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Traffic noise and pavement distresses: Modelling and assessment of input parameters influence through data mining techniques

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ABSTRACT

Traffic noise affects greatly health and well-being of people, consequently the knowledge and control of the factors affecting it is very important. In this study models to predict tyre-pavement noise acoustic and psychoacoustic indicators based on type of pavement, texture, pavement distresses and speed were developed and used to assess the importance of each factor. By applying data mining techniques, in particular artificial neural networks and support vector machines, models with good predictive capacity of both acoustic and psychoacoustic noise indicators were obtained, constituting a precious tool to reduce the tyre-pavement noise. Moreover, the proposed models allowed for the assessment of the influence of the input parameters controlling noise such as: type of pavement, texture, speed and pavement distresses for the first time. It was found that pavement distresses and, as expected, speed influence strongly tyre-pavement noise. In this way it is clearly shown that preventive maintenance of road pavements by authorities, which eliminates distresses, can have an important effect on tyre-road noise, promoting the well-being of the populations.

1. Introduction

The high population growth rate in urban and metropolitan areas has led to an exponential increase in car traffic in these areas leading to a substantial increase in noise. This noise is a major concern for populations given its negative impact on their health. Traffic noise may affect the mental health and sleep quality [1–3]. In addition, it is a risk factor for hearing, cardiovascular diseases and diabetes [4–7]. Taking into account these concerns of the populations the car manufacturers have been reducing the noise of the motors to very low levels, becoming more significant the noise caused by the tyre. Therefore, it is very important to study the tyre-pavement noise.

The tyre-pavement noise is influenced by a number of factors, namely driver behaviour, tyre characteristics, pavement surface characteristics and climate [8]. The speed of the vehicle has a strong influence on annoyance regardless the type of pavement, as well as the traffic composition, where higher densities correspond to higher annoyance rates [9]. However, with successive vehicle pass-bys and climatic variations, after a certain period of time, road pavements start to develop different types of distresses or pathologies, such as cracks and alligator cracking, rutting, potholes, ravelling, among others [10].

In the period of use up to the development of the first distresses, the tyre/road noise increases with different rates depending on the pavement type. Some studies report very important increases of noise levels in the first years of use [11,12] caused by the wearing of the tyres that removes the asphalt film from the aggregates, changes in texture, clogging and stiffness.

Although the surface characteristics are considered one of the influent factors in tyre-pavement noise, there are no studies relating the existing pathologies on the surface with tyre-pavement noise.

The existing pathological conditions on the surface of the pavement, besides causing discomfort to the drivers and increasing accident risk, appear to influence road traffic noise due to the perceptible intensification of tyre vibrations, which is expected to increase the auditive discomfort of road users. In order to demonstrate what is currently perceived by road users, a detailed acoustic study of distressed pavements is essential, therefore psychoacoustic indicators should be considered. There are three key factors associated with this type of studies: type of pavement, traffic speed and level of pavement distress. In this context, the aim of this study was to develop a tyre-pavement noise prediction model, with the traffic speed, the type of pavement and the existing pathological conditions on the pavement surface as inputs and as outputs the equivalent sound pressure level in decibels (dB) (L_{eq}), A-weighted equivalent mean sound pressure level (L_{Aeq}) and the A-weighted maximum sound pressure level (L_{Amax}) and also the psychoacoustic indicators such as Loudness, Roughness and Sharpness. In

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addition, it was intended to evaluate the influence of pavement distresses in the traffic noise.

For this purpose, data mining (DM) techniques were used. DM is a step of Knowledge Discovery in Databases (KDD) aiming at the extraction of useful patterns from observed data. The KDD process can be resumed in five main steps: data selection, pre-processing, transformation, DM and interpretation [13]. There are several DM algorithms. Artificial Neural Network (ANN), Support Vector Machines (SVM) and Multiple Regressions (MR) were used in this study.

2. Literature review

Early models of traffic noise prediction appeared in the 1950s [14]. Since then many models have been developed. Also, in the last few years there has been interest in developing predictive tyre-road contact noise models. As this article is focused on the application of data mining techniques to assess the influence of distresses on tyre-road noise, only the models related with these techniques will be treated here. Readers are encouraged to consult Refs. [14–17] that constitute a relevant contribution to the literature review. Most of the models presented in the literature are based on linear relationships between the considered parameters. Therefore, these models fail to capture the complex relationships between the involved parameters. Hence, the development of models based on data mining techniques.

Cammarata et al. [18] proposed an instrument for modelling and filtering urban noise by using neural networks. They used a learning vector quantization (LVQ) network as a filter of wrong measurements before the use of a backpropagation network (BPN) for the prediction of the sound pressure level, L_{eq}. They adopted as input parameters the number of cars, the number of motorcycles, the number of trucks, the average height of the buildings facing the road, and the width of the road. The results were compared with classical solutions to noise prediction and validated using data belonging to several medium and small-size towns. They point out the versatility of the BPN and its good capacity to predict the sound pressure level.

Nedic et al. [19] applied artificial neural networks for the prediction of traffic noise descriptor, L_{eq}. The number of light motor vehicles, the number of medium trucks, the number of heavy trucks, the number of buses and the average traffic flow speed were the input variables. It was shown that the artificial neural networks can be a useful tool for the prediction of noise with sufficient accuracy and that ANN model has much better capabilities to predict traffic noise level than any other statistical methods.

Kumar et al. [20] developed an ANN model to predict the highway noise descriptors, 10 Percentile exceeded sound level (L_{10}) and equivalent sound level (L_{eq}). The model input parameters are total vehicle volume/hour, percentage of heavy vehicles and average vehicle speed. Results obtained with ANN approach were compared with regression analysis and with the field measurement. They concluded that ANN approach is better than regression analysis and constitutes a powerful technique for traffic noise modelling.

Garg et al. [21] developed two ANN models to predict equivalent continuous sound level (L_{Aeq}) and 10 Percentile exceeded sound level (L_{10}) generated due to traffic noise. Eight input parameters, denominated number of two-wheelers, three-wheelers, cars, medium commercial vehicles, buses, trucks, average speed of heavy vehicles, and average speed of light vehicles were considered. The conclusions indicated that proposed models are able to produce accurate predictions of hourly sound levels in the urban environment.

Singh et al. [22] developed models to predict the equivalent sound level, L_{eq}, based on soft computing methods, namely, Generalized Linear Model, Decision Trees, Random Forests and Neural Networks. The input variables include the traffic volume per hour, percentage of heavy vehicles and average speed of vehicles. The Random Forest model gave the best results and the potential of using this method for traffic noise with accuracy and stability is highlighted by the authors.

Hamad et al. [23] employed artificial neural network technique to model L_{eq} in a city with known hot climate, namely Sharjah City in United Arab Emirates. They used the following inputs: Distance from the edge of the road in meters, hourly light-vehicle volume, hourly heavy-vehicle volume, average speed in km/h and roadway temperature. They ran several ANN models and compared the best-performing ANN models with two conventional models. In general, results showed that ANN models outperformed the conventional models.

Bravo et al. [24] presented a methodology, which allows to train an ANN model properly, in order to predict the willingness to pay (WPT) range to reduce road traffic noise annoyance within a given population. They performed a socio acoustic survey that collects the WTP of the respondents and adopted as input variables characteristics such as environmental noise perception of the respondents, modelled day-night noise exposure level (*LDN*) at the facade of their dwellings, and the respondents' demographic and socioeconomic status. The developed model predicts, with precision and accuracy, a range for willingness to pay from subjective assessments of noise, a modelled noise exposure level, and both demographic and socio-economic conditions.

From real-time acoustic analysis of tyre/road noise, Alonso et al. [25] proposed an asphalt status (dry/wet) classification system using support vector machines. They reported very high success rates. Freitas et al. [17] modelled tyre-road noise measured by the close proximity method (CPX) with Speed, Temperature, Aggregate size, Mean Profile Depth and Damping at 800 Hz and 2000 Hz as inputs. The support vector machine and artificial neural network algorithms showed high quality predictive performances.

Masino et al. [26] applied support vector machines to predict different types of road surfaces from tyre noise. Their approach took multiple features based on the power spectral density (PSD) of time series data of the tyre cavity sound under vehicle operation as input. Tests of the classifier revealed an accuracy above 90%.

3. Materials and methods

3.1. Road stretches

A total of 21 road stretches with different distresses, inserted in 6 national roads, were selected: 6 stretches in thin Gap Graded Asphalt (GGA), 8 stretches in Asphalt Concrete (AC) and 7 stretches in Gap Graded Asphalt Rubber (CGAR). The distresses chosen were the alligator cracking (high severity), cracking (medium severity) and ravelling, shown in Figs. 1–3, which are typical of urban areas. Also, a stretch of each pavement without distresses was considered for reference. In Table 1 are presented all the combinations used. At least two pass-bys were done in each stretch over each distress. The sounds registered by both microphones were included in the analysis.

Fig. 1. Example of pavement with alligator cracking.

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