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Relevant Variables for Crash Rate Prediction in Spain´s Two Lane Rural Roads

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ABSTRACT

This paper describes a research project conducted by Madrid Polytechnic University (UPM) in collaboration with the National Road Directorate (DGC) in Spain to develop an accident rate prediction model for the Spanish National Network two lane rural roads using a sample of 3 450 km of two-lane rural roads in the regions of Valencia and Western Castile. The first step in the development of the model was to define a set of variables based on highway characteristics and to analyze its correlation with accident rates. Access density, average sight distance, average speed limit and the proportion of no-passing zones are the variables that were found to present the highest correlations with crash rates and therefore included in the negative binomial multivariate crash prediction model that was calibrated at the end of the study. The results showed that the combination of several characteristics and the gradients of design speed between consecutive alignment elements are better predictors of crash rates than single characteristics of individual elements. Finally the conclusions that were derived from the relationships between the values of these relevant variables and crash rates are presented.

Key words: Highway safety, two-lane roads, highway characteristics, crash rate prediction

INTRODUCTION

The Spanish National Road Directorate (DGC) and Madrid Polytechnic University (UPM) are collaborating to develop a set of multivariate regression models to estimate crash rates using information on accident experience, traffic and infrastructure characteristics. The research includes identifying relevant variables, model calibration and precision analysis of the method for accident rate prediction and for assessment of road safety improvement projects effectiveness. Crash, traffic and road data from the Spanish National Road Network Safety Data Base are being used to adjust the models.

The resulting estimation procedures will be used as a tool in evaluating the accident reduction that can be accomplished by implementing road safety improvement measures and also to carry out cost-benefit analysis of the alternative measures. In the last phase of the project, the resulting method will be integrated in the computerised system that supports the Ministry's Road Safety Programme Management. This will provide road engineers with a user friendly tool that will contribute to improve the effectiveness of road safety improvement schemes.

LITERATURE REVIEW

Research efforts aimed to characterize and quantify the relationships between crash rates and traffic and highway infrastructure characteristics have been on-going for over 40 years. The Federal Highway Administration (*1*) compiled in 1992 the results of research conducted in the US until then. The results of this compilation show that over 50 different roadway variables have been identified as having some influence on crash rates. These variables pertain to different highway features: horizontal and vertical alignment (i.e.: degree of curvature, grade, sight distance, existence of spiral transition, etc); cross section (i.e.: roadway width, lane width, shoulder width, etc); roadside features (i.e.: roadside hazard rating, existence of guardrails, roadside slope, obstacle free zone, etc); intersections and interchanges (i.e.: intersection layout, intersection angle sight distances, channelization, etc); and access control (i.e.: driveway density, access channelization, etc).

In the development of crash prediction models it is crucial to determine which among these variables capture to a greater extent the effects of highway design and operation on safety.

Estimating the number of accidents that may result from a given highway design is a matter of great importance to develop accurate cost-benefit studies of highway safety alternatives. There has been considerable international experience in applying multivariate models to determine the relationship between accident rates and road and traffic characteristics. In a NCHRP report McGee et al. summarized some relevant efforts in this field (*2*).

In the development of accident prediction models two key questions have to be solved: functional model form choice and independent variable selection.

In recent years, there is a consensus among researchers in favour of modelling accidents as discrete, rare, independent events. Crash models are usually established as generalized linear Poisson models. The frequency of crashes that occur in a given road section is treated as a random variable that takes discrete integer non-negative values with probabilities obeying the Poisson distribution. A characteristic feature of the distribution is that the variance of the variable is equal to its mean. The mean number of accidents is assumed to be an exponential applied to a suitable linear combination of road variables. The resulting models are generalized linear models (GLIM), in which the exponential function guarantees that the mean is positive. Maher and Summersgill (*3*) developed at TRL in the UK a comprehensive methodology to fit predictive accident models applying this approach.

More recently Miaou (*4*) introduced negative binomial models, a generalization of the Poisson form that allows the variance to be over-dispersed, this to be equal to the mean plus a quadratic term in this mean whose coefficient is called the overdispersion parameter. When this parameter is zero, a Poisson model results.

It is common practice to build separate models for the crashes that occur in intersections and those taking place in highway segments. For example, Walmsley and Summergill (*5*) have applied the GLIM methodology developed at TRL to develop predictive models in two-lane highways, freeways and intersections.

Multivariate regression and Bayesian methods have been combined to predict accident rates in existing road sections and intersections taking into account its characteristics and the specific crash records of each site. In Canada, Persaud and Dzbik (*6*) applied this approach to relate freeway accidents to geometric and operational factors.

The most ambitious project that has been conducted in recent years is part of the development of the Interactive Highway Safety Designs Model (IHSDM) sponsored by FHWA. IHSDM is a suite of software analysis tools for explicit, quantitative evaluation of safety and operational effects of highway geometric design decisions. IHSDM has seven modules, each of which evaluates a design from a different perspective. The evaluations include checks for conformance with design policy and estimates of expected accident experience. A key component of IHSDM is an accident prediction algorithm which will estimate the number and severity of accidents on specified road segments. Vogts and Bared (*7*) developed a series of Poisson and Negative Binomial multivariate regression models to predict accident frequencies in 2-lane rural roads and intersections. Prediction variables in non-intersection models include traffic volume, commercial vehicles percentage, lane and shoulder width, horizontal and vertical alignment, road side condition and driveway density. These models are being used to establish base accident rates in an accident prediction model. Accident modification factors based on international literature and expertise will be applied to modify the estimate for deviation from base conditions as described by Harwood et al (*8*). Finally an Empirical Bayes method will be used to make prediction site specific in existing roads by incorporating historical accident data, following the procedure developed by Hauer (*9*).

Independent variable selection for accident prediction models remains a complicated problem. Krammes et al. (*10*) and Lamm et al. (*11*) have both shown with their works the importance of taking into account design consistency when considering safety effects of highway characteristics on crash risk. In the study reported in the present paper an attempt was made to identify the variables that best reflect design consistency.

RESEARCH DATA

A sample 3 450 km of two-lane rural roads in the regions of Valencia and Western Castile was used in the research. Crash data were obtained and analysed in two periods: 1993-97 y 1998-99. The first period was used in model calibrations, while the second period was reserved to assess model accuracy. Traffic and roadway characteristics proceed from the Roadway Inventory Data Base maintained by DGC. This data base contains one record every 10 m of roadway including the following data:

- AADT (veh/day)
- Curvature(m^{-1})
- Longitudinal grade (%)
- Roadway width (m)
- Right shoulder width (m)
- Left shoulder width (m)
- Sight distance (m)
- Access points
- Posted speed limit (km/h)
- No passing zones
- Safety barriers

Only those sections in which AADT was less than 20 000 veh/day were included in the study, because it was assumed that when traffic volumes are higher traffic conditions and safety problems are not representative of usual two lane rural roads. Equally, the segments in which there had been significant changes during the study period were excluded from the sample.

Dividing the sample in homogeneous sections in which all the characteristics of the highway were constant resulted in segments with of an average length of less than 400 m. Previously Resende and Benekohal (*12*) had reached the conclusion that to get reliable accident prediction models crash rates should be computed from 0.8 km or longer sections. It was decided that the average length of homogeneous sections was too short to allow for a meaningful analysis of the effect of potential roadway improvements on safety. Instead, the study was conducted in parallel for two types of sections. For the first one the 3 450 km sample was divided in 1 km fixed length segments. For the second, the same sample was divided into 236 *highway sectors* or sections of variable length limited by major intersections and/or built-up areas within which traffic volumes and characteristics could be assumed to be constant. The length of these *highway sectors* ranged between 3 km and 25 km, with an average of 14.6 km. The reason for conducting these two analysis is that the first type of segments correspond to those in which DGC conducts high accident location treatments, while the second type are subject to the development of preventive safety improvement measures. These are designed to suppress risk factors and to improve the safety standards including roadside protection, access control, signing, delineation, etc.

The variables that were considered in the analysis for the 1 km long segments (Table 1) were:

- Access density (access points/km)
- Average roadway width (m)
- Minimum sight distance (m)
- Minimum curvature (1/m)[1]
- Minimum speed limit (km/h)

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[1] Horizontal curvature is the inverse of the radius of curvature. The curvature of a tangent is 0.

- Maximum grade in absolute value (%)
- Minimum design speed (km/h)[2]
- Design speed reduction from the adjacent 1 km segments (km/h)[3]

Some of these variables are dependent on the gradient of design parameters along the highway (i.e. design speed reduction from the adjacent 1 km segments). Others depend on the combined effect of various highway features and roadside conditions (i.e. speed limits or sight distance, that depend on the combination of horizontal and vertical alignment, cross section, and road side restrictions). The objective of considering these variables in the analysis was to capture the effect on safety of the interactions between highway design parameters.

Roadside variables were not included in the study because no data were available on the hazard ratings of the roadside. It is intended to develop a roadside hazard rating procedure at a later stage of the model development. When this is accomplished the models will be reviewed and reformulated. In any case, the level of roadside protection along the Spanish National System is quite homogeneous and complies with standards set by the Spanish Roadside Protection Guidelines. Therefore, highway sections with hazardous roadsides are protected with vehicle contention devices, thus levelling to a certain extent roadside risk levels along the network.

Table 2 reflects the correlation coefficients between the independent variables in the 1 km segments study. As might be expected speed limits correlate with curvature and design speed, sight distance and access density. Sight distance has a significant correlation to grade curvature and design speed, which are in turn strongly related.

Roadway width presents the highest correlation with AADT of all the highway variables included in the study. The highways included in the study generally have 3.5 m wide lanes with paved shoulders ranging from 0.5 m to 2 m. The association between traffic volumes and roadway width indicates that the highways that carry heavier traffics usually have wider shoulders.

The first step to conduct the highway sectors study was to divide the highways included in the sample into sections in which traffic characteristics could be considered uniform. Once this identification process was completed, roadway average conditions within the segments were characterized using the following variables (Table 3):

- Access density (access points /km)
- Average roadway width (m)

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[2] The design speed for each alignment element was computed using the current Spanish Geometric Design Manual (*Instrucción de Trazado 3.1. IC. Ministerio de Fomento. Madrid, 1999*). Design speed for tangents was set at 120 km/h which is roughly the 85th percentile of free flow speeds in long tangents in two lane rural roads. For each 1 km segment the minimum value of all the alignment elements that were part of the segment was computed.

[3] For a given segment, the design speed reduction from adjacent segments is computed as the sum of the differences in design speed from each of the two adjacent 1 km segments whenever the design speed in them is higher than that of the segment. Otherwise 0 was computed.

- Average sight distance (m)
- Average curvature (1/m)
- Standard deviation of curvature (1/m)
- Average speed limit (km/h) [4]
- Maximum longitudinal grade (%)
- Average of the absolute values of grade (%)
- Average design speed (km/h)
- Standard deviation of design speed values (km/h)
- Average design speed variation between the 1 km long adjacent segments included in the sector (km/h)
- Proportion of no passing zones [5]

Averages were computed based on the weighed values of the variables in 10 m segments. The correlation coefficients between independent variables used in the highway sectors analysis are shown in table 4. The same patterns of association between independent variables found in the 1 km segments are present in the highway sectors.

SELECTION OF INDEPENDENT VARIABLES

Methodology

Independent variable selection was performed with the objective of identifying those variables that show higher degree of association with crash rates.

A univariante analysis was performed with accident frequency (personal injury accidents/km/year) and accident rate (personal injury crashes/10^8 veh-km) as dependent variables. For each of the independent variables the correlation coefficient was computed as well as the p-value.

Traffic volume was found to be the variable with the highest correlation with crash frequencies. As traffic volume is also correlated with most of the highway design variables, reflecting the fact that the highways with higher volumes usually have the highest design standards, the correlations of the rest of the independent variables with crash frequencies were biased by its relationship with volumes and it was decided not to use them for the univariate analysis. Instead accident rate was retained as independent variable for this phase of the study. Although it has been shown in different studies that the relationship between accident rates and traffic volumes is not linear, and therefore in multivariate regression analysis of crash rates traffic volume should be considered as independent variables, and crash frequencies as the independent variable, for the purpose of finding the variables with highest association with accident rates, the lack of linearity in the relationship was not considered to be decisive.

For those variables with a significant correlation at the 99% level of confidence a univariate regression model was adjusted. In each case eight different functional forms of the regression

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[4] Weighed average of the speed limits along the highway sector.

[5] The proportion of the total length of the sector in which passing is forbidden. It is computed in both directions of travel. Therefore the base length for the proportion is twice the length of the segment.

model were calibrated with a minimum squares procedure and the one showing the highest determination coefficient R^2 was adopted. The analysis was conducted with the aid of SPSS software package.

Correlation Analysis

Tables 3 and 4 show the correlation coefficients between highway variables and crash frequencies and rates for the two time periods included in the study.

In 1 km segments, the highest correlation coefficients with the average accident rate for the study period are:

- Access density (access points/km): 0.194
- Design speed reduction from adjacent segments (km/h): 0.140
- Speed limit (km/h): -0.131
- Average sight distance: -0.126

According to these results, access density is the characteristic with the highest correlation with crash rates in two lane rural road segments.

Among the variables depending of the geometry of the highway, the design speed reduction from adjacent segments is the one that shows the highest correlation with accident rates, while individual alignment element characteristics (radii of curvature, slope grade) yield much lower correlation coefficients. This result indicates that the degree of variation of the geometric variables and the lack of consistency within a highway section has greater effect on crash risk than the absolute values of the variables in each alignment element.

Posted speed limit and the available sight distance are two other characteristics that have a significant effect on crash rates and are related to highway geometry, although may also be determined by other factors. When considering this results it is important to bear in mind that the correlation coefficient is only a measure of the level of association between the independent and the dependent variables, but does not necessarily prove a cause effect relationship between them. For example, in the case of speed limit, the negative correlation coefficient indicates that those segments with lower speed limits tend to have higher crash rates. This does not mean that increasing the speed limit in a particular segment will contribute to reduce its crash rate. The interpretation is that if the segment characteristics are improved to allow the posted speed to be raised then the crash rate can be expected to diminish. This confirms the importance of achieving consistency along the highway: if the whole road was designed in a way that posted speed was always the legal limit, crash rates would be lower.

When longer sections are considered, the highest correlation coefficients with the average accident rate are:

- Access density (access points/km): 0.506
- Average speed limit (km/h): -0.487
- Average sight distance (m): -0.309
- Proportion of no-passing zones: 0.244

Similarly to what was obtained in 1 km segments, variables related to access control, design consistency and sight distance have the greatest influence on crash rates. In addition, the proportion of no-passing zones has also a significant effect on crash rates along the sectors. Correlation coefficients of average highway characteristics along the sectors are considerably higher than on 1 km segments due to the fact that on the 1 km sections the variability of accident frequencies and the randomness in its location has a much greater effect than on the much longer sectors.

Correlation Analysis by Accident Type

Table 5 shows the correlation analysis between the most frequent crash types and highway characteristics along the sectors. These included: single vehicle crashes, head on and lateral collisions, run-off the road crashes and night time crashes.

The variables showing the highest correlation coefficients with the average accident rate for each crash type are:

a) Single vehicle crashes
   - Sight distance (m): -0.130
   - Proportion of no-passing zones: -0.094

b) Head on and lateral collisions
   - Access density (access points/ km): 0.195
   - Sight distance (m): -0.093

c) Run-off the road crashes
   - Sight distance (m): -0.102

d) Night time crashes
   - Access density (access points/ km): 0.135
   - Speed limit (km/h); -0.132
   - Sight distance (m): -0.087

Sight distance is associated with all types of crashes, reflecting its validity as a surrogate for the safety level of the road design. Single vehicle crashes were found to be significantly correlated to the proportion of no passing zones, which reflects the fact that this variable measures not only the opportunities of overtaking but also the quality of the layout.

UNIVARIATE REGRESSION RESULTS

According to the results of the study, the effect of highway geometric design on safety depends on the combination of several characteristics and on the gradients of design speed between consecutive alignment elements rather than on the characteristics of individual elements.

Figure 1 shows the regression curve of the reduction of design speed between a 1 km segment to the adjacent and the adjacent ones. Average accident rates increase uniformly with growing speed reductions. When the reduction exceeds 30 km/h the slope of the regression curve increases considerably, and therefore it is advisable to avoid that changes in the alignment reach this value. In general, it is desirable that the variations in alignment characteristics be as gradual as possible.

When longer sections of highway(sectors) are considered, the variables related to the geometry of the highway that show greater effect on crash rates are average speed limit, average sight distance and the proportion of no-passing zones.

The regression curve of crash rate on the average speed limit along an sectory (Figure 2) has an important decrease until the average speed reaches 80 km/h, while between 85 km/h and 100 km/h the variation in crash rates is small. Taking into account that in Spain the legal speed limit in two-lane rural roads ranges between 90 and 100 km/h depending on the shoulder width, this results confirm the importance of designing highways with homogeneous characteristics, avoiding as much as possible using alignment elements in with the design speed is more than 15 km/h below the legal speed limit.

When sight distance is considered (Figure 3), crash rates diminish sharply as the average sight distance increases until 100 m. The reduction in accident rates is less acute for sight distances over this value.

The proportion of the length of an sectory in which passing is prohibited also is significantly correlated with crash rates. Figure 4 shows the regression curve that indicates that crash rate increase when the proportion of no-passing zones raises until it reaches 20% of the length of the segment. Between 20% and 70% crash rates are stable and then increase again sharply. Consequently, from a safety stand point it is advisable to provide drivers with passing zones in at least 30% of the length of each highway section.

Finally, although it is not strictly a geometric design characteristic of the highway, it should be pointed out that access density is the variable that showed the highest correlation with accident rates in the study. This points at the importance of including access management and control measures in preventive highway improvement programs. Figure 5 shows the regression curve of crash rates on access density. Crash rates are sensibly constant for access density values below 0,5 access points/km; then they start to increase. For access densities above 1,5 access points/km the increase is very sharp.

MULTIVARIATE REGRESSION MODEL

Following the procedure described by Bared&Voigt (*4*) a binomial negative binomial multivariate crash prediction model has been developed and calibrated for *highway sectors* in two-lane rural roads. The variables included in the model were selected on the basis of the results of the studied described in previous paragraphs. For the calibration of the model LIMDEP software was applied to the sample data set of 3450 km. The dependent variable in the model is crash frequency (personal injury crahes/year). The natural logarithm of traffic volume (vehicle-km/year) was considered as independent variable.

The resulting model is:

$$CF = e^{86{,}571 \mathrm{Ln}\, TrV + 0{,}31135\, AcD - 0{,}01139\, SpL - 0{,}09470\, SiD - 0{,}08434\, LGr + 0{,}59224\, NpP}$$

where:

CF: Personal injury frequency(personal injury crashes/year)
TrV: Traffic volume (10^8 vehicle-km)
SpL: Access density (access points/km)
SpL: Average speed limit (km/h)
SiD: Average sight distance (m)
LGr: Average longitudinal grade (%)
NpP: Proportion of no-passing zones

The R^2 of the model was found to be 87,15%. This equation will be used to predict crash rates under the following form:

$$CR = 86{,}571\ e^{0{,}31135\ AcD - 0{,}01139\ SpL - 0{,}09470\ SiD - 0{,}08434\ LGr + 0{,}59224\ NpP}$$

where:

CR: Personal injury crash rate (personal injury crashes/10^8 veh-km)

The accident prediction model for the DGC Safety Management System will combine a multivariate negative binomial regression model and an Empirical Bayes procedure developed by Pardillo Mayora (*13*). For each specific site, the accident rate estimate obtained from the multivariate regression equation is combined with it recorded rate to yield the final estimate.

The resulting accident prediction tool will be integrated in the computerised system that supports the Ministry's Road Safety Programme Management for the implementation of an automated procedure of cost-benefit analysis for road safety improvement schemes.

CONCLUSIONS

From the results of the research reported in this paper the following conclusions were obtained:

1. A key step to develop accident prediction models is to select a set of independent variables that capture as much of the interaction between roadway characteristics and driver safety performance as possible. To do this a univariate correlation analysis can be conducted prior to the calibration of multivariate models.

2. The highway variables that have the highest correlation with crash rates in Spain´s two-lane rural roads are: Access density, average sight distance, average speed limit and the proportion of no-passing zones. Access density is the variable that influences most the rate of head-on and lateral collisions, while in run-off the road and single vehicle crashes sight distance is decisive.

3. High access density has a negative effect on safety. Therefore preventive safety improvements should include access management and control measures. Ideally, on two-lane rural roads access points should be separated 2 km. When this cannot be achieved a desirable minimum distance between consecutive access points is 500 m. Although this may not be applicable in access roads, it might be achieved in some higher level highways by applying access management techniques.

4. Sight distance should be improved in those segments where it is below 100 m. On the contrary, the results of the study suggest that sight distance is higher than 200 m its improvement has a limited effect on safety in two lane rural roads.

5. To measure the influence of geometric design on crash rates it is necessary to use variables that measure the variation of characteristics between adjacent alignment elements or along a highway section. This confirms the importance of achieving highway design consistency to improve safety.

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TABLE 1.

Variables included in the study of 1 km segments

Variable	Mean	Standard Deviation
Personal Injury Accidents 1993-97	2.65	3.6
Accident Rate 1993-97 (Injury Accidents/10^8 veh km)	26.0289	35.7876
Personal Injury Accidents 1998-99	1.15	2.13
Accident Rate 1998-99 (Injury Accidents/10^8 veh km)	14.2043	26.8268
Average Annual Daily Traffic 1993-97	5818.93	3754.04
Access points per km	0.35	0.59
Average roadway width (m)	10.1911	1.4043
Minimum sight distance (m)	143.3	55.6
Speed limit (km/h)	88.04	19.66
Minimum curvature (10000/m)	0.191672	0.18253023
Maximum longitudinal grade (%)	3.6096	1.9889
Design speed (km/h)	107.11	20.89
Design speed reduction from adjacent segments (km/h)	5.92	11.47

TABLE 2.

Correlations between independent variables used in the analysis of 1 km segments

Variable		A	B	C	D	E	F	G	H	I
AADT 1993-97	A	1	.055(**)	.460(**)	-0.019	-.066(**)	-.151(**)	-.166(**)	.180(**)	-.090(**)
Access points per km	B	.055(**)	1	.045(**)	-.154(**)	-.416(**)	0.014	0.01	-0.019	.088(**)
Average roadway width (m)	C	.460(**)	.045(**)	1	.175(**)	.187(**)	-.276(**)	-.085(**)	.272(**)	.054(**)
Minimum sight distance (m)	D	-0.019	-.154(**)	.175(**)	1	.381(**)	-.467(**)	-.469(**)	.521(**)	-.279(**)
Speed limit (km/h)	E	-.066(**)	-.416(**)	.187(**)	.381(**)	1	-.441(**)	0.081	.392(**)	-.168(**)
Minimum curvature (10000/m)	F	-.151(**)	0.014	-.276(**)	-.467(**)	-.441(**)	1	.466(**)	-.874(**)	.557(**)
Longitudinal grade (%)	G	-.166(**)	0.01	-.085(**)	-.469(**)	0.081	.466(**)	1	-.514(**)	.199(**)
Design speed (km/h)	H	.180(**)	-0.019	.272(**)	.521(**)	.392(**)	-.874(**)	-.514(**)	1	-.593(**)
Design speed reduction from adjacent segments (km/h)	I	-.090(**)	.088(**)	.054(**)	-.279(**)	-.168(**)	.557(**)	.199(**)	-.593(**)	1

TABLE 3.

Variables included in the study of sectors

Variable	Mean	Standard Deviation
Access density (access points/km)	0.382	0.3133
Average roadway width (m)	10.1471	1.3366
Maximum grade (%)	5.6097	1.9925
Average sight distance	156.3	43.3
Average speed limit	90.5744	8.9488
Average horizontal curvature (10000/m)	34.8382	47.4894
Average design speed (km/h)	99.9691	19.6348
Average design speed variation (km/h)	6.7675	4.0536
Proportion of no-passing zones	0.5755	0.2445

TABLE 4.

Correlations between independent variables used in the analysis of highway sectors

Variable		A	B	C	D	E	F	G	H	I	J
Traffic volume (veh-km)	A	1	0.102	.461(**)	-.218(**)	-.158(*)	-.219(**)	.296(**)	-0.104	-0.059	.141(*)
Access density (access points/km)	B	0.102	1	-0.028	-0.063	-.420(**)	.150(*)	-0.116	.143(*)	.213(**)	-.219(**)
Average roadway width (m)	C	.461(**)	-0.028	1	-0.079	.221(**)	-.390(**)	.477(**)	-.299(**)	-0.117	.354(**)
Maximum grade (%)	D	-.218(**)	-0.063	-0.079	1	0.085	.306(**)	-.397(**)	.275(**)	.467(**)	-.331(**)
Average speed limit	E	-.158(*)	-.420(**)	.221(**)	0.085	1	-.448(**)	.398(**)	-.304(**)	-.324(**)	.379(**)
Average horizontal curvature (10000/m)	F	-.219(**)	.150(*)	-.390(**)	.306(**)	-.448(**)	1	-.883(**)	.416(**)	.429(**)	-.674(**)
Average design speed (km/h)	G	.296(**)	-0.116	.477(**)	-.397(**)	.398(**)	-.883(**)	1	-.426(**)	-.553(**)	.773(**)
Average design speed variation (km/h)	H	-0.104	.143(*)	-.299(**)	.275(**)	-.304(**)	.416(**)	-.426(**)	1	.436(**)	-.388(**)
Proportion of no-passing zones	I	-0.059	.213(**)	-0.117	.467(**)	-.324(**)	.429(**)	-.553(**)	.436(**)	1	-.610(**)
Average sight distance	J	.141(*)	-.219(**)	.354(**)	-.331(**)	.379(**)	-.674(**)	.773(**)	-.388(**)	-.610(**)	1

TABLE 5.

Correlation coefficients in 1 km segments

	Injury accident frequency 1993-97	Fatal accident frequency 1993-97	Injury accident rate 1993-97
Average Annual Daily Traffic 1993-97	.481(**)	.333(**)	-.058(**)
Access points per km	.195(**)	.076(**)	.194(**)
Average roadway width (m)	.223(**)	.191(**)	-0.008
Minimum sight distance	-.160(**)	-.076(**)	-.126(**)
Speed limit (km/h)	-0.027	-.064(**)	.062(**)
Minimum curvature (m^{-1})	-.204(**)	-0.014	-.131(**)
Maximum grade (%)	-.053(**)	-.078(**)	0.02
Design speed (km/h)	0.024	.057(**)	-.085(**)
Design speed reduction from adjacent segments (km/h)	.045(**)	-0.023	.140(**)

**Correlation in significant at 0.01 level (bilateral).
* Correlation in significant at 0.05 level (bilateral)

TABLE 6.

Correlation coefficients in highway sectors

	Injury accident frequency 1993-97	Fatal accident frequency 1993-97	Injury accident rate 1993-97
Traffic volume 1993-1997 (veh-km)	0.533(**)	0.484(**)	-0.105
Access density (access points/km)	0.061	-0.022	0.506(**)
Average roadway width (m)	0.292(**)	0.324(**)	-0.11
Maximum grade (%)	0.064	0.033	-0.072
Average sight distance	-0.01	0.003	-0.309(**)
Average speed limit	-0.048	0.082	-0.487(**)
Average horizontal curvature (10000/m)	-0.186(**)	-0.222(**)	0.248(**)
Average design speed (km/h)	-0.183(*)	-0.213(**)	-0.254(**)
Average design speed variation (km/h)	-0.004	-0.072	.159(*)
Proportion of no-passing zones	0.025	-0.075	0.244(**)

**Correlation in significant at 0,01 level (bilateral).
* Correlation in significant at 0,05 level (bilateral)

TABLE 7.

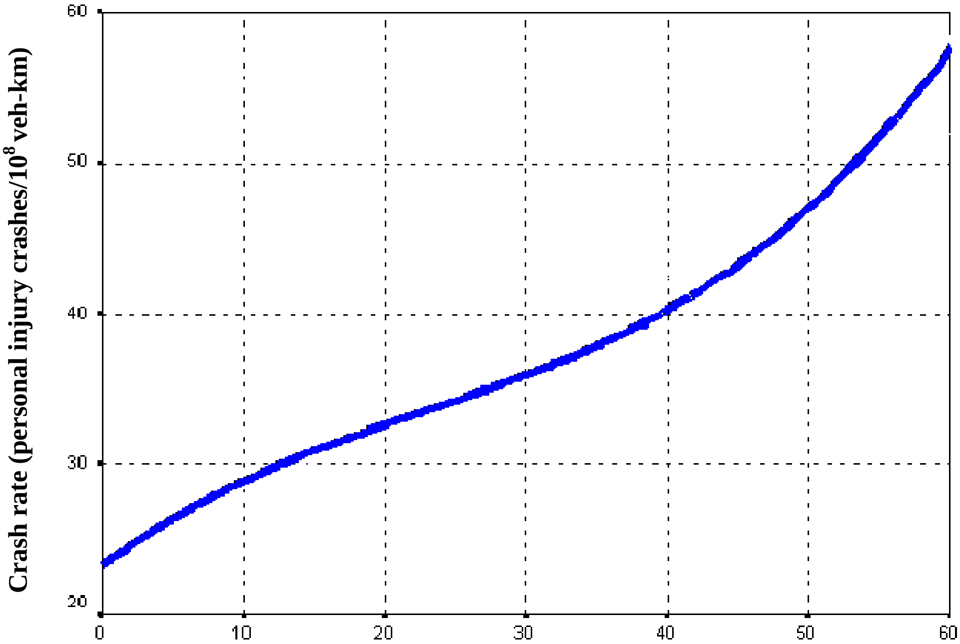
Correlation coefficients for different accident type frequencies in highway sectors

	Single vehicle crashes	Head-on and lateral collisions	Run-off the road crashes	Night time crashes
AADT	0.226 (**)	0.339 (**)	0.198 (**)	0.341 (**)
Access density (access points/km)	0.071 (**)	0.195 (**)	0.041 (**)	0.135 (**)
Maximum grade (%)	0.029 (*)	-0.047 (**)	0.016	-0.052 (**)
Average sight distance (m)	-0.130 (**)	-0.093 (**)	-0.102 (**)	-0.087 (**)
Average horizontal curvature (10000/m)	0.055 (**)	0	0.045 (**)	-0.005
Roadway width (m)	0.151 (**)	0.135 (**)	0.134 (**)	0.132 (**)
Average speed limit (km/h)	-0.076 (**)	-0.153 (**)	-0.014	-0.132 (**)
Proportion of no-passing zones	-0.094 (**)	-0.062 (**)	-0.060 (**)	-0.069 (**)

**Correlation in significant at 0.01 level (bilateral).
* Correlation in significant at 0.05 level (bilateral)

FIGURE 1.

Effect of design speed reduction from adjacent segments on crash rates



Design speed reduction from adjacent segments (km/h)

FIGURE 2.

Effect of the average speed limit on crash rates

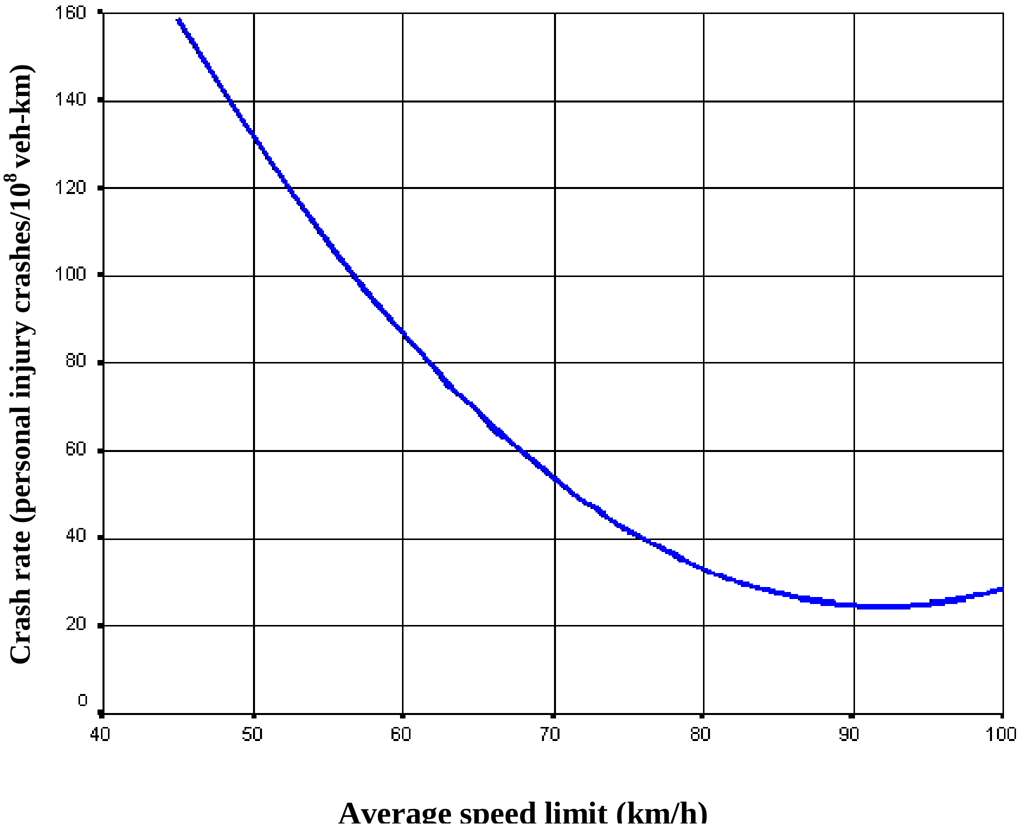


FIGURE 3.

Effect of the average sight distance on crash rates

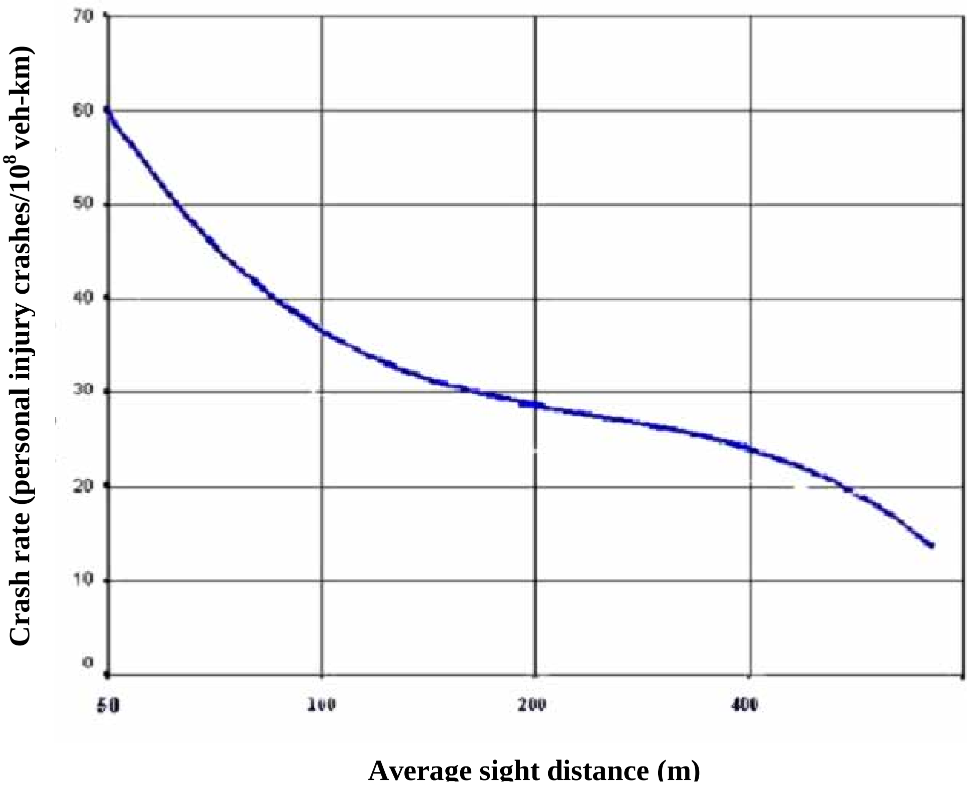


FIGURE 4.

Effect of the proportion of no-passing zones on crash rates

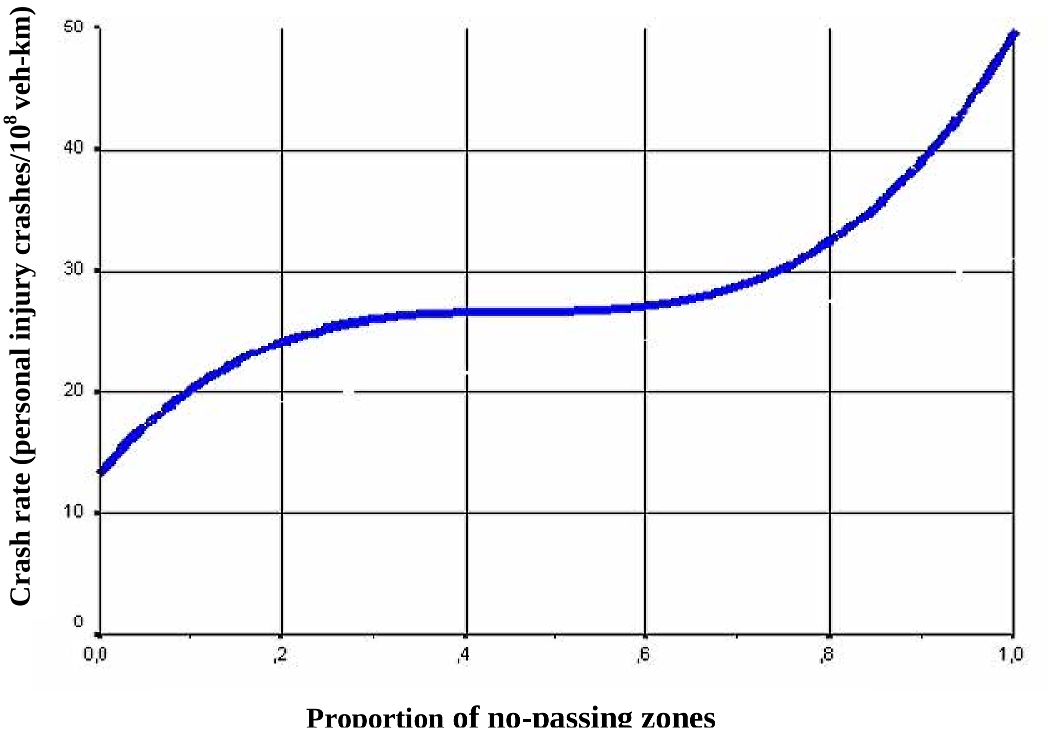


FIGURE 5.

Effect of access density on crash rates