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SAFETY PERFORMANCE FUNCTIONS FOR LOW-VOLUME ROADS

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Abstract. This paper analyzes roadway safety conditions using the network approach for a number of Italian roadways within the Province of Salerno. These roadways are characterized by low-volume conditions with a traffic flow of under 1000 vpd and they are situated partly on flat/rolling terrain covering 231.98 km and partly on mountainous terrain for 751.60 km. Since 2003, the Department of Transportation Engineering at the University of Naples has been conducting a large-scale research program based on crash data collected in Southern Italy. The research study presented here has been used to calibrate crash prediction models (CPMs) per kilometer per year. The coefficients of the CPMs are estimated using a non-linear multi-variable regression analysis utilizing the least – square method. In conclusion, two injurious crash prediction models were performed for two-lane rural roads located on flat/rolling area with a vertical grade of less than 6% and on mountainous terrain with a vertical grade of more than 6%. A residuals analysis was subsequently developed to assess the adjusted coefficient of determination and *p*-value for each assessable coefficient of the prediction model. CPMs are a useful tool for estimating the expected number of crashes occurring within the roads' geometric components (intersections and road sections) as a function of infrastructural, environmental, and roadway features. Several procedures exist in the scientific literature to predict the number of crashes per kilometer per year. CPMs can also be used as a tool for safety improvement project prioritization.

Keywords: crashes, prediction models, road safety analysis.

1. Introduction

Roadway safety is a multidisciplinary science involving several elements: (a) the components of the roadway system – people, vehicles, and the roadways themselves, (b) the agencies and groups that plan, design, build, and use roads and promote roadway safety, and (c) the public health and safety communities that are concerned with injury prevention, response, treatment, and rehabilitation (Chobya *et al.* 1999). While vehicle characteristics can contribute to traffic accidents (e.g., the lack of regular maintenance or vehicle overloading) human error is the most frequently cited factor contributing to both fatal and non-fatal injuries in motor vehicle accidents. Furthermore, driver behavior is improved more by enforcement and engineering than by training and education.

The crashes were defined in many researches of scientific literature (Lazda, Smirnovs 2009) as the result of bad decisions by the driver made in an environment created by the engineer. International researchers have thus suggested a variety of approaches to analyze the road traffic safety level as some procedures based on the valuation of the accident rates and accident frequency. The road traffic safety has thence become a priority field worldwide and one of the major factors describing the transport system's state with its positive and negative changes (Ratkevičiūtė *et al.* 2007). To restrict the consequences of the roadway accidents, some experimental analyses were addressed to road safety to assess the relationships between vehicles, users and the environment. The design consistency evaluation is one of several promising tools that can be employed by roadway designers to improve roadway safety performance.

Low-volume roads, as analyzed in this paper, comprise a significant portion of the rural roadway network in Italy and in many other countries in the world. Because of the higher frequencies of documented crashes and more severe injuries on these roads, many researchers have examined the factors leading to these crashes.

Stamatiadis *et al.* (1999) has observed that low-volume roads (e.g., roads carrying under 1000 vpd) make up 70% of the roadway network in the United States. Although such highways carry low volumes, historical data indicate that they have higher crash rates than other roadways. The authors found that the crash rates, and especial-

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ly fatality rates, were higher for southeastern states than the national rates. Crashes in Kentucky and North Carolina for 1993–1995 were used as a sample. The tendency to crash among drivers grouped by age and gender and vehicles grouped by age and type were examined. The results showed that drivers under the age of 25 and drivers over the age of 65 were more likely to crash than middle-aged drivers. On average, female drivers were safer than male drivers, and young drivers (under the age of 25) experienced more single-vehicle crashes, and drivers over 65 were more likely to be involved in two-vehicle crashes. The drivers of older vehicles were more likely to be involved in two-vehicle crashes on low-volume roads than drivers of newer vehicles. In single-vehicle crashes, drivers of older vehicles were more likely to have a serious injury than drivers of newer vehicles, and large trucks had the highest two-vehicle crash rate on low-volume roads, followed by sedans, pick-up trucks, vans, and station wagons.

Achwan and Rudjito (1999) later described the magnitude of the road crash characteristics on low-volume roads by using data from rural areas. Crash data from 1993 to 1995, recorded by the traffic police in the Purwakarta Police District, were used. These data included three districts in Indonesia (Karawang, Purwakarta and Subang). The authors found a serious road safety problem on low-volume roads in the Purwakarta region. These crashes caused significant losses in production, as well as damage and suffering. Clearly, all institutions involved in road safety should make every effort to reduce crashes. The study showed that the key vulnerable groups were motorcyclists and pedestrians, with truck casualties also being a problem on low-volume roads. Rollover was a common collision type and it appeared that this was caused by poor shoulder conditions in the majority of crashes; it was relatively rare on the national highway network. A systematic "Triple L Trial" approach – meaning data processing, crash, traffic-to crash investigation, prevention, and reduction proved successful and useful. In fact the authors found that although the number of accidents is small, it appeared that different road links do have different crash patterns. They introduced processes for identifying common contributory factors by using a stick diagram for hazardous locations.

Mahgoub *et al.* (2011) have observed that the fatality rate of South Dakota local rural roads was the highest of surrounding states and nearly 50% higher than the national average for similar roads. In general, 25% of all State highway deaths and 19% of all injuries occurred on local rural roads. The purpose of this study was to improve the safety performance of local rural roads in South Dakota by analyzing the crash occurrence and potential safety treatments. The study provided some low cost safety improvement strategies to county highway superintendents and other local agencies. The major issues that were identified by the study team were related to: intersections sight distance, angle of approach, signage, road alignment, vertical and horizontal curvature, culverts, table drains and location of signage, visibility and legibility of signs. If a non-frangible hazard on the roadside presented an unreasonable risk to road users, it should be considered for treatment. Acceptable treatments in descending order of preference included: 1) removal of the hazard to create a forgiving roadside environment, 2) relocation of the hazard, 3) replacement of the hazard with a more visible and frangible type, 4) shielding the hazard with safety barriers, 5) enhancing the visibility of the hazard, 6) warning road users of the hazard. A tool in the form of a Safety Priority Evaluation Matrix was offered for identifying and prioritizing safety issues, possible contributing factors, and countermeasures. Many of the recommended solutions were related to maintenance practices (e.g. maintaining the immediate roadside clear of vegetation to improve sight distance through curves), delineation (e.g. marking culverts with guideposts), and general sign improvement (e.g. installing signs to warn of particularly sharp or unexpected changes in the horizontal or vertical alignment). The study developed a Rural Road Safety Index (RRSI) in order to rank the road network according to the safety features and identify the deficiencies in road sections. Although RRSI was not the only method used to estimate the safety of the local road; several other methods have been suggested by authors that can be coordinated along with this Index.

Gross *et al.* (2011) have observed that low-volume roads are characterized with low traffic volumes, generally fewer than 500 vpd for most parts of the year. The investigators explained how the design of these roads is often at a lower standard than their higher volume counterparts and may not have ever been formally designed; the unique characteristics of both low-volume roads and their users create some particular safety concerns. Compounding these safety concerns on low-volume roads is a lack of quality crash data to identify the issues and the general lack of a systematic improvement program to address the issues. The study showed the importance of Road Safety Audits (RSAs) as alternative method to overcome several of the shortcomings of traditional studies. The application of RSAs was discussed to identify and address safety issues on low-volume paved roads through 10 years of RSA experience and on unpaved roads were also discussed with respect to the potential for RSAs.

For more than 40 years, multivariate regression techniques have been applied both in North America and in Europe to investigate the quantitative relationships between accident counts and road and traffic characteristics and to establish accident prediction models. Several pieces of research have focused on identifying variables to account for the impact of the interactions between highway design parameters on safety (Mayora *et al.* 2006).

Lank and Steinauer (2011) presented the necessity of safety enhancements especially on low-volume rural roads. The basic causes of accidents described in this paper are inattentiveness or excessive speed. On the basis of the findings rumble strips can be recommended as an effective and above all cost effective measure for improving road safety. Possible areas suggested of application for rumble strips were hazardous bends, black spot intersections and changes to the operational and structural properties of stretches of rural roads. On stretches with high curviness and a low speed limit rumble strips had little effect with regard to speed, as the characteristics of the stretch limit the choice of speed a priori. Another positive impact of rumble strips on road safety has been the increase in attentiveness. The results of this analysis showed how the rumble strips are cost-effective and quick to produce without weakening the road substance through milling work on the surface layer. Another advantage consisted in the additional visual warning of the road users through the retro-reflecting properties and the white coloring of the material. The impact on the drivers' behaviour – especially on the speed choice – was investigated on rural roads by before and after analyses with radar measurements and video surveying. Beside statistical analyses of the effect on the driving speed, detailed investigations on the impact to special driver groups and car types were performed. According to the analysis made in this research project transversal rumble strips have represented a cost efficient instrument which has positive effects on driving behaviour and hence on road safety.

2. Objective

The research described in this paper aims to calibrate two injurious crash prediction models (CPMs) per kilometer per year for two-lane rural roads in low-volume conditions: one for roadways located on flat/rolling land with a vertical grade of less than 6% and the other for roadways in the mountainous area with a vertical grade of more than 6%. This study illustrates a "network" approach to safety in order to identify the "black" roadway segment where the frequency of injurious crashes is higher than on the rest of the roadway. This experimental analysis is only one component of a larger study under way for several years now on a number of rural roads in low-volume conditions within the Salerno road network with a view to improving performance and safety (Dell'Acqua, Russo 2010; Dell'Acqua *et al.* 2010).

3. Literature review

For more than 30 years relationships between traffic crashes and geometric roadway design have been modeled by traffic safety engineers and researchers to estimate and predict accident frequency or rates under different roadway design conditions. It has been demonstrated that vehicle accidents are complex events involving the interaction of drivers, traffic, the road itself and the environment. It is believed that a significant proportion of variations in accident frequency are the result of differences in the major factors from site to site and time intervals and that a significant portion of accidents occur due to bad infrastructure, and lack of Alignment Consistency (Mattar-Habib *et al.* 2008).

Performing accident prediction models is a means of summarizing these complex interactive effects on the basis of information contained in the accident data, as well as using engineering judgment and analytical assumptions about the accident process.

Many types of regression models have been used over the years to develop accident prediction models: researchers are finding that conventional normal or lognormal regression models simply do not have the statistical properties necessary to adequately describe vehicle accident events on the road. Traffic accidents are better modeled by assuming a Poisson accident frequency distribution. The exponential function is a natural candidate to describe the interactive effects and at the same time ensure that the function values are always non-negative.

Fridstrøm *et al.* (1995) at the Norwegian Transportation Institute developed Poisson regression models to break down the variations in accident counts into parts attributable to randomness and the systematic factors that cause accidents. They correlated the number of crashes with four variables: traffic flow, speed limits, weather and light conditions. They also proposed a set of specialized goodness-of-fit measures explicitly taking into account the inevitable amount of random variation that would be present in any set of accident counts.

Lord and Persaud (2000) illustrated the application of the Generalized Estimating Equations (GEE) procedure to traffic-safety studies when data spanning several years are available and when it is desirable to incorporate trend. The application is for a sample of four-legged signalized intersections in Toronto, Canada, using data for the years 1990 through 1995. GEE procedure was introduced to develop a mathematical equation incorporating a trend in accident data. The quality of fit was examined using the Cumulative Residuals (CuRe) method.

Hauer *et al.* (2004) calibrated an accident rate model for multilane urban roads by using a binominal negative regression. The variables used were the annual average daily traffic, the percentage of trucks, the vertical grade, the horizontal curve length, roadway width, the type and width of clear zones, speed limits, points of access, and the presence of, and nature of, parking areas.

Mayora *et al.* (2006) described a research project conducted at Madrid Polytechnic University, with the objective of refining the negative binomial accident prediction models that had been developed previously for two-lane rural roads in Spain. Because over-dispersion had been detected in the sample, a negative binomial regression model with an additional exponential linkage equation was adopted. Injury accident counts (IACC) were used as the dependent variable. To test the significance of the regression coefficients, a new variable in addition to the criterion based on the p-value was used: the authors also proposed a set of specialized goodness-of-fit measures, such as the deviance of the model and the log-likelihood. The final equation of the resulting model contains the total traffic flow, access density, the min sight distance within the

1 km segment, the min design speed of the alignment elements included in the 1 km segment, the max longitudinal grade, and reduction in design speed in relation to the section analyzed starting from a distance of 1 km on the segment preceding the section being investigated. Cumulative scaled residuals plots were then used to identify where the model over- or underestimated accident frequencies.

Tarko (2006) presented two alternative formulations for the calibration problem in line with the max likelihood approach. Two methods are addressed to predict safety for the individual links and nodes of a transportation network. In both methods a planner has the freedom to portion a road network in a way that addresses expected local and sub-regional safety differences. Furthermore a planner may identify routes, corridors and areas to focus calibration on these locations if planning focuses on them. The study demonstrated the feasibility of those proposed approaches that may be helpful in developing a new class of tools for safety-conscious planning.

4. Data collection

The crash data used in this research study involve 983.58 km of two-lane rural roads in Southern Italy, of which 231.98 km are located on flat and rolling areas with a vertical grade of less than 6% and 751.6 km on mountainous terrain with a vertical grade greater than 6%.

Roadway segments on flat, rolling and mountainous terrains reflect some results of previous studies (Giummarra 2003) where several processes and methodologies were developed to reach acceptable standards to classify geometric design and maintenance standards for low-volume roads. A daily traffic volume is generally included in the research studies for each road class as a guide to the range of likely traffic for each class. Traffic volume is expressed as the average daily traffic (*ADT*) and represents traffic over the peak season. A description of the road type for each road class has also been included. In describing the road type, the service quality factor has been included to highlight the overall character of the road class which may be linked to adjacent land use or the recreational facilities it serves. The various levels of service were based on the subjective judgments of numerous practitioners closely associated with road network management. Quality of service is a qualitative term based on the concept of providing various levels of convenience, comfort, and safety to a driver.

Road classification systems were examined by numerous countries, namely Australia, South Africa, the United Kingdom, and the United States.

The rural roads analyzed in Italy which are presented in this study are in low-volume conditions with an *ADT* of less than 1000 vpd for which a 3-year (2003–2005) crash database was used. Table 1 shows the descriptive features observed on the roads analyzed.

Typical photographs of the analyzed roads are shown in Fig. 1: the first picture shows an example of rural roads located on mountainous terrain, while the second illustrates roads in a flat area. The surface type of the examined roads is generally paved while in some minor cases the surface consists of gravel roads.

Fig. 1. Photographs of a typical road located on the mountainous and flat/rolling area

Table 1. Geometric features of the low-volume roads analyzed

Observed features	Main statistic values	Flat and rolling terrain	Mountainous terrain
Roadway segment length, km	Average	3.60	4.90
	Std. Dev.	3.40	3.70
Roadway width, m	Average	7.20	6.80
	Std. Dev.	1.40	1.20
Predicted mean speed, km/h	Average	56.00	54.00
	Std. Dev.	12.00	7.30
Number of lanes		2	2
Vertical grade, %		< 6	≥ 6%
Curve radius, m		150–500	≤ 150

The calibration of the injurious crash prediction models was performed using 63 roadway segments referring to the roads in the flat/rolling area, and 151 roadway segments for the roads in the mountainous area. In particular, some of the analyzed data were made available to the Department of Transportation Engineering at the University of Naples by the Administration of the Province of Salerno. According to the aim of this research, that is to identify a relationship between the road alignment consistency and the crash counts, the total length of each observed roadway was divided in a number of segments based on the definition of the curvature change rate of a homogeneous road segment (*CCR* in gon/km). CCR_m variable is defined as the sum of the absolute values of angular changes in the horizontal alignment divided by the total length of the road section. A homogeneous roadway segment is characterized by an almost constant slope.

It can be identified at each analyzed homogeneous roadway segment the total number of crashes, and its percentage of fatal and injuries crashes. The examined database contains the number of injurious crashes at intersections but they weren't individually investigated due to low probability of vehicles meeting.

Table 2 shows the mean value of the parameters associated with each roadway segment.

Table 3 shows the descriptive statistics of the crashes observed on the rural roads from 2003 to 2005. It can be observed that the average injury count for a 3-year period is 0.94 crashes per km and 0.32 crashes per km for the roads on flat/rolling and mountainous terrain respectively.

It is not possible to know the principal types of crash for each roadway, or the precise location and weather con-

Table 2. Parameters of the analyzed roadway segments

Observed features	Full description
Roadway segment	the total length of the analyzed roadway is divided into a number of homogeneous roadway segments according to the CCR_m definition
Roadway segment length	length of a homogeneous roadway segment identified at each analyzed road
ADT	average daily traffic for a period of three years from 2003 to 2005 observed at each roadway segment
Curvature indicator	measurement of the curvature change rate of the homogeneous roadway segment. This indicator acquires the following three levels by using a range of values from 1 to 3 after a deep analysis and careful study of all discrete values in the database: – low curvature for a mean value of all curve radius falling within the analyzed roadway segment between 400 m and 500 m: the indicator is 1; – medium curvature for a mean value of all curve radius falling within the analyzed roadway segment between 150 m and 400 m: the indicator is between 1 and 2; – high curvature for a mean value of all curve radius falling within the analyzed roadway segment of less than 150 m: the indicator is between 2 and 3.
Vertical grade	the vertical grade indicator can acquire the following synthetic and simple levels by using a range of values from 1 to 3 after a deep analysis and careful study of all discrete values in the database: – low vertical grade when the mean value of grades associated to the analyzed roadway segment is less than 3% (the indicator is equal to 1); – medium vertical grade when the mean value of grades associated to the analyzed roadway segment is between 3% and 6% (the indicator is between 1 and 2); – high vertical grade when the mean value of grades associated to the analyzed roadway segment is over 6% (the indicator is between 2 and 3);
Roadway width	travel lanes plus shoulders
Predicted speed	is the mean speed at each analyzed roadway segment in which the Administration has divided the entire roadway segment length
Crashes count	number of total and injurious crashes each year for analyzed homogeneous roads segments

Table 3. Descriptive statistics of the analyzed crash counts

	Injurious crashes in 3 years (2003–2005)		Injurious crashes each year					
			Flat and rolling terrain			Mountainous terrain		
	Flat and rolling terrain	Mountainous terrain	2003	2004	2005	2003	2004	2005
Average per roadway segment	59	49	9	32	18	14	14	21
	0.94	0.32	0.14	0.51	0.29	0.09	0.09	0.14

ditions at the time of the crash. Similarly, there are no details about any obstructions within the lateral clearance area which may have contributed to the severity of the crash when vehicles were leaving the stretch of road. The crash reports used refer to the general features of the crash counts analyzed. They need to be improved for the future developments of the safety analyses and to better explain the average crashes/segment's year to year variation.

A user-friendly geographic information system (GIS) platform for road crash analysis and prediction models has been used. A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows to view, understand, question, interpret and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS helps answer questions and solve problems by looking at data in a way that is quickly understood and easily shared. GIS technology can be integrated into any enterprise information system framework. The GIS shows to the users the environmental conditions, the geometric and accident information on each analyzed homogeneous roadway segment.

5. Data analysis

Two predictive injurious crash models were developed for the roadways analyzed in low-volume conditions: the first can be applied for roads located on flat/rolling terrain (vertical grade of less than 6%) and the second was associated with the roads on mountainous terrain with a vertical grade greater than 6%). The prediction models were performed by using only the number of injurious crashes because since 1991, according to many European countries, the Italian Administrations, responsible for the collection and dissemination of crash data, recorded only the injurious accidents defined as "events that occur on public roads in which one or more people are killed or wounded and in which at least one moving vehicle is involved".

Hauer *et al.* (2004) suggested the possibility of stratifying the models to overcome the lack of flexibility of the most common exponential functional forms.

Specialized software was used to fit the models. The injurious crashes per kilometer per year were used as dependent variables. An iterative process was applied in the development of the two crash prediction models Hauer *et al.* (2004) distinguished two steps in the process: (a) the choice of model form (model equation) and (b) estimating the parameters. Both steps are repeated in each phase of the model development process.

The Gauss-Newton method, based on the Taylor series, was used to estimate the coefficients of employed variables by using ordinary least-square regression. All the parameters included in the model are significant to a 95% confidence level. The significance of the regression equations' coefficients were investigated by using two criteria: 1) the models were kept where the *p*-value of the coefficients was under 5%; 2) the cumulative residual analysis, which is discussed in the next section.

5.1. Injurious crash prediction models

The best crash prediction model on low-volume roads located in areas with flat/rolling terrain, in injurious accidents per year per km, was worked out from data for 59 crashes reported over three years; the equation form is the following:

$$Y = \left(\frac{ADT}{1000} \times 6 \times 10^{-5}\right)(6 \times 10^{-1.5} CI) e^{(0.25V - 1.42VGI)} e^{(0.81W)}, \quad (1)$$

where Y – number of injurious crashes per year per kilometer; ADT – average daily traffic, vpd; V – mean speed at each analyzed roadway segment, km/h; CI – the curvature indicator as explained above; VGI – the vertical grade indicator as explained above; W – lanes plus shoulders width, m.

A reasonably-goodness-of-fit indicator was made for this regression: the adjusted coefficient of determination ρ^2 is 91%. As can be seen from Eq (1), where all the variables are statistically significant as shown in Table 4, the ADT variable has little influence on the predicted number of crashes: as could be imagined, the road is in low-volume conditions, but its presence is due to the increase in ρ^2 value.

The best crash prediction model on low-volume roads located in areas with mountainous terrain, in injurious accidents per year per kilometer, was worked out from data for 49 crashes reported over three years; the equation form is the following:

$$Y = e^{\left[-190.48 + 5.98\left(\frac{ADT}{1000}\right) + 0.65V\right]} \times e^{(224.51 - 13.83CI + 6.81VGI - 7.15W)}, \quad (2)$$

where Y – number of injurious crashes per year per kilometer; ADT – average daily traffic, vpd; V – mean speed at each analyzed roadway segment, km/h; CI – the curvature change rate indicator as explained above; VGI – the vertical grade indicator as explained above; W – lanes plus shoulders width, m.

The adjusted coefficient of determination ρ^2 is 99%. The structural form of this model is close to the representative crash models presented by Vogt and Bared (1998) calibrated from data coming from the states of Minnesota and Washington on rural two-lane highways for segments and three-legged and four-legged stop-controlled intersections on minor legs. In these models the ADT is introduced as a primary effect in the $EXPO_m$ variable (a product of ADT and time), and as a secondary effect in the exponential form.

Table 4. Coefficient of the variables in CPMs 1 and 2

	Roads located on flat/rolling terrain				Roads located in areas with mountainous terrain			
Descriptive variable	Estimated coefficient	Std. error	*t*-value ; *df* = 1	*p*-level	Estimated coefficient	Std. error	*t*-value ; *df* = 1	*p*-level
–					–190.481	0.000000	0.00	0.00
ADT/1.000	0.00006	0.000000	0.00	0.00	5.988	1.577217	0.00	0.00
V	0.24556	0.2546692	0.00	0.00	0.651	0.386234	0.00	0.00
–					224.513	0.000000	0.00	0.00
CI	$6 \times 10^{-1.5}$	0.000000	0.00	0.00	–13.834	7.219135	0.00	0.00
VGI	–1.42373	2.760914	0.00	0.00	6.807	6.639895	0.00	0.00
W	0.80841	0.604812	0.00	0.00	–7.150	2.692705	0.00	0.00

The following visual aid shows *p*-values for each coefficient of the variables in the prediction Eqs (1) and (2), respectively.

5.2. Analysis of the residuals

Hauer *et al.* (2004) recommended analyzing residual plots as an essential tool in this process. The residual is the value of the difference measured between the predicted value of injurious crashes using the model and the real value of the number of injurious crashes surveyed on the same roadway segment. The goal is to graphically observe how well the function fits the data set.

The CuRe (Cumulative Residuals) method has the advantage of not being dependent on the number of observations, as are many other traditional statistical procedures (e.g., ρ^2) (Mayora *et al.* 2006; Lord, Persaud 2000; Hauer *et al.* 2004). The CuRe method was adopted in addition to using the *p*-value criterion to test the significance of the regression equations to identify the regions where models under- or over-estimated accident rates, which provides a basis for the stratification of the models. The research demonstrated the usefulness of this type of analysis in detecting redundancies in the statistical information contained in the calibration data sample and in comparing alternative prediction models calibrated with different sample sizes.

For this reason, the diagrams of cumulative residuals for each regression equations based on the *ADT* values were analyzed. On a basis of this analysis, it's clear how the models offer a correct interpretation of reality due to a fair distribution of residuals around the mean. Abrupt decreases or increases in the graph may reflect lack of flexibility in the functional form in the model and, in some cases, the existence of redundant data for a given value of the explanatory variable. For roads located in the flat/rolling area, the observed residuals, in injurious crashes per year per kilometer, have a min value of 0.0001, a max value of 0.09, a mean value of 0.022 and a standard deviation of 0.023. For roads located in the mountainous area, the observed residuals, in injurious accidents per year per kilometer, have a min value of –0.03, a max value of 0.080, a mean value of 0.012 and a standard deviation of 0.021.

The good prediction of two models of real injurious crashes is also confirmed by analyzing two diagrams of cumulated squared residuals basing on the *ADT* values. In fact, two plots of cumulated quadratic residuals, corresponding to the *ADT*/1.000 values, showed no vertical jump (more correctly known as "outlier"). The presence of an "outlier" would have indicated an observation very different from a sample data distribution and it can appear when the real crash rate is very dissimilar to the predicted value using regression equations: in this case more investigations to decide whether to use these observations or not are necessary.

6. Results

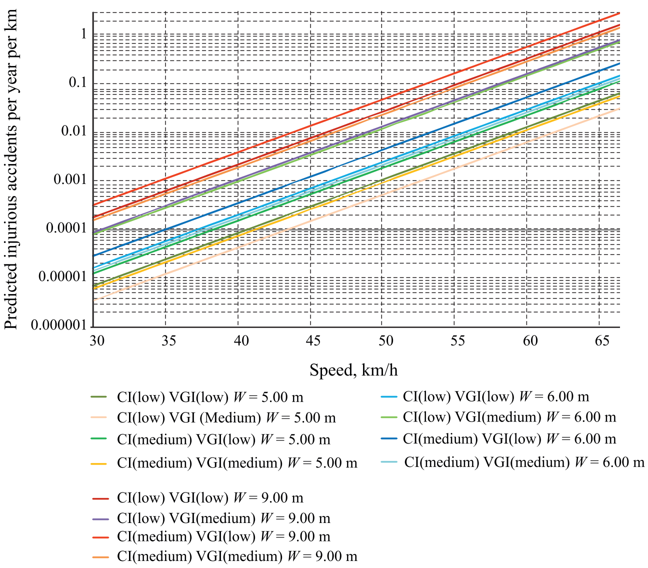
Two crash prediction models for injurious crashes per year per kilometer were calibrated for low-volume roads (with an *ADT* of less than 1000 vpd) located on flat/rolling and mountainous terrain within the roadway network of the Province of Salerno in Southern Italy. The data set includes 983.58 km of roads: 231.98 km on flat/rolling terrain (vertical grade < 6%) and 751.60 km on mountainous terrain (vertical grade > 6%). A 3-year (2003–2005) crash database was used.

The Gauss-Newton method, based on the Taylor series, was used to estimate the coefficients of the variables employed by using an ordinary least-square regression. All the parameters included in the models are significant to a 95% confidence level. In addition to the *p*-value criterion to test the significance of the regression coefficients (the models were kept when the *p*-value of the coefficients is less than 5%), cumulative residual analysis was used as above. The analyzed residuals for the rural roads located in the flat/rolling area have a max value of 0.09, while for the roads located on the mountainous terrain, the max value is 0.08 for injurious accidents per year per kilometer. The results proved the reliability of the regression equations and the complete absence of jumps.

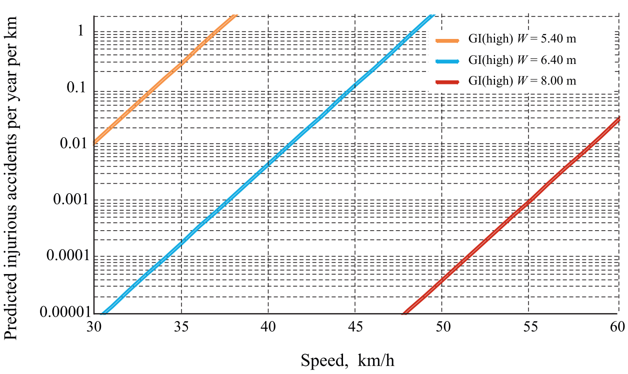
Because accident prediction models are non-normal, alternative measures such as scaled deviance and the Akaike information criterion will be performed in the next step of this research as well as some researchers in the scientific literature have shown to determine the goodness of fit of regression models (Mayora *et al.* 2006).

Fig. 2 illustrates an example of the profile of the two models. In the diagrams, the *y*-axis shows the number of injurious crashes predicted per year per kilometer, while the *x*-axis shows an independent variable of the predictive model. Each graph also presents a series of straight lines with a constant value for the remaining independent variables of the model in appropriate combination. The first graph refers to roads located on the flat/rolling area, and the second to the roads on the mountainous terrain. The two graphs refer to a particular *ADT* range below 300 vpd. Indeed the number of possible profiles of the two models is equal to the number of available variables employed in the model on which it can actually work to improve road safety conditions.

For example, to lower crash density on low-volume roads located in flat/rolling terrain, variations can be carried out (fixing an *ADT* range) on the speed, curvature rate



Roads on the flat/rolling area



Road on the mountainous area

Fig. 2. Abacus type for predicting the injurious crashes number per year per km

and roadway width. Here, the profile type of the crash density function of the mean speed on the roadway segment may be seen: it can be observed how for a specific combination of roadway curvature and width (respecting their range in the calibration procedure), the number of injurious crashes per year per kilometer increases with speed. Therefore by using the straight line which represents the combination of width and curvature associated with the analyzed roadway segment, and knowing the mean speed on the roadway segment, it is possible to predict the number of injurious crashes per year per kilometer. Among other things, if it is possible to reduce the density of crashes on the roadway segment without changing its width and curvature, by reducing speed through advisor signage and/or changing the geometric features of whole segments or defined elements, one must move along the same straight line to the left. In the same way, there can be a reduction in crash density on the roadway segment with no change in speed but only in roadway width and curvature, moving downward along a vertical line. Therefore a change in speed, curvature and width may be needed. The practitioners can apply this crash prediction model when the geometric and kinematic features of the examined roadways reflect those employed in the experimental analysis presented here. Potential safety problems may exist on the analyzed Italian rural roads located in a flat/rolling area when the Curvature Indicator is medium, the Vertical Grade Indicator is medium and the road width is max. The number of predicted crashes can reach 2 injurious crashes per year per km.

The crash prediction models presented here cannot be employed to find potential unsafe points on the examined roads but to analyze crash phenomena on the roads network because the safety analysis refers to the sample of homogeneous segments in which the total length of the analyzed roads were divided.

The same considerations can be applied to the model for roads located in the mountainous area. The graphs in Fig. 2 are represented logarithmically on the *y*-axis.

The countermeasures previously indicated to improve the safety conditions of drivers moving on the roads located in the flat/rolling area were chosen from various efficient operations. To reduce the frequency of the road injurious events, potentially cheaper procedures also exist such as delineations, rumble strips, advisor signage, isolated friction treatments, etc as many researchers in the scientific literature suggest.

Banihashemi and Dimaiuta (2005) have presented, for example, a linear optimization model that maximizes the safety benefits of improvements on an existing highway within specific budget constraints. The results obtained help designers maximize safety benefits, given a fixed amount of funding available for improvements.

It can state in the scientific literature that the roads and the road signs in good condition can be considered active safety means on the accident level. Active safety is the set of all capable structural elements of a vehicle to avoid a crash. These devices and systems have a duty to prevent collisions with other vehicles or obstacles, and above all they have a preventive function. The active elements help the pilot to control the vehicle in critical situations, so that the management of the vehicle is as comfortable and safe as possible. Based on this concept, the driver is the most important active safety system, its optimal psycho-physical conditions are among the best guarantees in order to avoid accidents and a critical situation. Nowadays the devices that offer max protection to the occupants of the vehicle in the event of a collision are increasingly technological.

However, the purpose of this experimental analysis was intended to recognize that on the existing roadways a potential combination of the values of geometric, kinematic, and traffic features can contribute to the occurrence of a crash. The helpfulness of these variables in reducing the number of crashes was examined through an experimental analysis using statistical approach. Two proposed crash prediction models have confirmed how by varying the values of some scheduled variables the number of crashes can be reduced. Future research will be devoted to the investigation of driver behavior where the above mentioned, less costly, countermeasures have been introduced. Analysis of the effectiveness of these devices may not initially appear to give a true account until drivers have become accustomed to these safety strategies. Thus, improving the features of the crash database (e.g., the crash type, the types of vehicles involved, the environmental and surface conditions when the crash happened) a complete analysis can be carried out to identify the best solutions to improve roadway safety, optimizing realization costs.

Future developments will be devoted to the investigations of driver behavior in the presence of defined countermeasures to be implemented or existing on the observed roads also including low-cost procedures. These advances are significant in analyzing the impact of stated devices on the public that may not initially appear ease and inclined to these safety strategies. So improving the features of crash database (e.g., the crash type, the types of involved vehicles, the environmental and surface conditions when the crash happened) it can develop a complete analysis to research the best solutions to improve the roadway safety optimizing the realization costs.

7. Conclusions and future development

The proposed objective was to identify the relationship between the existing causality events among the geometric and functional characteristics of the observed roadway network (Province of Salerno) and the number of recorded injurious crashes. Once the data had been gathered, a database was created to process the crash information. The proposed models can be used to analyze crashes on the road network and they can become a starting point for detailed models (e.g. crashes at intersections) also through *ad hoc* investigations of specific sites.

The models presented here predict the expected number of injurious crashes per unit length of roadway per year for rural roads in low-volume conditions located on the flat/rolling area and on mountainous terrain. The adjusted coefficient of determination ρ^2 has been used in this paper as well as the traditionally used criterion to determine how well the developed model fits the observed data, in addition to the CuRe (Cumulative Residuals) analysis. The results obtained may be said to be satisfactory, but the structural form and the analysis of the models to fit the data must be improved (i.e. the application of a generalized estimating equation procedure to develop CPMs). These injurious crash prediction models can also be used to compare the safety performance of alternatives in a rural road improvement project by estimating the total expected number of crashes for each potential alternative.

It can be stated that LVRs around the world consist of a single lane with gravel or even native surfacing. In some remote areas of the world LVRs follow travel routes many centuries old, while in developing areas LVRs may be the first steps up from human and animal pack trails or they may be entirely new roads opening up a new territory. Traditionally, LVRs have not provided the volume of business, funding, or glamour to attract and support a specialized field of engineering. When involved with LVRs, the engineers used the best information available and they extended their experience and training in higher-standard roads, pavements, or structures to LVR situations, even though they may have recognized the standards as excessive. It is therefore very difficult to classify these components of a transportation network because of the lack of standards, and it remains a very complex task to understand how to improve and repair them since there may be environmental and financial constraints, while huge sums of money are typically spent on ordinary roadways. Therefore it is necessary to establish some solutions and instruments to optimize roadway construction and management standards. Therefore, a further problem which affects rural roads, in addition to maintenance, is the impact that the various structural and non-structural operations can have on the surrounding environment, modifying natural terrain, disturbing large areas, and leading to major cultural and land use changes. Thus, rural roads need to be well planned, well designed, well constructed, and properly maintained for minimal adverse impact and to be cost effective in the long term with acceptable maintenance and repair costs.

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