	+150%
Traffic increase	+250%
Accident increase	+100%
Fatal accident increase	+5%
Variation of accident parameter /10^9 vehicles·km	96 → 60
– of which, fatal	2.6 → 1.4
– of which, with heavy vehicles	1.61 → 2.11

Table 2. Relationship between the Italian motorway development and accidents (22)

A subsequent Italian study, carried out again by Aiscat (23), shows how during the following period (1980-1994) the number of accidents/10^8 vehicles·km has been further reduced, though in a smoother way, with an even smaller fatal event impact and a more enhanced decrease of heavy vehicles involvement.
Later on (Istat data), the accident situation on the Italian motorway network has evolved as follows:

- increase of the number of absolute accidents;
- reduction, although limited, of accidents related to the number of vehicles·km;
- reduction of the degree of dangerousness (injuries, death);
- decrease in heavy vehicle involvement, even as their number has increased, mainly during night periods.

Considering the above-mentioned general and specific remarks, in the literature (10, 24, 11) some correlation may be found between the exogenous factors that influence motorway accidents and the accidents' frequency. The classic methodological approach to this issue is based on the linear regression between the number of accidents and each relevant factor, typically roadway geometry and traffic features. However, recent studies have highlighted irregular statistical results in the application of simple linear regression. For example, in (25) authors have underlined some difficulties in their studies: with the increase of vehicle covered mileage, the variance of accident frequency increases; moreover, they proved the

difficulty in correlating single exogenous factors with accident events. In order to overcome these limits, Shankar *et al.* (24), and Milton and Mannering (11) have employed, with quite a good result, binominal negative regression between yearly accident frequencies and the geometric characteristics, traffic level and also atmospheric conditions, with reference to some thoroughfares in the State of Washington.
Other researches have pointed out that Poisson or negative binomial models are more suited than linear regression for some accidents analysis; still, according to mentioned literature, to the facility to use a multiple linear regression model and to the usefulness of results, hereafter presented, this last has been chosen in the following.

Research within the Italian context

In Italy, as stated in (26), the number of accidents varies even tenfold in different areas of the road or motorway network, within the same period. Many theories may be considered to impute such differences to user behavioural habits in the various geographical areas; however, the impact of infrastructure and environmental factors certainly cannot be overlooked. The report states: «The phenomenon also highlights how the environmental, territorial, and infrastructure factors as well as the type of mobility present in a specific area considerably influence the safety levels, much more than individual behaviour».
There are 12 motorway branches presenting an accident-km rate approximately double that of the average national rate (*Table 3*). With a total extension equal to 21.1% of the whole national network, they contribute nearly half the total number of accidents. It has been estimated that, if some maximum risk conditions could be lead to "normality", every year a death reduction of 1700 units and an injury reduction of 37,000 units would be obtained.

	Network	*Accidents*		*Deaths*		*People involved*	
Motorway branch	[km]	n.	on 10^2 km	n.	on 10^2 km	n.	on 10^2 km
1. Naples ring-road	20	625	3125	5	25	423	2115
2. Milan-Brescia	94	1165	1239.4	25	26.6	655	696.8
3. Naples-Salerno	52	720	1384.6	12	23.1	352	676.9
4. Genoa-Savona	46	730	1587	6	13	308	669.6
5. MI-VA / Lainate-Como	78	1042	1335.9	16	20.5	466	597.4
6. Milan-Bologna	192	2094	1090.6	51	26.6	1056	550
7. Bologna-Ancona	236	2626	1112.7	36	15.3	1311	555.5
8. Rome-Naples	202	1907	944.1	42	20.8	1004	497
9. Bologna-Florence	91	1201	1319.8	21	23.1	353	387.9
10. Genoa-Sestri	49	601	1226.5	4	8.2	200	408.2
11. Genoa-Serravalle	50	579	1158	10	20	182	364
12. Padua-Venice (Mestre)	*23*	*272*	*1182.6*	*3*	*13*	*59*	*256.5*
In total	1133	13,562	1197	231	2038.8	6369	562.1
Compared to Italy total [%]	21.1	41.2	-	37.9	-	43.8	-
Rest of the nation	4235	19,388	457.8	378	892.6	8156	192.6
National total	*5368*	*32,950*	*613.8*	*609*	*1134.5*	*14,525*	*270.6*

Table 3. Situations of maximum motorway risk (based on Aiscat data 1995, 1997)

The Venice-Padua toll-motorway is one with the "maximum risk situation", even though it is the least dangerous among the 12 identified branches. This branch represents a small percentage of the Italian network, but it is interesting to focus on this specific case in order

to make a detailed analysis. Another reason for taking a single motorway into consideration is the difficulty in finding the detailed material required for a careful statistical analysis.
At this point, there are two main obstacles to be overcome:
1. Multiplicity of sources in Italy: concessionary companies, National Institute of Statistics (Istat, 27) and other organisations;
2. Selection of correct variables: infrastructure, environmental, chronological, economic, related to traffic, drivers and vehicles.

Data sources and bibliographies

In searching for an analytical relationship between the number of motorway accidents and the variables influencing them, it must first be established which ones are the most significant, in order to avoid a uselessly complex analysis. Thereafter, an appropriate model must be selected, capable of describing the contribution of each factor to the accident phenomenon. Based on the considerations found in the literature and abovementioned considerations, *multiple linear regression* has been selected, which is a well known extension of the method of minimum square interpolation to the case of various independent variables.
Having selected a methodology, it must be explored which variables, usually identified as causes for fatal accidents, may actually be dealt with as independent (28, 29, 30). Often, it may be difficult to assign a measure unit to factors of remarkable importance, such as some climate conditions or human behaviour; besides, some variables may have only true/false values.
Main sources for this study are the statistics compiled by the concessionary companies, by Aiscat (Italian Association of the Motorway and Tunnel Concessionary Companies) and by other research organisations that make meteorological or environmental surveys in the areas involved in the concerned study (31, Hydrographic Office in Turin). Available data do not always meet the requirements of this study. Some surveys have been carried out intentionally referring to single factors (for example, fob).
One defect of the available sources is insufficient uniformity (32, 33): it is difficult to find factors impacting the number of all accidents that are dealt with in a homogeneous way in all statistics. Even in case of correspondence, considering data associated to one motorway branch and then data relating to another one, often an immediate comparison may be misleading. In this context, reference could be made to Aiscat (Report 60, 1995), dealing with a whole set of parameters that allows placement of different motorway branches on the same level. This publication may be used to identify some variables, for an indicative evaluation of their weight; it may even be used to evaluate the efficiency of some analytic tools, such as the interpolation of multi-variable functions, which until now were rarely used in this sector.
On this subject, the Italian work of Caracoglia (1984 and others, between the end of the seventies and the first half of the eighties; 6), may be mentioned. It contains useful ideas on the link between speed reduction and fatal accident reduction, the incidence of heavy vehicles, of the roadbed, the day of the week, and the type of vehicles involved. Moreover, multiple linear regression and other mathematical models are applied, such as the particularly original one based on inertia ellipsoid theory.
Even in Aiscat (1995) an attempt is found, referred to the whole Italian motorway network in the 1967-1992 period, to link the number of accidents to some of the determining causes. In particular, the “number of accidents, number of fatal accidents, deaths” units of measure

are identified, with a relationship among them and with time (yearly data), distance, and traffic density.
In addition, there are more sectorial studies focused on the analysis of a single parameter of environmental or infrastructure nature, or linked to the vehicle driver conditions when the accident took place. Fob is particularly relevant; the study published by Aiscat (1986) contained various statistics helping to identify the vehicle driver's behaviour and their reactions in case of fob. Other studies have permitted some agreed-upon remarks on this issue, for example, how an increase of fob hours has entailed an increase in accidents and their seriousness, especially during the autumn and winter months.
Conclusions that may easily be foreseen by common sense are therefore supported by actual data, although focusing on just one variable is reductive.
On the above-mentioned assumptions, it has been possible to draw up an initial classification of the main variables influencing the number of accidents on motorways; still, any selection on them is not yet operated, waiting to be able to find out, using available actual data, which variables are the most significant for defining a multiple regression function.

ANALYSIS OF DATA RELATING TO ACCIDENTS

General considerations

The start point in the study is the database directly provided by the concessionary companies of the motorways taken into account (34); it consists of the collection of accident sheets, filled in by the staff in charge at accident registration. The motorway branches initially taken into consideration are Turin-Milan (1991-1995) and Venice-Padua (1993-97). The fact that the two time intervals do not coincide or are not recent is not a limit: the idea is not to compare the two realities in a strict way, rather to compare the adequacy and significance of data collected by the two sources. Both infrastructures have similar climate conditions; they have three lanes in each direction, are practically straight and without tunnels. The Venice-Padua motorway is later analysed in depth.
The accident sheets contain the infrastructure, accident and environmental characteristics relating to the moment when each accident took place. Examining these accident sheets may result useful in classifying the phenomena, associated with the various accidents, on their frequency basis. Starting from a database of this type, it is not yet possible to think about building a multiple regression function. In fact, if the dependent variable is the number of accidents which occurred in a predefined time period, the independent variables can only be the "numbers of accidents", even if there are special conditions (rain, fog, wet road bed, working day, bend, etc.).
In order to write a linear multiple regression function:

$$y = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + a_3 \cdot x_3 + \ldots + a_n \cdot x_n$$

coefficients a_i will all be smaller than one. However, their meaning is not significant, because the dependent and independent variables belong to the same universe, therefore a relationship among the various phenomena influencing one of them is not being researched. A second step concerns therefore the research of variables describing the motorway branch taken into consideration within the same time period (rainy days per year, vehicle flow composition, etc.) and no longer the "number of accidents in a specific condition".
It is not certain *a priori* that data availability allows us to fully meet our requirements, and it is also not certain that a deterministic method such as multiple regression is suitable to

properly face the problem we are dealing with. The preliminary investigation on each single variable, with frequency calculation, aims at drawing up an initial hierarchy of variables that must then be re-examined based on data of a different type.

Remarks on available data: dominating variables

The accident sheets contain a large variety of data concerning the two motorways; for Venice-Padua, the values of 35 variables are shown for each accident (time references, accident position, its dynamics, seriousness, people involved, vehicle causing the accident, vehicle make and type, theoretical average vehicle flow per day, percentage of heavy vehicles, type of day, weather conditions, road bed conditions, speed limit, geometric characteristics of the route, and data concerning the vehicle drivers involved).
Only a limited number of mentioned variables must be selected to draw statistical evaluations; the original choice of the parameters to be recorded on the accident sheets is not so useful for our aims; besides, the large amount of values to be indicated for each accident risks generating confusion to the people in charge of filling in the accident sheets. For most of the variables mentioned which are considered significant in studying the accident causes, an initial elementary processing is used, consisting mainly of the calculation of the frequency function, in order to provide an initial picture of the situation. Traffic data used, divided by quarter of the year, are shown in *Table 4*.

	Quarter	I	II	III	IV	I	II	III	IV	I	II	III	IV
Year	*Vehicles*	Actual average vehicles per day				Theoretical average veh. per day				Vehicles·km in millions			
1993	Light	42,886	54,064	57,376	47,534	37,338	47,519	51,083	41,268	78.3	100.7	109.5	88.5
	Heavy	13,819	15,561	14,578	14,424	12,031	13,677	12,978	12,522	25.2	29	27.8	26.8
	Totals	56,705	69,625	71,954	61,958	49,369	61,196	64,061	53,790	103.5	129.7	137.3	115.3
1994	Light	46,335	55,810	58,919	49,804	40,342	48,966	52,316	43,176	84.6	103.8	112.1	92.5
	Heavy	14,462	16,474	15,606	15,693	12,587	14,453	13,856	13,605	26.4	30.6	29.7	29.2
	Totals	60,817	72,284	74,525	65,497	52,929	63,419	66,172	56,781	111	134.4	141.8	121.7
1995	Light	50,325	58,596	61,843	52,360	43,470	51,229	54,725	45,211	92.2	108.6	117.3	96.6
	Heavy	16,865	18,312	17,260	17,111	14,568	16,010	15,274	14,774	30.9	33.9	32.7	31.7
	Totals	67,190	76,908	79,103	69,471	58,038	67,239	69,999	59,985	123.1	142.5	150	128.6
1996	Light	50,325	60,080	64,910	54,361	43,470	52,503	57,290	46,807	92.2	111.3	122.8	100.3
	Heavy	16,865	18,641	17,652	17,678	14,568	16,290	15,579	15,222	30.9	34.5	33.4	32.7
	Totals	67,190	78,721	82,562	72,039	58,038	68,793	72,869	62,029	123.1	145.8	156.2	133
1997	Light	52,805	63,114	67,327	57,034	45,596	54,845	59,225	48,836	95.6	116.3	127	104.3
	Heavy	17,163	20,161	18,990	19,133	14,820	17,519	16,713	16,383	31.1	37.1	35.8	35.5
	Totals	69,968	83,275	86,317	76,167	60,416	72,364	75,968	65,219	126.7	153.4	162.8	139.8

Table 4. Values of traffic used for the analysis, referred to the Venice-Padua toll-motorway (quarterly values)

Basically, the first work phase consists of assigning a *weight* to each variable and to search for the possible links of each one with the others. In view of the analysis carried out on accident sheets, it is significant to notice that only 9 of 35 variables included in the sheet give useful indications, namely the subdivision of statistics based on:

1. Time of day,
2. Month,
3. Type of day (working, holiday/weekend, pre-holiday/weekend),

4. Traffic level (theoretical average vehicles per day),
5. Weather conditions,
6. Road bed conditions,
7. Mileage progression,
8. Area,
9. Dynamics of the accident.

Though many variables are not useless, the accident sheets allow us to deduce a sufficiently precise picture of the situation. Furthermore, the hydro-graphic offices in each Italian Region provide detailed data concerning the meteorological phenomena during each day of the year.

After taking the infrastructure and environmental aspects into consideration, the question concerns the possibilities of research aimed at isolating the factors dependent on the driver and on the vehicle. From the accident sheet, data on the people involved in the accidents may be obtained only in relation to accident seriousness; this means that information is provided about the number of deaths and of the more or less severely injured persons. However, no other indicator is provided which could be useful in quantifying the impact of specific risk behaviours.

One variable universally acknowledged as a cause for accidents is *speed,* halfway between the "environmental" units of measure and those dependent on human behaviour. In fact, while one feature of the environment of a vehicle may be considered as the average speed of traffic flow in the same lane or in the same general area; too much speed may be considered a factor that, combined with a sudden dangerous situation, leads to an accident by not giving the driver sufficient time to react and avoid the sudden event. Reasoning in these terms, the importance of the "safety distance" factor is underlined. Even if this factor is not suitable for statistical surveys (it is rather difficult to establish, for example, whether or not the vehicle responsible for an accident kept the safety distance from the vehicle in front of it, unless a cruise control radar system is placed on-board), it is certainly recognised as one of the most significant factors.

In the Venice-Padua motorway accident sheets, the only reference to speed is the "Speed limit" item. As previously highlighted, this is not significant because, as it may be guessed, the truly significant factor is the level of driver's acceptance of the limits imposed by law.

In some countries, research has been conducted in the attempt to find a link between the reduction of permitted speed on motorways and the actual reduction of average speed and the number of accidents as well (*Table 5*). Unfortunately there are no comparison figures referring to the Italian situation.

	Speed limit variation		Average speed variation	Variation in number of accidents
	From	to	[%]	[%]
Switzerland	36.1 m/s (130 km/h)	33.3 m/s (120 km/h)	-5% (approx.)	-3.7% (approx.)
Sweden	30.55 m/s (110 km/h)	25 m/s (90 km/h)	- 3.9 m/s (-14 km/h)	-21%
United States	24.6 m/s (55 mph)	26.8 m/s (60 mph)	+0.89-1.79 m/s (+2-4 mph)	+19-34%

Table 5. Impact of speed limit variation on the number of accidents (35)

Another variable significantly affecting the number of accidents is *traffic level*. The Venice-Padua motorway accident sheets contain the "level of traffic" item that refers to theoretical

average vehicles per day recorded at the time of each accident. This information is only indicative because the flow entity is divided into various classes, made of theoretical average vehicles, by groups of 10,000. The tables in the Aiscat bulletins, keeping the quarterly subdivision, are particularly interesting. Only two traffic components are identified: light and heavy vehicle traffic; light vehicles include motorcycles and motor vehicles with two axles with the height from ground, at the rear axle, smaller than 1.30 m.
Concerning the Venice-Padua motorway, during the reference period of this research, the vehicle flow composition remains nearly constant (*Table 6*). Even if no big variations take place every year, it may be remarked how traffic composition undergoes changes that may be seen in shorter periods.

Year	*1993*	*1994*	*1995*	*1996*	*1997*
Light vehicles	77.604%	77.225%	76.259%	76.438%	76.060%
Heavy vehicles	22.396%	22.775%	23.741%	23.562%	23.940%

Table 6. Venice-Padua motorway, traffic composition in vehicle·km (percentage values)

This variable will be one of those to be entered into the multiple regression function in order to determine to what extent the number of accidents is influenced by the flow of vehicles as a whole and by its composition.
Finally, some analysed variables should be considered separately, as they cannot be taken into account for the definition of a regression function. First of all, the accidents are subdivided according to the *type of day* (working, holiday/weekend or pre-holiday/weekend) and to the *area* (full lane, junction, exit, etc.) where they occurred. As mentioned, the fact that this type of characterisation is available for each accident entered into the database will possibly allow separate investigations for accidents that occurred in special conditions such as during weekends or near a work site.
A similar consideration would also be applicable for the subdivision *time of day*: for example, it could be interesting to isolate all accidents that occurred at night and set a specific regression function to highlight how they are particularly influenced in some specific conditions. However, it must be borne in mind that the independent variables of a function of this type would in any case refer to a period of time of one year or of one month. In fact, today it is not possible to have, for example, data relating to climate subdivided by time of day.
As a first conclusion, it may be written that the accident sheets recording accidents on the Venice-Padua motorway provide a picture of the situation that is certainly below the expectations of the analysis, but they allow indications to be drawn which address the search for additional data, to be used for later study developments.

MULTIPLE REGRESSION FUNCTION DETERMINATION

After the preliminary analysis is carried out:
1. the independent variables are selected;
2. an analytical expression is proposed to quantify impact on accident probability – intended as the number of all accidents and the number of involved vehicles – with reference to the Venice-Padua motorway (1993-97 period).

As a conclusion, two different types of equation will be written: two different independent variables will generate different coefficients and this makes the analysis more significant.

The independent variables

One of the environmental type variables that means to represent a quite important danger factor is *raininess,* namely the number of rainy days. For a complete scenario on rainfalls in the concerned area, the yearbooks of the Hydro-graphic and Mari-graphic Office in Venice, published by the National Technical Services of the Council of Ministers Presidency, are taken as a reference, namely data relating to the Mestre and Padua measurement stations. Defining a relationship between the number of rainy days with the days of the year (366 in 1996), percentage values are obtained for comparison with those obtained by processing accident sheet data relating to the number of accidents which occurred during rain or in wet roadbed conditions.
From *Table 7* it may be deduced that there is no constant relationship between raininess and danger. However, data relating to 1993 and, to a smaller extent, data relating to other years require some thinking: in the first case, it seems that a wet roadbed represents double risk. The year 1994 is peculiar, since rain even seems to reduce the risk of accident.

	1993	*1994*	*1995*	*1996*	*1997*	*Average*
Rainy days in the year	63.5	71.5	92	89.5	74	78.1
Percentage in the year	17.397%	19.589%	25.205%	24.454%	20.274%	21.384%
Accidents with rain	23.560%	14.027%	20.848%	19.288%	15.517%	18.648%
Accidents with wet road bed	34.031%	15.837%	28.269%	28.487%	24.138%	26.152%

Table 7. Comparison between the percentage of rainy days and the percentage of accidents with rain or wet roadbed

Concerning *fog,* the same publications used for raininess have been consulted. Reference has been made to the "Metrology" section, containing the atmospheric pressure values, relative humidity, wind speed and direction, cloudiness, foggy days in the area where the Venice-Padua motorway develops.
Concerning the *vehicle flow and traffic subdivision between light and heavy vehicles* variables, their trend in time is obtained from bulletins published every quarter by Aiscat. Associated statistics are shown in *Table 4*. The table shows how the percentage of heavy vehicles repeats, from year to year, in a periodic way in each quarter, with small variations.
It is complicated to evaluate the infrastructure characteristics and condition variations. An indication relating to the good conditions of the examined motorway may be drawn by the balance-sheets published yearly by the Venice and Padua Motorway Company. In particular, the yearly trend of the *maintenance costs*, shown in the Profit and Loss Account, is quite interesting. The subdivision among the various types of preservation interventions is detailed. It is therefore possible to focus attention just on some aspects, such as expenses for road signs or paving. Moreover, the indication relating to the *yearly expenses reserved to traffic data processing* is also of much interest.
The sudden increase in maintenance expenses exposed in 1996 seems to have had a positive impact on the following year, when the number of accidents was reduced by 16.2%. A detailed item analysis reveals that expense increase as to 1995 is mainly due to re-paving using draining and sound-deadening materials. Therefore, *the good roadbed conditions seem to have given a substantial contribution to safety.* A further index on which paving renewal has probably had an impact, although modest, is the number of accidents which

occurred in wet roadbed conditions: from 96 in 1996 (28.49% of total) down to 70 in 1997 (24.14% of total).
Therefore, the variables from balance sheets must be considered in a different way than others. It cannot be said that the maintenance intervention effect may be found in the year where work was carried out. Actually, the contrary may be true, that is to say, the *work sites* generate trouble to road circulation and may cause accidents. Therefore, it appears more sensible to combine each year with expense data relating to the year before.

Multiple regression function

We want now to establish a function allowing the forecasting of values of the dependent variable y, starting from a sample of its values corresponding to r samples of value relating to the independent variables x_i:

$$y = b_0 + \sum_{i=1}^{r} b_i x_i$$

Coefficients b represent the best estimates of the equation obtained by entering the data corresponding to the units of measure taken into consideration; y represents the best estimate of the actual dependent variable value, corresponding to:

$$y = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 + \ldots + b_r \cdot x_r + \varepsilon_t$$

The procedure to estimate the coefficients b_i is the same used for the minimum square method (simple linear regression); the total of squares of discards among the actual values of the dependent variable and those included in the model is minimised.

$$\varepsilon_i = y_i - \hat{y}_i$$

$$S(b_0, b_1, b_2, \ldots, b_r) = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 = \sum_{i=1}^{n} (y_i - b_0 - b_i - b_1 x_{1i} - b_2 x_{2i} - \ldots - b_r x_{ri})^2$$

Introducing the matrix notation:

$$Y = Xb + \varepsilon$$

The estimate of coefficient b is obtained by solving: $b = (X^T X)^{-1} X^T Y$
In order to evaluate the model suitability, reference must be made to some indicators, dealt with in another section.
In the examined case, variable Y is represented by the number of accidents, that is to say, the number of total vehicles involved in accidents on the Venice-Padua motorway; the independent variables that must be entered in the matrix X are those described above, i.e.:

1. the vehicle flow, expressed in vehicle·km in millions;
2. the percentage of heavy vehicles;
3. raininess, expressed in rainy days during the reference period;
4. the number of foggy days during the reference period;
5. the expenses borne by the concessionary company for infrastructure maintenance;
6. the expenses borne by the concessionary company for traffic data processing.

Assumptions must be made on data taken from the concessionary company balance sheet. The figures concerning meteorological conditions are detailed by day. Since statistics concerning traffic are quarterly, the quarter has been taken as the reference interval of the examined period (the years 1993-97). However, maintenance expenses and traffic data

processing expenses are provided yearly. Trying to consider the year as the reference time interval, the adopted model does not allow us to obtain even slightly significant results. In fact, the number of independent variables (six) it too high compared to the number of remarks (five), therefore a perfectly explained variation of the dependent variable is obtained. However, in reality, as the variance-covariance matrix is singular, it is impossible to make evaluations about the equation coefficient inference. It has therefore been assumed to subdivide equally the yearly expenses on four quarters. Moreover, as already mentioned, it has been considered convenient to offset data taken from the balance sheets by one year. The set of data to be processed may therefore be schematised (*Table 8*).

	Y		x_1	x_2	x_3	x_4	X_5	x_6
Quarter-year	*Accidents*	*Involved vehicles*	*veh·km [millions]*	*% heavy vehicles*	*Rainy days*	*Foggy days*	*Maintenance expenses [10^6 It. liras]*	*Traffic data process. expenses [10^6 It. liras]*
1-93	39	95	103.5	0.243	5.5	16	659.375	123.775
2-93	39	67	129.7	0.224	16.5	2	659.375	123.775
3-93	54	78	137.3	0.202	19	0	659.375	123.775
4-93	59	92	115.3	0.232	22.5	1	659.375	123.775
1-94	33	39	111	0.238	9	4	770.757	101.082
2-94	54	82	134.4	0.228	29	0	770.757	101.082
3-94	60	108	141.8	0.209	18.5	0	770.757	101.082
4-94	74	130	121.7	0.240	15	15	770.757	101.082
1-95	60	101	123.1	0.251	26	5	810.442	113.358
2-95	63	223	142.5	0.238	30	1	810.442	113.358
3-95	90	169	150	0.218	21.5	1	810.442	113.358
4-95	70	113	128.6	0.247	14.5	7	810.442	113.358
1-96	70	107	123.1	0.251	15.5	5	751.472	123.956
2-96	88	141	145.8	0.237	26	0	751.472	123.956
3-96	94	57	156.2	0.214	15.5	0	751.472	123.956
4-96	85	145	133	0.246	32.5	11	751.472	123.956
1-97	68	111	126.7	0.245	15	15	1030.403	139.037
2-97	66	114	153.4	0.242	19	0	1030.403	139.037
3-97	73	151	162.8	0.220	18	1	1030.403	139.037
4-97	83	146	139.8	0.254	22	15	1030.403	139.037

Table 8. Database used for multiple regression

The most significant results are mentioned below. The question is not only which are coefficients *b*, but also which ones are actually significant in explaining the dependent variable trend. Therefore, the analysis result may have a deeply different result when excluding some of the dependent variables from the model using proper tests.

Case when the number of accidents represents the dependent variable

The obtained equation is:

$$y = 1{,}512x_1 + 532{,}265x_2 + 0{,}155x_3 + 1{,}606x_4 - 0{,}07087x_5 - 0{,}08375x_6 - 204{,}885$$

It justifies nearly 70% of y variation, as deduced from:

$$R^2 = \frac{\left(b^T X^T Y - n\bar{y}^2\right)}{\left(Y^T Y - n\bar{y}^2\right)}$$

Often, this parameter is overestimated. Therefore, the *adjusted* R^2 value is calculated too:

$$R^2_{adj} = R^2 - \frac{r(1-R^2)}{n-r-1}$$

where r is the number of independent variables and n is the number of observations.
Parameter F, the ratio between the total of squares due to regression and the total of squares due to residuals, represents the unit to be tested in order to verify that coefficients b are not all void. Its increase means that the independent variables give an important contribution to the explanation of the dependent variable variation. Instead, if this parameter tends to reduce, it means that the limit condition is approaching (all coefficients b are equal to zero). It follows a Fisher distribution with $n-2$ degrees of freedom.
The "void assumption"(b all equal to zero) must be refused when F_{calc} is greater than the Fisher standardised distribution value relating to a given significance value. Reference has been made to the value of significance corresponding to the void assumption limit acceptance situation.
This is confirmed in test t, executed on the values of the calculated b. The distribution assumption on which the test being executed is based requires to adopt the standardised distribution t Student's with $n-2$ degrees of freedom as a model. After calculating the value of t, dividing b by the corresponding standard error (average quadratic discard), the value of significance corresponding to the concerned number of degrees of freedom is obtained.
Therefore, the fact that the estimates of coefficients relating to "rainy days" and "expenses for traffic data processing" variables are probably not correct is highlighted.
It must be remarked that this type of evaluation is not useful to the greater or smaller weight to be assigned to the various independent variables, in order to estimate the number of accident trend. Instead, an indication on this subject may be drawn from the standardised coefficients, independent from the units of measure.
The variable with greater impact seems to be the *vehicle flow*, followed by *foggy days* and *maintenance expenses* (that reduce the number of accidents when they increase, therefore a negative sign has been assigned to them).
The result of this analysis is in contrast with statistics on data taken from the accident sheets. In fact, the latter highlighted a quite modest impact of fog. On the other hand, rain appeared to be an extremely important factor of danger, but no confirmation may be found, as the contribution of this parameter cannot be quantified. Instead, it is interesting to note that maintenance expenses have an important role in the explanation of the variation in number of accidents. This could mean that *the infrastructure conditions represent a parameter of essential importance within the exogenous type risk factors.*
Concerning the traffic variable, it may be said that, on one hand, the average flow increase in the 1993-97 period seems to have had a decisive impact on the number of accidents; on the other hand, the indication relating to heavy traffic impact has some significance as well (the standardised coefficient is 0.463). Unfortunately, parameter t and the corresponding significance level do not allow us to rely fully on this result.

After entering all independent variables into the model by iterative procedures, the regression function calculation results may be refined by eliminating, step by step, the variables for which coefficients not satisfying some tests are obtained. One procedure is the *backword*. It consists in initially entering all available independent variables into the model. Then, step-by-step, the units that generate coefficients (b) are eliminated, so that the value of F is smaller than a fixed value equal to 2.71 (F-to-remove). Obviously, the value of this parameter may be changed.

Alternatively, the independent variable elimination condition may be placed on the corresponding probability, which must not be greater than a predefined value (maximum probability of *F*-to-remove), fixed by default to 0.10, but may be changed. The two parameters, 2.71 and 0.10, correspond to the same setting. Therefore, they generate the same results, as shown below; it must be reminded that the wording "Model" contained in the tables, indicates the iteration steps.

Model		*B*	*Std.Error*	*Beta (β)*	*t*	*Sig.*
1	(Constant)	-204.885	83.008		-2.468	0.028
	Veh. x km (millions)	1.512	0.372	1.365	4.069	0.001
	% of heavy vehicles	532.265	310.891	0.463	1.712	0.111
	Number of rainy days	0.155	0.490	0.062	0.317	0.756
	Number foggy days	1.606	0.664	0.561	2.420	0.031
	Maintenance expenses [x10^6 It£]	-7.09E-02	0.036	-0.522	-1.960	0.072
	Expenses for traffic data proceed. [x10^6 It£]	-8.38E-02	0.252	-0.063	-0.333	0.745
2	(Constant)	-216.631	71.841		-3.015	0.009
	Veh. x km (millions)	1.572	0.310	1.419	5.071	0.000
	% of heavy vehicles	582.351	258.944	0.506	2.249	0.041
	Number foggy days	1.574	0.635	0.550	2.481	0.026
	Maintenance expenses [x10^6 It£]	-7.45E-02	0.033	-0.549	-2.248	0.041
	Expenses for traffic data proceeding [x10^6 It£]	-9.90E-02	0.239	-0.075	-0.414	0.685
3	(Constant)	-219.375	69.531		-3.155	0.007
	Veh. x km (millions)	1.541	0.292	1.391	5.269	0.000
	% of heavy vehicles	571.391	250.372	0.497	2.282	0.037
	Number foggy days	1.526	0.606	0.533	2.517	0.024
	Maintenance expenses [x10^6 It£]	-7.73E-02	0.032	-0.569	-2.448	0.027

Table 9. Values of the multiple linear regression coefficients (backword method)

The "number of rainy days" and "traffic data processing expenses" are excluded from the model, as expected. The situation improves remarkably, as proved by the *F*, *t* increase and by the associated significance levels. The regression equation obtained is:

$$y = 1{,}541x_1 + 571{,}391x_2 + 1{,}526x_4 - 0{,}07728x_5 - 219{,}375$$

The second iterative procedure to exclude the less-significant variables is the *stepwise*, particularly used in case of high correlation among the independent variables (differently from what happens in the examined case): the variables are entered into a model one by one, starting from the one showing the greatest simple correlation. While new parameters are entered, the situation changes and the variables not passing tests similar to the *backword* method are eliminated. This means that either the test on *F* or the test on corresponding probability takes place, assigning the same values to comparison parameters.
Only two independent variables are left, traffic and number of foggy days:

$$y = 0{,}951x_1 + 1{,}311x_4 - 67{,}844$$

The correlation coefficient is sensibly reduced. The variation explained by the number of accidents is equal to 54%.

Case where the number of vehicles involved represents the dependent variable.

The calculation procedure is similar to the previous one. At the beginning, all independent variables are entered into the model. Entering the number of involved vehicles as an independent variable, the situation changes completely. The correlation coefficient is smaller, changing from 0.836 to 0.711. The difference is further amplified by coefficient R_{adj}, even changing from 0.559 to 0.278; also parameter F reduces from 2.221 to 0.107. Therefore, the regression equation assumes the following expression:

$$y = 1{,}754x_1 + 768{,}221x_2 + 2{,}355x_3 + 2{,}836x_4 - 0{,}015x_5 - 0{,}449x_6 - 295{,}195$$

As for the standardised coefficients, which give an idea of the contribution of each variable regardless of the unit of measure, again it may be noticed that the most significant parameter is traffic, even if its value is much lower than in the previous case.
It is advisable to exclude some risk factors, initially by the backword method. The two expense variables and the percentage of heavy vehicles are excluded. The levels of significance of the surviving variables acquire better values then the previous ones, exception made for the value relating to the equation additive constant.
The standardised coefficients relating to traffic, rainy days and foggy days, are all very close: therefore, no one contribution greater than the others is highlighted. The regression equation looks like:

$$y = 1{,}232x_1 + 3{,}006x_3 + 3{,}341x_4 - 126{,}847$$

Finally, the stepwise procedure is applied; it leads to the exclusion, at the first iteration step, of five variables on six. Only the number of rainy days is left, generating a very low correlation coefficient. In this case, the regression equation is as follows:

$$y = 3{,}174x_3 + 51{,}472$$

As a conclusion, *it can be stated that the number of vehicles involved is significantly influenced by climate conditions, namely by precipitation and, to a smaller extent, by the presence of fog.* This mainly supports the remarks made at the end of the preliminary analysis, which resulted in a high percentage of (chain) accidents occurring in rainy conditions or, in any case, with wet roadbed.

Carriageway enlargement effect on accidents

In 1992, two operations took place on the Venice-Padua motorway aimed at improving traffic safety: the third lane and a telematic traffic control and management system (1). The Venice-Padua motorway has no infrastructure features that favour danger situations. Therefore, an increase in the number of accidents before that date was rather worrying. The inauguration of the third lane caused an immediate improvement, from a safety point of view, followed, as soon as 1993, by a fast increase in the number of accidents for some years. One reason for this phenomenon seems to be the driver behaviour change: when widening the carriageway, the vehicle flow density was significantly reduced; the immediate level of service improvement was accompanied by an increase in average speed and risky handling. Then, considering that traffic continued to increase during the years, it is easy to understand the reasons for the immediate reduction of positive effects following the above-mentioned operations.
In view of the results obtained, it is interesting to apply the multiple linear regression to a longer period of time, in the attempt to highlight the variable impact of the “number of lanes

per direction" on the number of accidents. Therefore, a seventh independent variable x_7 is added, that acquires value 2 for the years before 1992, and 3 since 1992.
At first, the model has been applied in its traditional format; the resulting function is:

$$y=1,105x_1+373,670x_2-0,0326x_3+0,432x_4-0,0120x_5-0,193x_6-7,948x_7-115,585$$

Notice that traffic (x_1) is always the heaviest variable, having the highest standardised coefficient and a very high significance level. Also the heavy vehicle percentage has a remarkable relevance.
As for the impact due to the introduction of the third lane, starting in 1992, it is correctly taken into consideration by the model; its coefficient is negative: with the increase in the number of lanes per direction, the number of accidents is reduced. However, the variable significance level is too low for an accurate judgement. The significance level of all the other parameters is even lower; in particular, the indication relating to the influence of the number of rainy days is not reliable. The associated coefficient is even negative: based on this result, raininess even seems to reduce the risk of accidents!
Also in this case, it is considered convenient to adopt iterative procedures requiring the exclusion of the less significant independent variables. At the beginning, the *backword* method is applied. The "number of lanes per direction" variable is removed only at the last iteration. As usual, traffic maintains its primary importance role in the justification of the number of accident variation. The latter is explained for just less than 60% ($R^2 = 0.595$, $R^2_{adj} = 0.575$): this result is not excellent, but it is considered acceptable because of the multiple regression and considering the fact that only two independent variables of seven have survived. The resulting equation is as follows:

$$y=0,777x_1+256,336x_2-98,606$$

The application of the stepwise has led to identical results as those of the backword.
Widening the time horizon, it is possible to highlight the negative influence of heavy traffic, but not the positive influence of a wider lane. In order to try and highlight it, the analysis has been repeated, but limiting the time horizon to 1992, the year of the third lane inauguration, when a sudden reduction in the number of accidents was experienced. The application of the model, with the seven variables, does not lead to significant results.
Even the application of the backword method leads to unreliable results. First of all, the number of accident variation is too low ($R^2 = 0.493$); furthermore, two of the variables that remain at the end of the iteration are the expenses for traffic data processing and the percentage of heavy vehicles, which presents a negative sign coefficient *b*. This would mean that the increase of heavy vehicles presence would improve safety!
The third parameter left at the fifth and last iteration is the number of lanes per direction, which would support the choice to reduce the period of analysis. Even in this case, the regression equation is not applied, as there are too many doubts about its significance.
The best results are obtained with the stepwise method. The number of accident variation explained by the regression is slightly greater than the one relating to the backword method (R^2=0.501), but it remains very low. However, the surviving variables at the end of the three interactions are the expected ones: traffic, the number of lanes per direction and infrastructure maintenance expenses. The heavy vehicle contribution is missing, but it can somehow be related to the positive influence following the motorway widening. The obtained regression equation is as follows:

$$y=0.3197x_1-0,01445x_5-11,426x_7+46,258$$

RESULTS

Considerations drawn about motorway accidents, specifically those concerning the Venice-Padua motorway, refer to two investigations.
The first one is the frequency analysis of variables - collected from the accident sheets - that have a more or less significant influence on accidents; the analysis has been compared with that of the Turin-Milan motorway data (36). This type of analysis enables us to count the accidents occurring in presence of circumstances recorded on sheets. Remarkable clues may be drawn, for example, by relating the statistics concerning two or more variables that mean to be somehow correlated, as has been done for fog and the number of involved vehicles.
The second analysis aimed at finding a multiple regression equation to explain the number of accident variation and the number of vehicles involved in them, by the contribution of some variables relating to infrastructure and atmospheric conditions. These variables have been chosen in light of indications deduced by the previous investigation.
The results of the two investigations are not always consistent. However, some phenomena observed from a different point of view may acquire more significance. For example, from the statistics concerning accident frequency, it is not possible to draw important conclusions about *traffic* impact on the number of accidents; in fact, it is highlighted that most of them occurred in average density traffic conditions, but no further consideration is made. Instead, by the multiple regression analysis, it is possible to highlight a very high correlation between vehicle flow and number of accidents, which is much greater than that of all the other examined variables (*Table 9*, *Table 10*).
Another somewhat surprising datum is the influence of *fog* on the number of accidents; if, based on preliminary analysis, it seemed possible to state that this meteorological phenomenon had a moderate influence, in view of the equation coefficient calculation, fog is proven to have a very important impact (*Table 10*). This means that the low visibility caused by similar climatic conditions, infrequent in the area where the considered motorway is located, significantly increases risk, thus raising accident possibility.
The situation appears more complex when studying the *raininess* contribution; while in the first instance, it seemed to represent a remarkable risk factor, when determining the multiple regression equation, very different results are obtained according to the dependent variable taken in consideration. In fact, when trying to explain the variation in number of accidents, precipitation does not appear a decisive factor. This is proven by the fact that the "rainy days" parameter is rejected both by the stepwise iterative procedure and by the less restrictive backword procedure. However, precipitation has a significant relevance in the explanation of the number of vehicles involved.
Concerning data related to maintenance expenses and the percentage of heavy vehicles, they do not lead to relevant results in the analysis of accident frequency. Instead, the *maintenance expenses* impact on the number of accidents in the multiple regression analysis. An accurate analysis allows us to prove the inverse relation between the expenses borne in a given period (for example, one year) and the number of accidents occurring in the same period or, more often, in the following months.
The *percentage of heavy traffic* appears among the variables falling within the acceptability limits of the backword method applied to the 1993-97 period (when the number of accidents is considered as a dependent variable). However, this unit passes the exclusion test with the worst result among those not excluded (*Table 10*). It certainly is a primary importance indicator, even if this statement finds no evidence in the preliminary analysis context, as the Venice-Padua accident sheets do not testify to its contribution.

With reference to the backword procedure, applied to the 1993-97 period, results are shown in *Table 10*, concerning the influence (quantified by the standardised coefficient β) of each one of the non-excluded variables on the number of accidents. Depending on the independent variable taken into consideration, remarkable differences are noted.

	Standardised coefficients	
	Influence of independent variables on the n. of accidents	Influence of independent variables on the n. of involved vehicles
Maintenance expenses	-0.569	-
Foggy days	0.533	0.476
Percentage of heavy vehicles	0.497	-
Traffic in vehicles per km	1.391	0.453
Rainy days	-	0.488

Table 10. Influence of independent variables on the number of accidents and on of involved vehicles, quantified by the regression equation standardised coefficients (backword method), period 1993-97

The results pertaining to the *enlargement of carriageway* from two to three lanes per direction (1992) deserve a separate consideration (*Figure 1*). The quick weakening of this positive effect with time may be a reason for which the data processing based on the 1987-1997 period has given no significant results. Instead, considering the year 1992, the immediate impact of lane widening is clearly highlighted by the stepwise method.

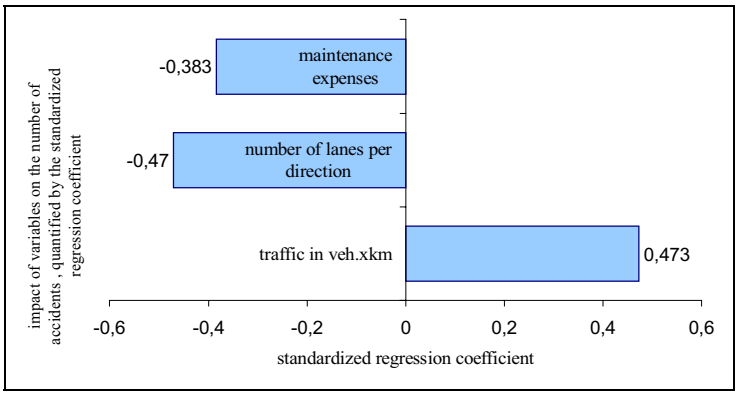


Figure 1. Influence of the independent variables on the number of accidents, quantified by means of the regression equation standardised coefficients (backword method), period 1987-92

CONCLUSIONS

The aim of the paper was to try to understand, on the basis of a detailed analysis of a case study, how far on-board ITS might reduce accidents or the risk of accidents on motorways. Since on-board telematics are not diffused yet, this aim can be pursued only if we can quantify how far the not-telematics factors may influence safety and the occurrence of accidents.

The investigations, aimed at identifying the exogenous variables with the greatest influence on the number of accidents, have been focused on a limited reality such as the Venice-Padua motorway. It appears that the total number of accidents can be statistically explained, as an average, between approximately 54% and 70% of the cases by the variables available, that

is, the exogenous ones. Analogous values can be obtained also when analysing the related literature.
Therefore, it is deduced that a relevant percentage of accidents, unexplained, can be attributed to the endogenous variables, which, at present, cannot be quantified; yet, it may be said that on-board ITS might influence - hopefully, reducing them - the not-explained accidents, operating directly on the vehicle or on the driver, whenever a dangerous situation crops up.
The diffusion of telematics within road vehicles - disregarding excessive driver reliance on them! – might therefore have a positive impact on levels of motorway safety: on-board systems may be added to the measures pursued until now, i.e. infrastructure design interventions, the design and maintenance of the infrastructure, fixed and variable message signs, the design of the vehicle and its performance.

REFERENCES

(1) B. Dalla Chiara, 2000. Effects of The Introduction of The Third Lane and a Traffic Control System on the Safety of the Venice - Padua Motorway, *Proceedings of 7th World Congress on Intelligent Transport Systems*, 6-9 November, Turin (I), Brussels.
(2) A. Giralt *et al.*, 1997. Driver vigilance video monitoring, *ATA - Ingegneria automobilistica*, n°5, Torino.
(3) M. Aschenbrenner, B. Biehl, 1994. Improved safety through improved technical measures? Empirical studies regarding risk compensation processes in relation to anti-lock braking systems, in R. M. Trimpop and G.J.S. Wilde, *Challenges to accident prevention: The issue of risk compensation behaviour*. Groningen, the Netherlands: Styx Publications.
(4) IEEE Intelligent Transportation Systems Council, 2000. *Third IEEE Conference on Intelligent Transportation Systems*, 1-3 October, Proceedings, Dearborn, USA
(5) IEEE, 2000. *Tenth international conference on road transport information and control*, Proceedings, IEE CP 472, ISBN 0 85296 725 X, 2000
(6) S. Caracoglia, 1984. "Ricerca dei fattori principali di accadimento degli incidenti stradali e proposte di miglioramento della sicurezza", Istituto strade e trasporti, Trieste.
(7) E. Hauer, P. Garder, 1986. Research into the validity of the traffic conflicts technique. *Accident Analysis and Prevention*, 18, pp. 471-481.
(8) T.J. Zlatoper, 1989. Models explaining motor vehicle death rates in the United States. *Accident Analysis and Prevention*, 21, pp. 125-154.
(9) PIARC/AIPCR, 1991. XIXe Congres mondial de la Route - Securité, Rapport Général, Marrakech.
(10) S. P. Miaou, H. Lum, 1993. Modeling vehicle accidents and motorway geometric design relationships. *Accident Analysis and Prevention*, 25, pp. 689-709.
(11) J. Milton, F.Mannering, 1998. The relationship among motorway geometrics, traffic related elements and motor vehicle accident frequencies, *Transportation*, 25, pp. 395-413.
(12) E. Cascetta, 1998. "Un programma integrato per la sicurezza stradale", Roma, pp. 1-23.
(13) OECD, 1990. Behavioural adaptations to changes in the road transport system. Paris: Organization for Economic Co-operation and Development, *Road Transport Research*, pp. 5-6.
(14) V.P. Kallberg, 1992. The effects of reflector posts on driving behaviour and accidents on two-lane rural roads in Finland, Helsinki, The Finnish National Road Administration Technical Development Centre, Report 59/1992.
(15) B.A. Grant, A. Smiley, 1993. Driver response to antilock brakes: a demonstration of behavioural adaptation. *Proceedings, Canadian Multidisciplinary Road Safety Conference VIII*, Saskatoon, Saskatchewan, June 14-16.
(16) G.C. Blomquist, 1988. The regulation of motor vehicle and traffic safety, Boston, Kluwer Academic Publishers.

(17) L. Leden, O. Hämäläinen, E. Manninen, 1998. The effect of resurfacing on friction, speeds and safety on main roads in Finland, *Accident Analysis and Prevention*, 30, pp. 75-85.
(18) Aiscat, 1986. "Nebbia, un problema di sicurezza. Sintesi dei sistemi sperimentali in Italia e all'estero", Roma.
(19) H. Brodsky, A.S. Hakkert, 1988. Risk of a road accident in rainy weather. *Accident Analysis and Prevention*, 20, pp. 161-176.
(20) G. Maycock, W. Brilon, 1995. Reducing speed-related casualties. The role of the European Union, Symposium ETSC, Brussels.
(21) K.W. Odgen, 1997. Safer roads, a guide to road safety engineering. Avebury, Aldershot (GB).
(22) Aiscat, 1981. "Un'analisi aggiornata della sicurezza della circolazione stradale", Quaderno n. 38, Roma.
(23) C. Cidda, M. Rotondo, 1995. Aiscat, Quaderno n. 60, "La sinistrosità sulla rete autostradale a pedaggio", Roma.
(24) V. Shankar, F. Mannering, W. Barfield, 1995. Effect of roadway geometrics and environmental factors on rural freeway accident frequencies. *Accident Analysis and Prevention*, 27, N. 3, pp. 371-389.
(25) P. Jovanis, H. Chang, 1986. Modelling the relationship of accidents to miles travelled. *Transportation Research Record* 1068, pp. 42-51.
(26) Ministero dei Lavori Pubblici, Ispettorato Generale per la Circolazione e la Sicurezza Stradale, 1998. "Schema di relazione al Parlamento sullo stato della sicurezza stradale", Roma.
(27) Istat, 1992. "L'incidentalità stradale attraverso le statistiche (anni 1971-91)", Roma.
(28) M. Hjar *et. al.*, 2000. Risk factors in motorway traffic accidents: a case control study. *Accident Analysis and Prevention*, 32/5, pp. 703 - 709
(29) J.F. Shyder, 1982. Environmental determinants of traffic accidents: An alternate model. *Transportation Research Record*, 486, pp. 11-18.
(30) D. Ivey *et al.*, 1991. Predicting wet weather accidents. *Accident Analysis and Prevention*, 13, pp. 83-99.
(31) Presidenza del Consiglio dei Ministri, Servizi Tecnici Nazionali, Ufficio Idrografico e Mareografico di Venezia, 1988-1998. Bacini Adriatici delle Tre Venezie. 1986-1993, Roma, Poligrafico dello Stato.
(32) eSafety Working Group, 2002. eSafety - Final Report of the eSafety Working Group on Road Safety, Final Report, Information Society Technology, European Commission, November 2002
(33) J.B. Sheu, S.G. Ritchie, 1999. A new methodology for incident detection and characterization on surface streets, *Transportation Research Part C*, 6, pp. 315-335.
(34) Società delle Autostrade di Venezia e Padova, 1992-1997. "Relazioni e bilancio" and "Schede degli incidenti" (internal documents of the concessionaire company).
(35) M. Geoff, B. Werner, 1995. Reducing speed-related casualties. The role of the European Union, *Symposium ETSC*, Bruxelles.
(36) F. Mescia, 1999. "Correlazioni tra sinitrosità autostradale e fattori che la determinano", degree thesis, tutors: Crotti A., Dalla Chiara B., Polytechnic University of Turin.