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Accident data analysis and on-field inspections: do they lead to similar conclusions?

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Abstract

Network Safety Ranking and Road Assessment Programme (RAP) are two procedures used in road infrastructure safety management to rank the road sections of a network according to estimated road safety performance. The former uses indicators based on road accidents and their consequences while the latter method is based primarily on inspections of the road infrastructure. The aim of this study was to verify whether there is a relationship between the indicators used within these methods, in order to evaluate if and under which conditions RAP scores contribute to the prediction of accident numbers. The adopted approach is based on the calibration and analysis of a wide array of models in order to reproduce the observed events – injury road accidents, fatalities and injuries - with reference to different aggregations of the original data and in the two reference situations: with and without EuroRAP (European Road Assessment Programme) indicators.

. From the obtained results, the introduction of the EuroRAP indicators ends up making the models that explain the frequency of accidents more convincing from a statistical point of view. These indicators, which summarise the road safety performance of a road section, could prove useful in replacing the covariates (e.g. presence of intersections, geometrical and functional features of roads) that are used in the calibration of accident prediction models. However, it should be stressed that not all types of accident are addressed by the EuroRAP approach, and this may represent a limitation for those roadways where such kind of accidents are frequently observed, like rear-end collisions on motorways. Probably, by including these accident types, the explanatory power of the EuroRAP variables would increase, at least on motorways.

Keywords: Network Safety Ranking; Road Assessment Programme; Accident prediction model

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1. Introduction

Over the last few years, countries such as Sweden, the Netherlands and Australia have adopted a new approach (or philosophy) towards road safety called "Safe System" (OECD / ITF, 2008), which starts from two assumptions: vulnerability of the human body and admission of the road user's fallibility. The road system and, consequently, the infrastructure should be designed and operated so as to overlook the user's oversights or errors. The planners and managers of the road network have the responsibility to provide the user with a safe infrastructure (Wegman and Aarts, 2006). In support of the initial approach which was more of the "reactive" type, a more "proactive" approach of safety management of road infrastructure has been proposed (PIARC, 2004). This approach is characterized by procedures and tools that aim to prevent accidents, by acting not only on the existing roads but also on the entire life cycle of the infrastructure (Elvik, 2010, Persia et al., 2016). A group of these procedures is dedicated to assessing the safety performance of the road infrastructure with the aim to obtain a ranking of the road elements of the network (road sections and road intersections). In general, these procedures differ in the type of data used to assess the safety of road elements. The procedures that go under the name of Network Safety Ranking use indicators based on historical accident data (HSM, 2010). The procedures generally referred to as Road Assessment Programme (RAP) are based exclusively on road inspections (e.g. Lane width, roadsides characteristic, etc.) (Cafiso 2007; Perandones et Ramos 2008; Appleton, 2006; Lynam et al., 2004). They rank road sections on the basis of the infrastructure features increasing the risk/severity of an accident. RAP has the advantage to be applied even if a database of accidents data located on the network is not available, a common situation in low- and middle-income countries (or during the design stage of a new roadway). Given that the safety of a road section is "the number of accidents by type and severity, expected to occur on it in a specified period of time." (Hauer, 1997), and that safety depends on the safety related features of the road section, it is reasonable to wonder whether the Network Safety Ranking and the Road Assessment Programme lead to similar results, i.e. similar rankings of road sections, and whether any relationship between the indicators used within the two procedures exists.

The relationship between indicators based on accidents and indicators based on road infrastructure characteristics has already been investigated in the literature. Most of the studies refers to Road Protection Score (RPS) an indicator proposed by the European Road Assessment Programme (EuroRAP), a not-for-profit organization. The EuroRAP method is currently the most widely used internationally (Vlakveld & Louwerse, 2011; Lawson, 2011; AusRAP, 2008; Harwood et al., 2010). Based on the value of the RPS, EuroRAP suggests assigning a number of stars (from one to five) representing the safety level of a road section (see Lynam et al., 2004).

The methods used to verify the presence of a relationship vary from the simple visual comparison of maps produced by applying the two procedures (Lawson, 2011), to the more elaborate ones. Vlakveld & Louwerse (2011) found that as the number of stars increases (safer roads), the average serious accidents rate per million vehicle-km decreases. However, they showed a high variance in the accident rate linked to the presence of road sections where no serious accidents occurred. Harwood et al (2010) have verified that the accident rate decreases in a statistically significant way along with the increase in the number of stars (safer roads). They also investigated the type of accidents involved, finding for instance a significant relationship for run off road accidents on single carriageway two-lane roads and dual carriageway six-lane roads. An Australian study (AusRAP, 2008) examined the relationship between the number of stars (and RPS) and accident costs per vehicle-km. In this study, road sections have been grouped by number of stars by calculating an average cost per vehicle-km. As the number of stars decreases, the cost per vehicle-km increases. A regression analysis between RPS and cost per vehicle-km was also attempted, however, the wide variability observed in the results discouraged this approach.

Although several studies have been conducted on the subject, in no case the strength of the relationship between the two types of indicators was discussed in depth. In most cases they ended up with a verification of their coherence through aggregation.

The aim of this paper is to verify whether there is a relationship between the two types of indicators, in order to evaluate if and under which conditions RAP scores contribute to the prediction of accident numbers. For this purpose, a real case study is used to assess whether the accidents and their consequences are explained by specific road infrastructure safety indicators. The used infrastructure safety indicator is RPS from the EuroRAP method because of its greater diffusion at the international level and the presence of several studies with which to compare the results.

A direct comparison between the outcomes of the phenomenon (accidents, fatalities and injuries) and EuroRAP indicators is not statistically significant because of the stochastic nature of road accidents; where the EuroRAP assessment indicates risk situations, the observed data may not identify situations with a high accident rate and vice versa. However, statistical analysis techniques normally employed in the field of road safety have been used.

The adopted approach is based on the calibration and analysis of a wide range of models in order to reproduce the observed events – injury accidents, fatalities and injuries - with reference to different aggregations of the original data and in the two reference situations: with and without EuroRAP indicators. In this way, it was possible to check what is the predictive power of these indicators which, as mentioned before, are defined starting from the characteristics of roads, but with no reference to road safety outcomes (i.e. accidents and any related personal injury).

2. Materials and methods

2.1. Description of the two procedures

Both the examined procedures aim at the classification and identification of critical road elements of the network.

The Network Safety Ranking (NSR) divides a road network in homogeneous road sections. For each section then it associates a value based primarily on accidents history data like: number of accidents per kilometer, accident rate (accidents compared to vehicle-kilometers), cost of accidents per kilometer, cost of accidents potential savings, number of equivalent accidents (equivalent to Property Damage Only accidents).

The evaluation system of EuroRAP (Star Rating model) is based on assigning scores, the so-called Road Protection Score, formulated as a result of visual and video inspections and defined for each road section by the sum of three indicators related to three types of accident: head-on collision, run-off accidents and intersection accidents. The closer to zero the RPS value, the more secure is the road. At the end of the assessment procedure, one or more stars rating (1 to 5) are assigned to each road section in relation to the safety features offered by the road. Additional information on EuroRAP method is available on the website: www.irap.org.

2.2. Methodology

In order to verify whether and to what extent the EuroRAP approach leads to results similar to the assessment based on the road accident frequencies and severity (NSR approach) an analysis based on the calibration of accident prediction models was adopted. These are regression models providing estimates of the expected frequency of road accidents (or fatalities or injuries) as a function of the characteristics of the road section and the level of associated risk. The hypothesis is that the inclusion of EuroRAP indicators among the covariates of these models should enhance their capability to explain the dependent variables. This hypothesis is tested by assessing several regression models combining different covariates and dependent variables.

The covariates used in this study are: the length of the road section, the annual average daily traffic volumes (AADT: Annual Average Daily Traffic), the EuroRAP indicators by type of accident, i.e. Run Off, Head On, Junction and the global EuroRAP indicator, which is the sum of the three previous indicators.

The dependent variables of the models are: injury road accidents, fatalities and injuries frequencies. Furthermore, road accident frequencies were distinguished in frequencies related to the total number of accidents and frequencies related to the accidents belonging to the three EuroRAP accident categories.

Before calibrating the models, a data aggregation process has been undertaken. To make the analysis robust with respect to the possible aggregations of the data and the way in which the EuroRAP indicators were calculated, six road datasets were developed, with different criteria to define homogeneous road sections and related EuroRAP indicators. Moreover, to address the potential overdispersion of data (i.e. when the variance exceeds the mean of the crash counts, see: Miaou, 1994), both Poisson models and Negative Binomial (NB) models have been calibrated.

A total of 96 pairs of homologous prediction models was calibrated considering the combination of datasets, the output variables (accidents, fatalities and injuries, EuroRAP accidents), the reference models (Poisson and NB) and the examined covariates. Having calibrated twice the same model with different sets of independent variables that differ in the presence or absence of EuroRAP indicators gives way to the definition of improvement potentialities in the model fitting by adding the EuroRAP variables. The pairs of homologous models that differ only in the set of covariates (with and without EuroRAP variables) were submitted to the so-called Likelihood Ratio Test (LRTest) in order to ascertain whether and to what extent the inclusion of EuroRAP variables improves the explanatory power of the model.

After choosing the best models, the analysis continued with a detailed assessment of the significance of the coefficients and the explanatory power of the EuroRAP indicators in explaining the outcome variables of the model.

3. Results

3.1. Case Study and data preparation

The analysis involved approximately 400 km of roads in the region of Lazio in Italy and in particular on the four main motorway routes of the region: A1 - section Orvieto-San Vittore, the A24 - section Rome Torano, the A12 and the North Branch - section Rome-Fiano Romano.

Three datasets have been used in the study, in particular: historical series of injury accidents recorded on the portion of interest of the motorway network for the period 2008-2011; EuroRAP Star Rating on data provided by the Automobile Club of Italy (ACI); data related to traffic flows provided by the road authorities.

The accident dataset reports only accidents with damage to people occurred during the period 2008-2011. Every single record identifies a section of road with a one-kilometer length, at which the matching data regarding the total number of recorded accidents, accidents by type and consequences to people (total number of fatalities and injuries) have been noted. Data were filtered to include only the three types of accidents considered by EuroRAP.

The dataset for Star Rating analysis is based on field inspections carried out in 2010 and contains the performance indicators of the motorway network of interest aggregated to 100 m.

EuroRAP data needed to be further aggregated to a one km of motorway section to make them congruent with the type of aggregation adopted for accidents. Two aggregation criteria were adopted: the first coincides with the maximum value of the series of 10 RPS values in a km of road, and the second is its simple average.
The two datasets have been associated with the dataset of annual average traffic flow. Data were then combined and aggregated to create six working datasets whose characteristics are shown in the following Table. 1.

Table 1 Characteristics of datasets used

	Dataset	Road section lenght	EuroRAP score calculation	N° records
1	STAR _LKM	1 km	Maximum value of the series of 10 RPS values defined for a 1 km road section	396
2	SMOOTH KM		Average value of the series of 10 RPS values defined for a 1 km road section	396
3	STAR LAGG	2 - 5 km	Maximum value of the series of 2-5 values associated to each 1 km road section	114
4	SMOOTH LAGG		Average value of the series of 2-5 values associated to each 1 km road section	114
5	STAR ADTAGG	Road sections with the same annual traffic flow	Maximum value of the series of n values associated to each 1 km road section	55
6	SMOOTH ADTAGG		Average value of the series of 2-5 values associated to each 1 km road section	55

In the first two datasets, marked with code KM, information relating to accidents and EuroRAP indicators are aggregated to a one km motorway section. The road network has been divided into 396 road sections each with a length of 1 km.
The codes STAR and SMOOTH refer, instead, to the way with which EuroRAP indicators were calculated: in the first case as the maximum value of the values defined for the elementary component subsections, in the second case as the average value of the same subsections.

The other two datasets marked with the code LAGG have been developed in order to define homogeneous motorway sections from a geometrical and functional point of view of a length between 2 and 5 km. The result is the aggregation of the initial 396 sections in 114 road sections. An additional aggregation of series of contiguous sections distinguished by the same flow value was then produced. The result is the development of two datasets (STAR_ADTAGG and SMOOTH_ADTAGG) with 55 sections.

A statistical summary of AADT and RPS scores is reported in Fig. 1.

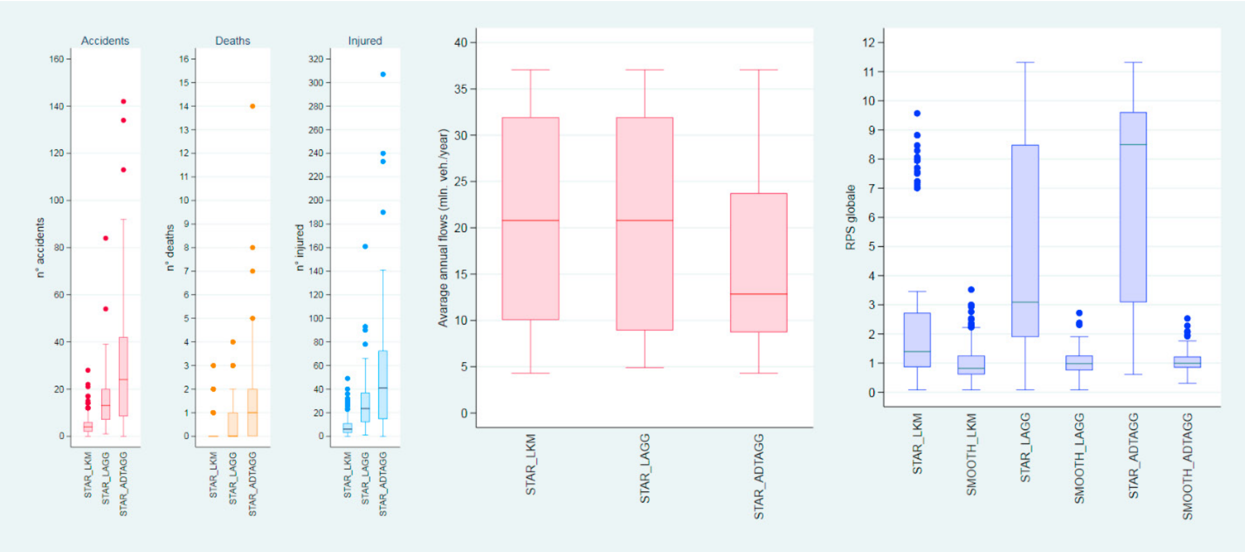

Fig. 1. Box plots of Accidents, Deaths, Injured, AAT and RPS scores in the datasets used

3.2. The selection of models with the best performance

The analysis required the calibration of 96 pairs of homologous models distributed according to:

- type of dataset used (6 datasets)
- dependent variable (injury accidents INC, fatalities MOR, injuries frequency FER and EuroRAP accidents, with reference to the three types of EuroRAP accidents)
- model type: Poisson (P) or negative binomial (NB)
- set of covariates with global or separated EuroRAP indicators.

The strength with which EuroRAP indicators explain the output variables has been evaluated through the Likelihood Ratio Test (LRTest) that compares homologous pairs of models differing only in the configuration of the set of covariates.

On the other hand, to evaluate the fitting of the models to the observed data, Akaike Information Criterion (AIC) was used. This is a statistic that is normally used to define the fit of the model, taking into account its complexity. However, it should be noted that the more numerous the elements of a dataset, the more the AIC tends to increase in value. Consequently, in order to compare models calibrated on datasets of different sizes the indicator AIC was divided by the number of observations n: AIC/n.

To identify the best performing models two criteria have been considered: a level of significance of 0.05 (pchi2<0.05) for the LRTest and values of AIC/n lower than the average value of the AIC/n indicator, equal to 6.63.

A fair number of models resides in the region of the graph of non-significance of the LRTest. In most cases these are models in which the dependent variable is fatalities frequency or injuries frequency.

Considering only the set of models passing the test of significance of 0.05 (i.e. EuroRAP coefficients are significant in explaining the dependent variables), it can be noted that there are 33 models in total (out of 72, equal to 45.8%) in the first group (i.e. models in which the dependent variable is road accidents, fatalities and injuries frequency) and 12 models (out of 24, equal to 50%) in the second group (i.e. models in which the dependent variable is represented by partial counts of the accidents related only to the EuroRAP classification). In the first group of 33 models passing the test, 22 are Poisson and 11 are NB. In the second group Poisson models are even more frequent than NB models: 8 models vs 4 models.

A total of 25 models out of 96 models (26%) are located in the region of plan identified by the two chosen criteria. The range of models from the best performance narrows to 13 in the first group (18% of the total of the 72 of the first group) and still 12 in the second group, all models of the second group are placed on values below the average of the AIC/n indicator (Fig. 2).

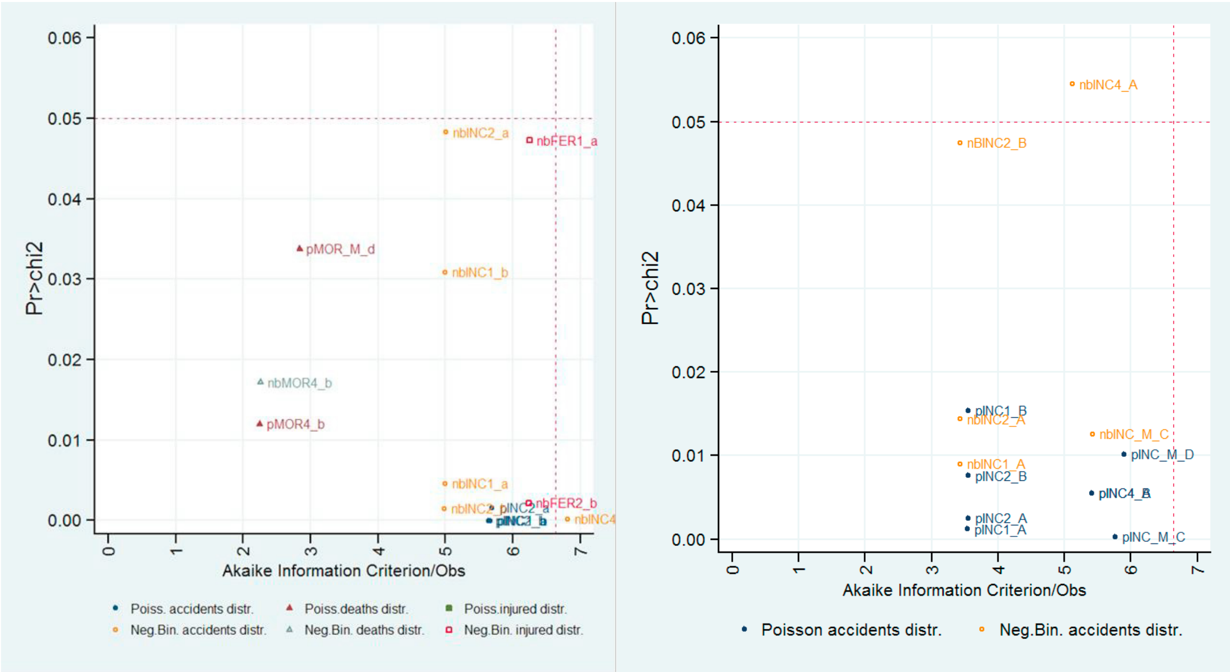

Fig. 2. Best performing models showing pchi2 <0.05 and AICn < 6.63 (Left) Dependent variable: Total road accidents, fatalities and injuries frequency, (Right) Dependent variable: frequencies related to accidents belonging to the three EuroRAP accident categories.

Table 2 summarizes the number of models that pass the significance test of LRTest with the indicator pchi2<0.05 and limited to the region defined by AIC/n value less than the average.

It is clear that among the best performing models those that explain the number of accidents (INC variable) are the most frequent (20 models). The models that explain the fatalities and injuries are present to a lesser extent. Moreover, models based on the datasets with indicators referred to motorway sections of one km (STAR_LKM and SMOOTH_KM) are more frequent (17 cases out of 25).

Table 2 Distribution of calibrated models with *pchi2<0.05* and *AIC/n<6.63* by dataset and dependent variable

	Dataset	Total Accidents (INC)	Total fatalities (MOR)	Total injured (FER)	EuroRAP Accidents (INC_p)	**TOTAL**
1	STAR LKM	4	0	1	3	8
2	SMOOTH KM	4	0	1	4	9
3	STAR LAGG	0	0	0	0	0
4	SMOOTH LAGG	0	2	0	2	4
5	STAR ADTAGG	0	0	0	2	2
6	SMOOTH ADTAGG	0	1	0	1	2

	TOTAL	8	3	2	12	25

To rank the 25 models with the best performance the two diagnostic indicators were standardized (AIC = 0 corresponds to AIC = 6.63, while LRtest indicator = 0 corresponds to 0.214). It is worthwhile to point out that at the top of the ranking there are the models of the second group. In the middle part of the list (from the 4th to 15th place) the models calibrated with the first two datasets are present (code 1: STAR_KM and code 2: SMOOTH_KM), i.e. with the dataset containing sections of one km unit length. Best models are calibrated with the subtotal of accidents (final letter capitalized) followed by the models calibrated considering the absolute total of the dependent variable (the final letter of the code in lower case), standing from the 11th to 15th place in the list.

3.3. Reliability of EuroRAP indicators in models with the best performance

Using the LRTest, the performance of Poisson models was compared to their homologous, NB models. Only in the case of the fatalities (MOR) the LRTest was negative, confirming that the overdispersion parameter α is not significant, with the result that it is preferable to adopt the Poisson model.

However, in the case of accidents the α value is significant to a greater extent for the two models in which the dependent variable consists of the total frequency of accidents and to a lesser extent in the case where the dependent variable consists of the sum of the partial frequencies of accident.

The coefficients signs are largely in agreement with the direction of the expected response of the models: the higher the traffic flow (AADT variable) the greater is the expected value of the response variables. However, as far as the EuroRAP indicators in the two models calibrated with respect to the single global ER variable are concerned, the sign of their coefficient is in agreement with the expectations: the higher is the value (greatest risk condition), the greater is the expected frequency of the explained events, in this case accidents. However, in the case of the three models calibrated with respect to the set of three distinct EuroRAP variables, if the two run-off and front-lateral collision indicators show a sign consistent with the expectations, the ER_HO indicator (head-on collision) seems to emerge an inverse correlation in the sense that the more serious is the risk assessment (indicator increases), the lower is the expected frequency of the response variables.

4. Discussion and conclusion

The aim of this analysis was to compare the methods to assess safety performance of road sections based on road accidents and their consequences with the evaluation methods based on inspections of the road infrastructure (EuroRAP methodology). Several models have been calibrated to study the relationship under various conditions: different possibilities of aggregation of road sections and different sets of covariates used to determine whether and to what extent the EuroRAP indicators prove to be effective in explaining accidents, fatalities and injuries frequencies.

Among the 96 pairs of models tested, 45 models pass the exam of the LRTest (i.e. almost 47% of the total), with a significance value of the test of less than 0.05. This means that EuroRAP coefficients are significant in explaining the dependent variables in half of the cases. From the obtained results, the introduction of the EuroRAP variables ends up making the models that explain the frequency of accidents more convincing from a statistical point of view.

If the selection is limited to those models associated with a good fit (AIC unit value of less than 6.63, equal to the average of that index), 25 models can be identified. By focusing on these models, the following can be reported.

Type of aggregation. Models based on shorter sections (i.e. 1 km) seems to perform better rather than longer road sections (i.e. 2-5 kms or road sections with the same annual traffic flow). 17 out of the 25 best performing models (68%) are based on the aggregation of 1 km. The road features averaged on shorter homogeneous road sections are more significant in explaining the accident frequencies of road features averaged on longer sections. Likewise, there is no substantial difference in terms of number of models calibrated with respect to EuroRAP variables of STAR type (calculated as the maximum value of the related values to the elementary sections composing it) and SMOOTH type (calculated as the average value).

Dependent variable. Only in 5 cases out of 25 best performing models, the dependent variable is the frequency of fatalities or injuries. This suggests that rankings on RPS are more likely to be similar to rankings according to the number of accidents rather than those based on the accident consequences (number of fatalities or injuries).

Model type. As expected, the negative binomial models have a greater explanatory power, given the frequent overdispersion that characterizes many distributions of the outcome variables considered. This confirms the evidence from past research studies on the topic (e.g. Miaou, 1996).

Set of covariates with global or separated EuroRAP indicators. In the specific application case, the EuroRAP indicators are sufficiently explanatory, indeed in some cases they have proved to have even greater explanatory power than the variable "traffic flow AADT", which is normally used as the main variable in the construction of Safety Performance Functions (SPF). This suggests, among other things, that these indicators, which summarise the road safety performance of a road section, could prove useful in replacing the series of covariates (intersection flows, geometrical and functional characteristics of roads) that are normally used in road safety modelling applications, in the calibration of the aforementioned SPF curves. Moreover, it seems that there is a fair distribution, in the ranking of the best models, among models in which it was employed only global ER indicator and the set of three EuroRAP indicators distinguished according to the category of accidents.

However, it is necessary to point out that only 26% of models pass the two applied criteria. Lynam (2011) lists a number of conditions for which such a relationship might be lacking. First, the RPS does not reflect those accidents where the driver's behavior was not in compliance with the existing traffic rules (e.g. driving above the legal speed limits). Secondly, the RPS also evaluates the ability of the infrastructure to mitigate the severity of injuries of occupants of vehicles marked as safe by EuroNCAP project (score of at least 4 stars). Finally, RPS takes into account only specific crash types, i.e. run-off, junction or head-on collisions.

This last condition is inevitably reflected on the frequency of the models that have passed the test and on related offered performance. Having brought back the total accident count to the three categories considered by EuroRAP greatly enhances the proportion of models that pass the test of robustness of the EuroRAP indicators, even if the performances offered improve slightly as it was observed in the detailed analysis.

In any case, in both groups (partial counts and total counts), whenever reference is made to the set of the three EuroRAP indicators, some discrepancies were noted: the head-on collision indicator has a negative sign, i.e. as if along with the increase of the indicator (and thus the decrease of the safety conditions of the road), there is a decrease in accidents and related events. This is probably explained by the fact that there are few cases in which head-on collision score was assigned and this may have led to some distortion effects.

Furthermore, the junction indicator is not a significant variable in most cases, although it affects the defining of the frequency of the observed events in a considerable way. On the other hand, the run-off indicator (run off road) in most cases proves itself as significant, producing inter alia marginal effects that are superior to those produced by volumes of traffic, in two of three cases in which the set of three EuroRAP variables was used.

Unfortunately, there are no available EuroRAP indicators specific to certain types of accidents that occur frequently on the motorway network, such as rear-end collisions.

Only in the case of models with accidents as dependent variable, where it was possible to define a functional link between available EuroRAP indicators and related accident frequencies, it has been observed that EuroRAP indicators are sufficiently explanatory, although with a slightly lower explanatory power with respect to AADT variable which is normally used as the main variable in accident prediction models.

Probably, by including in the analysis other categories of accidents occurring on motorways (precisely, rear-end collisions), the explanatory power of the EuroRAP variables increases reversing the balance of power with the AADT variable. This may give good future openings in the fact that these indicators could prove useful, in the calibration of accident prediction models, as substitutes of the set of covariates (presence of intersections, geometrical and functional roads characteristics) which are normally used in accident prediction models.

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