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Road and Rail Infrastructure V

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ACCIDENT PREDICTION MODELS CONSIDERING PAVEMENTS QUALITY

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Abstract

Worldwide, more than 1.25 million people die annually in road traffic accidents and between 20 and 50 million more are injured. By 2030, highway-related crashes are projected to be the 5th leading cause of death in the world. Road accidents have a number of contributing factors, including roadway conditions, vehicle conditions, and factors related to the road users. While some of these factors have been studied extensively by researchers very few focused on quantifying the relationship between accidents frequency and pavement quality. Before 1990s, due to the lack of pavement data collection technology, it was very difficult to carry out statewide scale studies relating pavement quality and road safety. However, in the past decades, there has been a huge growth and awareness in the importance of road safety as a public health issue, leading to a significant increase of research in the topic. Researchers started to study other contributing factors to accidents occurrence such as the pavements quality. Moreover, with the development of high-speed friction measurement tools, agencies can now include friction into network level Pavement Management Systems (PMSs). Therefore, incorporating safety concerns is one of the urgent needs of PMSs, not only in order to optimize the management of the resources but also, and above all, towards the reduction of road fatalities. Despite the fact that there is limited research on the topic, important results were already achieved proving that there is a correlation between the frequency of traffic accidents and variables, which state the condition of the pavement such as friction, macrotexture and microtexture. This article aims to present a short review of the existing literature in Accident Frequency Prediction Models and Modelling Techniques already used or that can be used in PMSs. Moreover, the most interesting Accident Frequency Prediction Models for inclusion in PMSs will be tested with real data provided by a Portuguese Road Agency. The final part of the paper contains the conclusions and presents how these models can be incorporated in PMSs.

Keywords: road, accident prediction model, traffic, pavement quality, friction, macrotexture

1 Accident prediction models a literature review

Road accidents depend on several aspects such as the driver behaviour, the road environment and the vehicle conditions. The development of Accident Prediction Models (APMs) is a key component in the improvement of Road Safety. It allows to identify the factors that cause the accidents and consequently act preventively. Several models were developed or calibrated using traffic, length of the section and in some cases geometric characteristics of the road as explanatory variables.

One of the main references is the RIPCORD-iSEREST Project [1-3]. The goal of this project was to develop best practices guidelines for several road safety tools including APMs. Within the project a State of the Art report [1] was defined. The conclusion was that the Generalised

Linear Models (GLM) should be used in the development of the APMs. In the next phase of the project [2] based on data from Austria, Portugal and Netherlands APMs were developed using GLMs with a Negative Binomial Distribution. Furthermore, a Safety Performance Function was developed [3], based on a three-year period (2003 – 2005) of accidents on the rural road network located in Germany.

Another important reference in this subject is the Highway Safety Manual (HSM) developed by AASHTO [4, 5]. The HSM presents a predictive method for estimating the expected average crash frequency by total crashes, crash severity or collision types. Different multiple regression models called Safety Performance Functions were developed for specific facility types and base conditions. These models depend on just two variables the average annual daily traffic (AADT) volumes and the length of the section. For calibration purposes Crash Modification Factors (CMFs) and a Calibration Factor (C) were also developed. Several reports [6-8] providing guidelines on the implementation of the methods and procedures were writen as a complement of the HSM.

In the RISMET Project [9] several APMs for rural junctions based on data from Norway, Austria, Portugal and Netherlands were developed. Within the project an APM with a Poisson Regression Model based on the road network of the German federal state Brandenburg was developed [10]. The model was then tested on the Portuguese Road IP4 resulting in significant differences in the number of accidents predicted. Researchers justified the fact with the need of calibrating the model to the Portuguese conditions. Other important relevant initiatives are:

- ROSEBUD Handbook [11], assessing user related, vehicle related and infrastructure related measures, by application of Cost-Effectiveness Analysis (CEA) or Cost-Benefit Analysis (CBA);
- SUPREME research project [12, 13], identifying best practice in road safety measures;
- Handbook of Road Safety Measures [14], which includes a systematic overview of current knowledge regarding the effects of road safety measures and Crash Modifications Factors (CMFs);
- CEDR Reports [15, 16] investigating in depth specific road infrastructure safety measures;
- “Countermeasures That Work” guide [17], aimed primarily to legislation, enforcement, training and communication measures and secondarily to infrastructure treatments;
- PRACT Project [18] aimed to develop an European Accident Prediction Model (APM) that could be applied to different European road networks with a proper calibration.

The Web-Based Databases and Road Safety Toolkits are also an extra extremely useful tool to the Road Safety Managers. The most recognised ones are: the FHWA CMF Clearinghouse; the Austroads Road Safety Engineering Toolkit; and the iRAP Road Safety Toolkit.

More recently, researchers started to study other contributing factors to accidents occurrence. The introduction of the Condition of the Pavements as a new explanatory variable represented a step forward in the Incorporation of Road Safety into Pavement Management. The parameters describing the texture of pavement are very important for a comprehensive assessment of skid resistance, which is defined as the frictional resistance at the interface between a vehicle tyre and the road surface. The measure of skid resistance is the friction coefficient, closely related to the surface texture. The surface texture ensures draining water from the tire-pavement interface area. The role of skid resistance in road safety becomes particularly relevant when the pavement is moist or wet. Microtexture is defined by the resistance to polishing of coarse aggregate and the content of particles smaller than 2 mm in the aggregate mix used for the wearing course. It corresponds to a wavelength below 0.5 mm and it is assessed indirectly based on Polished Stone Value (PSV) and by measuring the friction coefficient at low slip speed (10-20 km/h) in-situ. Macrotexture is characterized by the type of surface layer and by the particle size distribution of the aggregate mix used. It corresponds to deviations from a flat plane having wavelength between 0.5 and 50 mm. Macrotexture parameters include Mean Texture Depth (MTD) determined by the volumetric method and Mean Profile Depth (MPD) derived from profilometric analysis. Both microtexture and macrotexture evolve under the effect of traffic and weathering. The most rapid evolution of the friction coefficient occurs in the early life of using road pavements after which it stabilizes. In the latter period changes to the friction coefficient are of seasonal nature and depend on the climate zone. Roughness is the largest scale with characteristic wavelengths of 0.1–100 m and it is defined as the irregularities of the pavement surface caused by cracking, rutting, ravelling and potholing. It is measure by the International Roughness Index (IRI) and when presents high values may cause the lost of control during braking and steering. When pavement roughness increases the contact area between tires and pavement decreases leading to a lower brake friction [19]. The Present Serviceability Index (PSI) is a numerical index, which is indicative of the ability of the pavement to serve traffic at any particular time during its service life. PSI plays a significant role in evaluating pavement safety. In Europe, the evaluation of road safety measures appears to be the weakest component of PMSs. Only in few countries the evaluation of road safety measures is part of a routine activity with a dedicated budget. Similarly, in the United States almost all states do not use the safety analysis in their Pavement Management Systems. In Table 1 some of the studies on the development of APMs considering Pavement Condition parameters as explanatory variables are presented.

Table 1 Summary of the Models Considering Pavement Condition

Model	Reference	Modelling Technique	Independent Variables	Dependent Variables	Results
1	[25]	Hierarchical Tree-Based Regression Models	Geometric Design, Pavement Condition	Traffic Crash Rates	Geometric design and pavement condition variables are key factors
2	[26]	Simple and Multiple Linear Regression Models	Friction	Wet-Weather Crashes	Skid resistance is statistically significant Friction data explain only a small portion of the variation
3	[27]	Poisson Regression Models	Friction, Texture Depth, IRI, Rut Depth, Road Geometry, Roadway Characteristics	Crash Risk	Strong correlation between skid resistance and crash rate
4	[28]	Simple Linear Regression Models Multivariate Linear Analysis	Friction, Macrotexture, IRI, AADT	Wet-Weather Crashes	Poor statistical correlations
5	[19]	Negative Binomial Regression	AADT, Right Shoulder Left clearance, PSI, IRI, Rut Depth	Crash Frequency Crash Types	Rut Depth was not significant Due do collinearity, PSI and IRI cannot be applied in the same model
6	[29]	Random-Parameters Count Models	IRI, Pavement Condition Rating	Accident Frequency	
7	[30]	Negative Binomial Regression Models	IRI, Ruth Depth, PSI	Number of Accidents	IRI had a significant influence
8	[31]	Negative Binomial Regression Models	Friction, Pavement Condition	Crash Severity	
9	[32]	Multivariate Tobit Model	Pavement Condition	Crash Rates by Severity Levels	Road condition is a significant factor Effects on collisions was found to vary significantly across roadway segments
10	[23]	Negative Binomial Regression	Grip Number	Crash rates	Grip Number is significant Amount of savings obtained by preventing crashes has very high potential
11	[33]	Bayesian Ordered Logistic Regression Model	Road Condition Index	Crash Severity Levels	Severity levels of most crash types can be reduced when the pavement condition is well maintain

2 Modelling techniques for safety analysis

The modelling techniques for safety analysis can be divided mainly in: Statistical models, Numerical models, Traffic conflict analysis and Simulation models. For the purpose of this work only statistical models will be referred. Statistical Models study the relationships between the number/severity of crashes with the main safety-related factors. These models are divided into 3 types: Crash count models (or quantitative response models), Crash severity models (or qualitative response models) and the combination of both. A comprehensive review on different statistical methods for crash count modelling can be found in [20]. With regard to the evolution of methodological alternatives in accident research, the frequency of crashes has been studied with a wide variety of methods over the years. Because crash frequencies are count data (non-negative integers), the Poisson Regression models have served as a basis in the development of APMs. As research progressed, due to the limitations of the simple Poisson regression models Poisson variants started to be applied. The Negative Binomial model (or Poisson–Gamma) became widely used because it can handle over dispersed data. Another approach was looked at crashes not as count data per se, but instead as the duration of time between crashes (duration models), which in turn can be used to generate crash frequencies over specified time periods [21]. Recently, a series of studies have recast Count Models as a restrictive case of a Generalized Ordered-Response model. For the multiple discrete outcome models, multinomial models that do not account for the ordering of injury outcome such as the Simple Multinomial Logit model, the Nested Logit model, and the Random Parameters Logit model have been widely applied. Modelling approaches that do consider the ordering of injury severities, such as the Ordered Probit and Logit model, have also been applied to overcome possible restrictions imposed by traditional ordered-modelling approaches [21].

3 Application of the APMs to the Portuguese data

After the analysis of the previous research concerning the development of APMs, the next step was to try to apply some of the models to the Portuguese data. The data used is from a main Portuguese highway divided in 5 sections. It is related to the years 2009 and 2013. Although, more data related to the accidents was available the data related with the Pavement Condition was not. The models tested [19-24] are defined in the following Equations (1-4):

$$NAcc = 4.07 \times \ln(AADT)^{0.655} \times \exp^{(-0.345 \times PSI)} \quad (1)$$

$$NAcc = AADTacc \times \exp^{(-13.25672714 - 0.06660080 \times IFI)} \quad (2)$$

$$CrashRate(10^8 veic \cdot km) = L \times \exp^{(-0.35 + 1.25 \times \ln(AADT) - 1.19 \times GN)} \quad (3)$$

$$CrashRate(10^6 veic \cdot km) = 0.103 \times \exp^{(2.156 \times -IRI)} \quad (4)$$

Where NAcc is the expected number of accidents, AADT is the annual average daily traffic, PSI is the Present Serviceability Index, AADTacc is the accumulated annual average daily traffic, IFI is the International Friction Index and GN is the Grip Number. Crash Rate is defined in Equation (5).

$$CrashRate = \frac{\text{Number of Accidents}}{AADT \times 365 \times years \times Length} \quad (5)$$

4 Discussion of results and conclusions

In Table 2 are presented the number of accidents observed and also the predictions using the different models. Model 1 predicts very similar results between the sections, which could make sense, since the values of PSI are also very similar. However, this model presents some differences to the observed values. Model 2 presents a wider range of number of accidents predicting more accidents than the observed ones. Model 3 predictions are similar to the observed values showing that there is a correlation between the number of accidents and the GripTest measurements. Model 4 is the one which presents a higher difference between the observed values and the predicted by the model. In this case the number of accidents predicted is much higher. Therefore, it can be concluded that in order to apply these models to the Portuguese data a calibration procedure is essential. This work aimed to contribute to the incorporation of road safety into pavement management through the study of different APMs. The main conclusion is that the availability and quality of the data is crucial to the development/calibration of the models. In the case of missing data or poor data the final models only will have a few explanatory variables and will present a very limited accuracy in their predictions. However, the development and implementation of APMs into PMSs is considered extremely important towards the reduction of road fatalities.

Table 2 Results obtained for the different models

Nº ac. obs.	Nº ac. pred. (1)	Nº ac. pred. (2)	Nº ac. pred. (3)	Nº ac. pred. (4)
5	4.2	7.2	4.1	14.3
7	4.3	7.2	4.1	18.1
4	4.4	2.9	1.4	17.4
3	4.0	2.9	1.4	6.8
1	4.5	7.0	0.9	6.6
1	4.5	7.0	0.9	6.1
2	4.9	3.7	0.5	11.2
1	4.5	3.7	0.5	4.7
3	4.4	5.0	2.1	19.3
1	4.3	5.0	2.3	16.6
2	4.1	2.5	1.0	8.2
2	4.8	7.5	2.4	22.4
2	4.3	7.5	2.2	9.3
2	4.2	3.1	0.8	5.4
5	4.3	5.7	2.1	12.3
3	4.1	5.7	2.2	8.9
1	4.1	2.6	1.0	6.2

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