The Influence of Skid Resistance on Traffic Safety in Different Road Environments

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ABSTRACT: The main purpose of this paper is to present the methodology and the results of PhD research at Technical University of Lisbon (IST) that is now in its final stages. The study deals with the problematic of establishing different maintenance programmes for skid resistance and texture depth in different road environments, from a perspective of increasing traffic safety without necessarily spending more money. The first stage of this work, which is presented in this paper, consisted of applying different traffic characteristics, road layouts and weather conditions to road environments, using a cluster analysis. For this purpose, a sample of eight itineraries of the Portuguese Road Network, divided in 254 segments with a length of 1 km, was used. Those segments were classified and grouped according to their characteristics. The next task consisted of identifying the influence of pavement properties (skid resistance and texture depth) on road accidents in each environment, using Generalised Linear Models, more specifically the Poisson regression. Finally, to complement and validate the results obtained in the previous step, some simulations were made in virtual scenarios with different pavement properties and traffic speeds, using *PC-Crash* software which reproduces vehicle crashes. These results were fundamental to establishing threshold values for the International Friction Index (IFI) to be used in pavement maintenance programmes.

KEY WORDS: Road safety, Road environments, Pavement management system, Skid resistance, Texture depth

1 INTRODUCTION

Surface properties of road pavements nowadays are more relevant due to significant investment in new materials and technologies. Many countries have skid resistance and texture depth guidelines to ensure safe levels on their roads (Highways Agency, 2004; Transit NZ, 2002). Those levels are the result of research carried out on the relationship between skid resistance and accident risk. In the literature, there are several references to observational studies of the influence of pavement on road accidents (Gothié, 1993; Larson, 2005; Murad, 2006), the results of which indicate some trends, though they are not fully defined. Research is still needed concerning pavement surface properties and their relationship to traffic safety.

In Portugal, the traffic safety performance indicators used to assess functional road pavement quality, are skid resistance and texture depth. Estradas de Portugal (EP), the Portuguese Road Administration, stipulates threshold values for quality controls applied to new roads (EP, 2008). The quality requirements for existing roads are generally related to maintenance programmes. EP has a new Pavement Management System in which skid resistance and texture depth are not considered directly but rather function as a triggerparameter due to their relationship to traffic safety. Low skid resistance values are sufficient to prompt investigation and intervention when necessary. EP recommends the use of the International Friction Index (IFI); at the moment, however, there are no reference values for this parameter (EP, 2006). The heavy investment involved in road maintenance requires more robust studies with more frequent monitoring of road conditions and more reliable accident data.

2 OBJECTIVES AND METHODOLOGY

The principal objective of the PhD thesis on which this paper is based is to contribute towards defining a maintenance programme for the surface characteristics of asphalt pavements in order to improve the quality of the Portuguese Road Network, thus reducing the probability and severity of road accidents. To reach this goal, the methodology adopted was structured around smaller targets, essentially based on safety and technical-economic criteria.

The study began with the selection of a set of itineraries, typically in rural environment, which sufficiently represents the primary and secondary Portuguese road network. For the selection procedure, a sequential type of non-random sampling method was chosen, as it was considered the most appropriate in light of data availability constraints.

Using cluster analysis, the selected itineraries were divided into 1 km-long segments and organised into quite homogeneous groups. The groups, denoted by type of road environment, possess different traffic characteristics, road layout and weather conditions.

Next, the expected number of accidents for each road environment was modelled by pavement condition in order to study the influence of surface pavement properties on accident risk. Generalised linear modelling was chosen as a statistical technique. From the results, and following analysis of the coefficients associated with the pavement condition variable, it was possible to establish minimum and safe skid resistance and texture depth threshold values.

In order to be able to extrapolate the results and apply them to similar situations, the data's strengths and weaknesses as well as the limitations of the results of statistical analysis were considered. For that reason, the threshold values were validated with the use of software for accident reconstruction by simulating the most frequent manoeuvres in segments with characteristics typical of each road environment through varying surface properties and traffic speed.

3 CASE STUDY

3.1 Selection of itineraries

Itineraries were selected by applying a sequential type of non-random sampling method. Despite this method's disadvantages, it was considered the most appropriate for the prevailing conditions. The sample was chosen and adjusted according to the information available. The final set comprises eight itineraries, spanning a total length of 254 km. To avoid a biased sample, itineraries covering different road categories (primary and secondary networks) were chosen, ensuring a varied geographical distribution throughout the country and including good and bad levels of pavement conditions and accidents.

The pavement surface characteristics were obtained from a pavement condition survey performed in 1999 by the Portuguese Road Administration. Skid resistance and texture depth were measured using a SCRIM and a laser-based texture meter device, respectively. For these devices, the formula that relates the IFI with friction (CAT) and texture depth (AAE) measurements is presented in Equations 1 and 2, where CAT is measured with SCRIM at 60 km/h. An analysis of IFI, CAT and AAE is presented in Table 1.

$$\mathrm{IFI} = -0{,}0141 + 0{,}875 \times \mathrm{CAT} \times e^{\left(\frac{-39{,}5}{S_p}\right)} \qquad (1)$$

$$S_p = 17{,}63 + 93 \times \mathrm{AAE} \qquad (2)$$

Table 1: Analysis of IFI, CAT and AAE by itinerary

Itinerary	IFI			CAT			AAE (mm)		
	Mean	Percentile 85	Standard Deviation	Mean	Percentile 85	Standard Deviation	Mean	Percentile 85	Standard Deviation
A	17	20	5.7	34	37	8.3	0.584	0.688	0.1193
B	32	35	3.8	58	64	5.9	0.729	0.789	0.0698
C	38	42	3.3	72	78	4.7	0.650	0.736	0.0821
D	31	33	2.5	61	63	3.4	0.586	0.636	0.0508
E	20	25	3.5	40	48	6.7	0.576	0.642	0.0627
F	35	37	1.8	68	71	2.3	0.622	0.704	0.0712
G	36	39	3.9	67	70	4.1	0.700	0.784	0.1573
H	37	39	2.9	69	72	2.9	0.675	0.752	0.1099

Accident data include only accidents between 1997 and 2002 with victims. This information was obtained from the Directorate-General for Traffic. However, even with a standardised form filled out by police at the time of the accident, there are often inconsistencies and a lack of information, making data analysis difficult. Figure 1 shows some information about accidents in different itineraries.

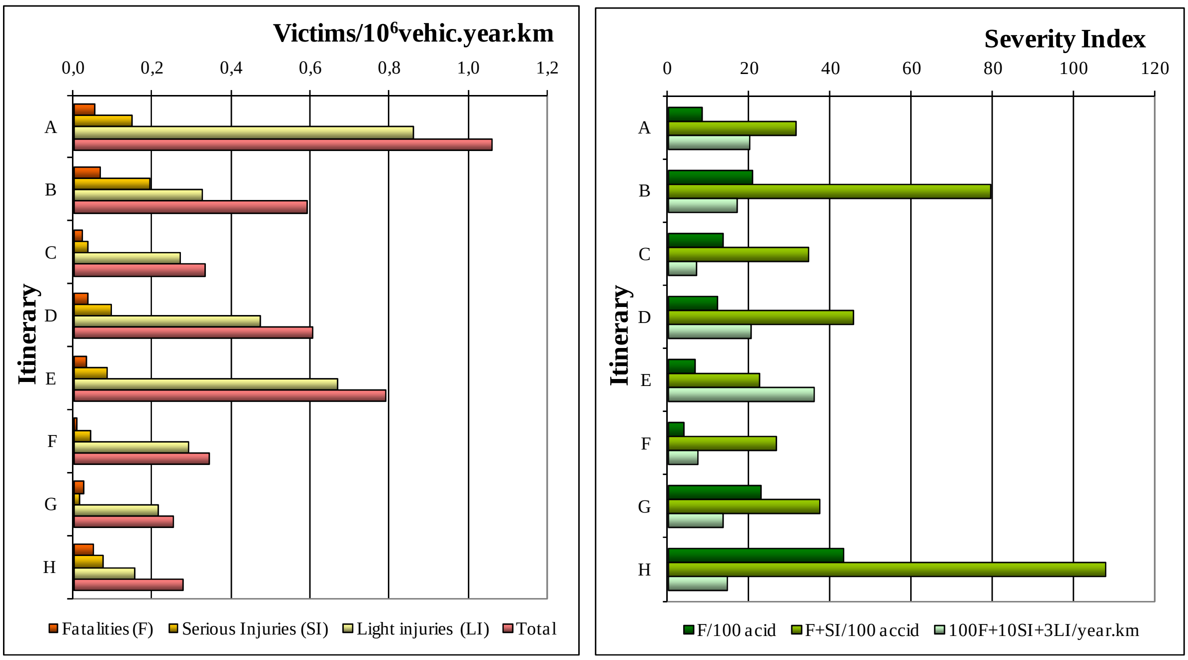

Figure 1: Accident analysis by itinerary

It is almost impossible to analyse the influence of pavement on road accidents without considering other explanatory variables. In addition to skid resistance and macrotexture, information about traffic, road layout and weather conditions was also collected. This information was obtained from the Portuguese Road Administration and the Hydro Resources Information System.

3.2 Definition of road environments

Some road environments require higher levels of skid resistance. To isolate different road environments with distinct traffic characteristics, road layouts and weather conditions, a cluster analysis was undertaken using STATISTICA 6.0 software. The variables used in the cluster analysis were carefully chosen to closely reflect reality and to appropriately characterise the road environments (RE). Variables representing traffic conditions (volume and speed), the presence of intersections and urban characteristics, road layout (curvature radius and gradient) and weather conditions (precipitation) were adopted. These variables include the percentage of heavy traffic (%H_TRAF), average speed (AV_SP), 85th percentile speed (SP_85), percentage of a segment's stretch in intersections (%EXT_I), percentage of a segment's stretch in urban zones (%EXT_UZ), curved stretch (EXT_C), class of curvature (CL_C), class of longitudinal gradient (CL_G) and annual precipitation (A_PREC).

In cluster analysis, the number of groups was determined through a dendogram produced by the hierarchical technique (Figure 2) and then this information was applied in the optimisation technique, with which the composition of the final groups was obtained. In the hierarchical technique, the Ward criterion was selected as the criterion of (dis)aggregation of individuals. In applying the optimisation technique, the iterative partitive k-means was used as a method.

Since the cluster analysis was done with a set of 254 elements (segments), Figure 2 cannot show the distribution of those segments into groups. However, there is a clear trend to form from four to seven groups. The final result was a set of seven distinct road environments, a solution which presented better statistically significant results. Table 2 summarises information about each cluster, necessary to classify each road environment.

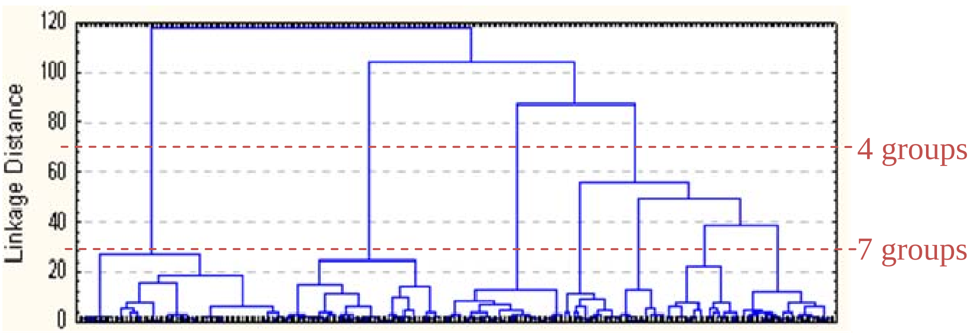

Figure 2: Dendogram produced by the Hierarchical Technique / Ward Criterion

With cluster analysis, one starts with the assumption that the characteristics of each element in each cluster are homogenous. However, while this may naturally occur in some variables, it is not true for all of them. In the final seven groups, some features clearly differentiate the cluster, while others are less important and present some variation (though lower within a group than between groups).

Table 2: Means of variables for each cluster

Variables	Cluster 1 (RE1)	Cluster 2 (RE2)	Cluster 3 (RE3)	Cluster 4 (RE4)	Cluster 5 (RE5)	Cluster 6 (RE6)	Cluster 7 (RE7)	Mean	Standard Deviation
%H_TRAF	26%	4%	8%	7%	10%	9%	9%	10%	6%
AV_SP (km/h)	81	81	84	83	89	94	85	86	5
SP_85 (km/h)	90	90	94	92	91	101	93	94	4
%EXT_I	7.9%	29.2%	2.1%	3.8%	10.4%	7.3%	50.3%	11.7%	19.4%
%EXT_UZ	23%	87%	1%	1%	0%	0%	0%	7%	24%
EXT_C (m)	320	220	41	466	486	471	270	321	264
CL_C	2.3	1.8	0.1	2.2	3.0	2.3	1.7	1.8	1.5
CL_G	0.3	0.0	0.1	0.3	0.8	0.6	0.2	0.4	0.4
A_PREC (mm)	1058	735	591	693	1669	490	722	881	461
Nº of elements	19	15	63	38	55	39	25		

From Table 2, one may conclude the following:

- RE1 differs from the others with its very high percentage of heavy traffic and a significant proportion of urban crossings;
- RE2 is characterised by an extremely high percentage of urban crossings, a low percentage of heavy traffic and segments with no longitudinal gradient;
- RE3 segments are mostly straight, with low annual average precipitation;
- RE4 is characterised by segments with 50% of their stretch curved;
- RE5 is characterised by very high precipitation and segments with 50% of their stretch curved, a longitudinal gradient and a small radius of curvature;
- RE6 is characterised mainly by very low precipitation and speeds above the acceptable speed, and by segments with 50% of their stretch curved with a longitudinal gradient;
- RE7 is characterised by a heavy presence of intersections in rural areas.

3.3 Modelling the expected number of road accidents

Modelling the expected number of road accidents (Naccid/km) was achieved by using generalised linear models in order to assess the influence of pavement surface properties on road accidents. The International Friction Index (IFI) was chosen to represent the pavement surface. The models were calibrated according to two different assumptions:

- In each road environment, segments present homogeneous traffic conditions, road layouts and precipitation, and regression was done with only one explanatory variable, the IFI – RE_IFI;
- In defining road environments, some characteristics were dominant, leading to some heterogeneity among the other variables. For this reason, the regression was made by introducing other explanatory variables into the model (i.e., the same variables used in the cluster analysis) – RE_MULT.

In both cases, the traffic volume was introduced in the model as an “offset variable” to represent exposure to risk. To do this, a variable representative of the total traffic accumulated during the period of analysis, $TRAF_{ACUM}$, was created, Equation 3 represents the general model, where β_i is the regression coefficient associated with each variable.

$$N_{accid}/km = TRAF_{ACUM_i} \times \exp\left(\beta_0 + \beta_1 \times IFI_i + \beta_2 \times \%H_{TRAF_i} + \beta_3 \times AV\_SP_i + \beta_4 \times SP\_85_i + \beta_5 \times \%EXT\_UZ_i + \beta_6 \times \%EXT\_I_i + \beta_7 \times EXT\_C_i + \beta_8 \times CL\_C_i + \beta_9 \times CL\_G_i + \beta_{10} \times A\_PREC_i\right) \quad (3)$$

Over-dispersion, common to this type of analysis, influenced the choice of regression method. Whenever over-dispersion was not negligible, the “overdispersed” Poisson regression proved most appropriate for modelling the frequency of accidents. However, in cases where over-dispersion was insignificant, the Poisson regression was employed. The model was adjusted using historical accident data and the maximum likelihood method was used for calibration. The Wald statistical test was used to evaluate the statistical significance of the estimated coefficients for each explanatory variable.

Table 3 shows models that were calibrated for each road environment. Figure 3 compares the observed number of accidents per km between 1997 and 2002 and the respective numbers modelled by RE_IFI and by RE_MULT. Figure 4 represents absolute residuals, which are slightly higher for RE_IFI than for RE_MULT.

Table 3: Calibrated models

	Models – Expected number of accidents per km
RE1_IFI	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-13,33159143 - 0,07200512 \times IFI_i)$
RE2_IFI	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-13,30480979 - 0,06142634 \times IFI_i)$
RE3_IFI	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-15,03645919)$
RE4_IFI	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-13,15179749 - 0,06462487 \times IFI_i)$
RE5_IFI	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-14,61692487 - 0,03868385 \times IFI_i)$
RE6_IFI	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-10,54165889 - 0,14862363 \times IFI_i)$
RE7_IFI	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-13,10895401 - 0,06231246 \times IFI_i)$
RE1_MULT	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-13,47795416 - 0,07110064 \times IFI_i + 3,97236439 \times \%EXT\_I_i - 0,00176367 \times EXT\_C_i + 0,12736545 \times CL\_C_i)$
RE2_MULT	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-12,29729723 - 0,05282552 \times IFI_i - 15,79183049 \times \%H\_TRAF_i - 0,51636687 \times \%EXT\_UZ_i)$
RE3_MULT	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-20,65217963 - 8,91674072 \times \%H\_TRAF_i + 0,06816295 \times AV\_SP_i + 0,49964424 \times CL\_C_i + 1,10121070 \times CL\_G_i)$
RE4_MULT	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-19,76790052 + 6,31894173 \times \%EXT\_UZ_i - 0,38473111 \times CL\_C_i + 0,00770285 \times A\_PREC_i)$
RE5_MULT	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-20,12119517 + 33,04189428 \times \%H\_TRAF_i + 0,24315918 \times CL\_C_i)$
RE6_MULT	$Naccid/km = TRAF_{ACUM_i} \times exp\ (-12,56629289 - 0,10450580 \times IFI_i + 1,24587417 \times \%EXT\_I_i + 0,23521016 \times CL\_C_i - 0,44545829 \times CL\_G_i)$
RE7_MULT	$Naccid/km = TRAF_{ACUM_i} \times exp\ (12,37636232 - 8,778280935 \times \%H\_TRAF_i + 0,38973746 \times AV\_SP_i - 0,61437746 \times SP\_85_i - 0,00334864 \times A\_PREC_i)$

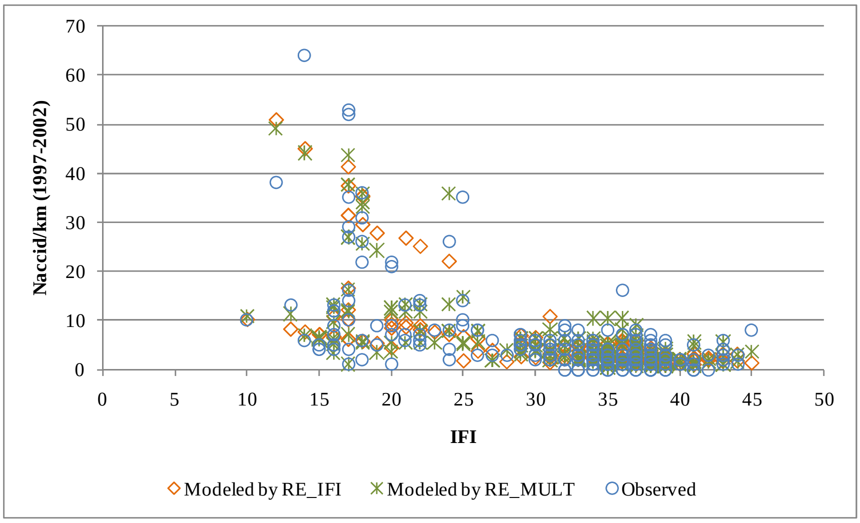

Figure 3: Comparison between the observed number of accidents and the respective numbers modelled by RE_IFI and by RE_MULT

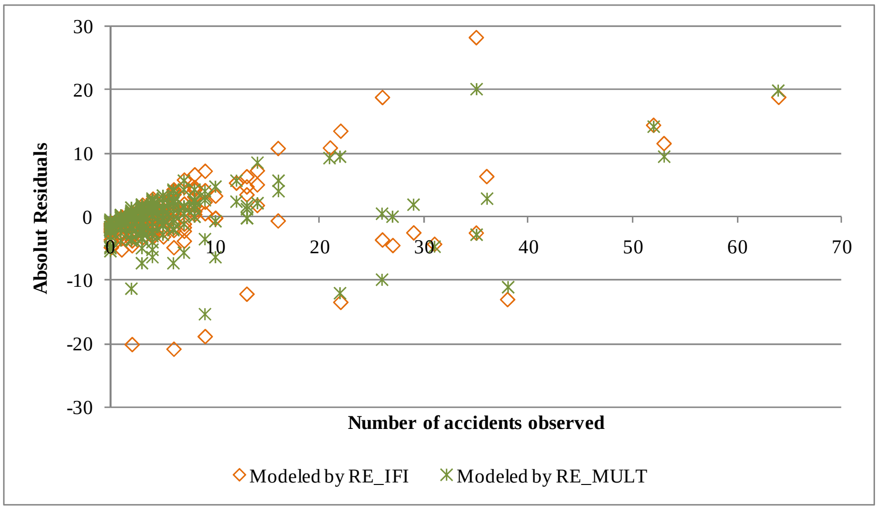

Figure 4: Absolute residuals

The influence of surface characteristics on accident occurrence was evaluated by analysing the coefficients associated with the explanatory variable IFI and measuring the impact that a change in IFI produces in the expected number of accidents.

From this analysis, it was possible to conclude that there are, basically, three environments (E_i) where the pavement properties significantly, yet distinctly, influence the occurrence of accidents:

- E_1: Rural environment with a heavy presence of urban characteristics (e.g., urban crossings and intersections) – RE1 and RE2;
- E_2: Environment characterised by a considerable predominance of intersections in a rural environment – RE7;
- E_3: Environment with curved segments, high longitudinal gradients and average speed higher than the tolerable speed – RE6.

Figure 5 represents the accident risk (Naccid/vehic.km) as a function of IFI where one can see some differences between the three environments. Clearly in E_3, when IFI falls below 30, there is a sharp increase in accident risk, reaching unacceptable levels for values below 22. In environments with urban characteristics (E_1) and intersections (E_2), where braking manoeuvres are often necessary, the permissible IFI values fall to 20 and 25, respectively, while for smaller values a strong increase in accident risk is expected.

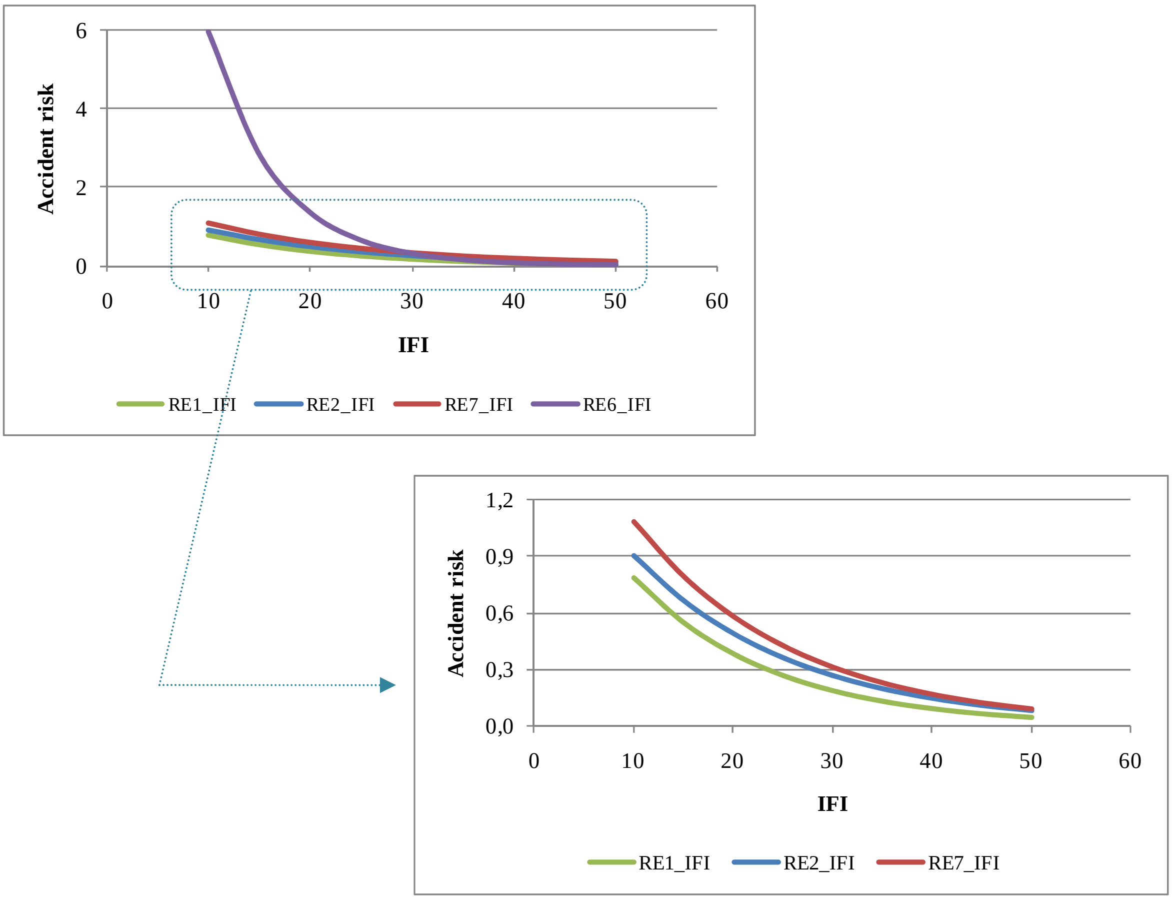

Figure 5: Accident risk and IFI

The IFI, coefficient of friction (CAT) and texture depth (AAE) threshold values for these three environments were established according to these results and by using the relationship between IFI, CAT and AAE, as expressed in Equation 1 and Equation 2. As the Highways Agency (2004) recommends, the values should not be set too low. Therefore, safety values were also set to intervene in a preventive manner. These safety values translate into an increase from the minimum values of 0.1 mm for texture depth, 10 units for coefficient of friction and 3 to 5 units for IFI (Table 4).

Table 4: Threshold values for IFI, coefficient of friction (measured with SCRIM at 60 km/h) and texture depth

	Minimum Values / Safety Values		
	IFI	CAT	AAE (mm)
E_1	20 / 25	40 / 50	0.4 / 0.5
E_2	25 / 28	45 / 55	0.4 / 0.5
E_3	30 / 33	50 / 60	0.5 / 0.6

3.4 Simulation with *Pc-Crash*

Road accident reconstruction is essential for understanding the factors that gave origin to them. The *PC-Crash* programme has proven an effective tool in helping experts in accident reconstruction by simulating the movement and collision of vehicles. The use of *Pc-Crash* in this study was important for assessing the influence of surface properties on vehicular movement, validating and complementing results from the previous modelling step.

The characteristics of the segments selected for simulation are similar to those of the road environments in which they operate. Collision and skidding are the most frequent accident types in the segments under study. To simulate the manoeuvres that cause them, traffic safety was evaluated in three possible scenarios: taking curves, braking on a straight section and braking on a curved section. The simulations were performed by varying the speed and the conditions of friction. To consider the sensitivity of coefficient of friction to speed, the sequence of wet friction was adopted. The results validate and support the minimum values identified in the previous section:

- Taking curves is significantly affected by vehicle speed, curvature radius and coefficient of transverse friction. Skidding occurs when a dangerous combination of factors is observed: high speed (>100 km/h), low friction values (<25 for 60 km/h) and a curvature radius less than 500 m;
- In straight sections, stopping distances are greater in segments with smaller longitudinal gradients. With friction values less than 45 (measured at 60 km/h), there is a slight change of direction during the braking manoeuvre, especially for speeds greater than 90 km/h. For values of approximately 25, there is a trajectory deviation for low speeds and skidding for speeds above 90 km/h;
- In curves, it is possible to immobilise the vehicle safely only with high values friction values.

4 CONCLUSIONS

This work constitutes a further scientific attempt to establish relationships between functional characteristics of pavement and road accidents by using a set of itineraries selected from the Portuguese road network.

In the literature, the cluster analysis used to identify different road environments is presented as innovative and a valid alternative for choosing the segments to be used in road accident prediction models. This methodology has the major advantage of considering compound road environments (characterised by traffic, road layout, weather conditions, etc.), thus seeking to counter the tendency to consider uniform segments that is cited as a limitation of this kind of model.

This approach also has some weaknesses, however. In addition to requiring a careful definition of variables to use in defining the road environment, the groups formed are not, in most cases, completely homogeneous and there is some variation of characteristics within the same group, even if the variation within the group is less than between groups.

Concerning the modelling of the expected number of road accidents, difficulties identified by other authors (Ferrandez, 1993) mostly took place during the calibration process (e.g., problems with statistical significance, over-dispersion and reliability of accident data). Prior to the complex modelling process all precautions were taken in order to ensure that the final output can be used to calculate the benefits associated with the improvement of pavement surface properties to reduce the expected number of accidents.

Results show that road environments where braking manoeuvres (E_1 and E_2) are more common or those with small radii of curvature and high speeds (E_3) require higher skid resistance and macrotexture levels.

The Portuguese Highways Agency recently recognised the importance of research studies to support the development of maintenance programmes for surface characteristics to be incorporated into pavement management systems. This work seeks to contribute a set of values established according to safety criteria for skid resistance and texture depth maintenance.

REFERENCES

EP (2008). *Caderno de Encargos Tipo Obra. 14.03: Volume de Pavimentação - Métodos Construtivos*. Almada: EP - Estradas de Portugal.

EP (2006). *Sistema de Gestão de Pavimentos. Manual de utilização.* Almada: EP - Estradas de Portugal.

Ferrandez, F. (1993). *Analyse des accidents. Infrastructure et securité*. Bulletin de liaison des Laboratoires des Ponts et Chaussées, pp. 19-26.

Gothié, M. (1993). *Influence de l'adhérence sur la securité routière*. Bulletin de liaison des Laboratoires des Ponts et Chaussées, pp. 27-32.

Highways Agency (2004). *HD 28/04: Skid resistance. Design Manual for Roads and Bridges (Vol 7, Section 3)*. London: Highways Agency.

Larson, R. M. (2005). *Using friction and texture data to reduce traffic fatalities, serious injuries and traffic delays*. Surface Friction of Roads and Roadways. Christchurch, NZ.

Murad, M. M. (2006). *Modelling asphalt pavement friction and wet-pavement traffic accidents for two-lane rural highways*. International Journal of Pavements.

Transit NZ (2002). T/10: *Specification for skid resistance investigation and treatment selection*. Transit New Zealand Specifications. Wellington, NZ: Transit New Zealand.