



An ANN model to correlate roughness and structural performance in asphalt pavements



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HIGHLIGHTS

- Proposal of a neural network method to correlate roughness and structural capacity.
- Adoption of an LTPP-based database, including many influencing parameters.
- Comparison of various networks to analyse the method potential.
- The method can reduce traditional deflection tests (HWD, FWD) frequency for PMSs.

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ABSTRACT

In this paper, using a large database from the Long Term Pavement Performance program, the authors developed an Artificial Neural Network (ANN) to estimate the structural performance of asphalt pavements from roughness data. Considering advantages of modern high-performance survey devices in the acquisition of road pavement functional parameters, it would be of practical significance if the structural state of a pavement could be estimated from its functional conditions. To differentiate various road section conditions, several significant input parameters, related to traffic, weather, and structural aspects, have been included in the analysis. The results are very interesting and prove that the ANN represents an adequate model to evidence this relation. The papers shows the effectiveness of the adoption of a large database for the analysis of the correlation. ANN provides also better results in comparison with Linear Regression. Further, the authors trained three different ANNs to analyse the effects of modified datasets and different variables. The numerical outcomes confirm that, by using this approach, it is possible to correlate with good accuracy roughness and structural performance, allowing road agencies to actually reduce the deflection test frequency, since they are generally more costly, time consuming, and disruptive to traffic than functional surveys.

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1. Introduction

Assuring good conditions to the pavement allows users to drive with acceptable comfort and safety levels. However, in order to guarantee high quality standard, road agencies have to monitor the performance parameters of the entire network frequently and to adopt the most proper maintenance operations where needed. Indeed, continuous collection of new data regarding pavement conditions is a strategical operation to update Pavement Management Systems (PMSs) and optimize network maintenance and agency funds. Pavement performance parameters are also very

numerous and diversified (structural and functional parameters). Since surveys to be performed are very different and numerous, this represents a very expensive and time-consuming task. Today it is relatively economical to perform roughness or distress measurements through high-speed profilometers or laser-lightning detection systems [31,29]. However, deflection data collection by means of Falling Weight Deflectometer (FWD) or Heavy Weight Deflectometer (HWD) is slow, with high unit costs, and adverse effects on traffic due to the stop-and-go procedure [14,26].

To overpass this limitation, many researchers have tried to analyse various performance indicator (roughness, distresses, structural capacity, etc.) and to identify some useful correlation among them [3,23,32,7,11]. In this way, it would be possible to estimate the value of some indices performing other surveys,

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reducing then the frequency of the slowest and most expensive ones. The most interesting and remarkable relationship should exist between roughness measurements and the pavement structural performance. It is known that roughness and irregularities are related to deterioration of the pavement structural capacity and, if a pavement structure is not designed adequately, roughness would increase quickly [26]. Moreover, attention should be paid on overlay and maintenance operations that can alter the relationship, since they can immediately reduce roughness, without improving the pavement structural capacity significantly. However, despite some research attempts, it is not easy to analytically develop this relationship. In a report for proposing a novel index describing structural adequacy, Zhang et al. [36] combined data to visualize a possible trend between some deterioration variables (including also ride quality) and structural parameters, but they did not establish any analytical relationship between them through linear regression or other mathematical methods. The most significant contribution on the topic was provided by an FHWA report [26], in which several highway sections were studied to find a numerical relationship between International Roughness Index (IRI) and Structural Number (SN). The researchers investigated a performance data set from the Long Term Pavement Performance (LTPP) program, but did not find any relationship neither in the parameter values nor in their change rates. They concluded that good ride quality does not mean good structural adequacy and that it is very hard to find a simple relationship between IRI and SN excluding most other factors. Bianchini and Bandini [6] suggested a Neuro-Fuzzy model for prediction of pavement performance (in terms of Pavement Serviceability Index) in Minnesota asphalt pavement roads, considering deflection and distress data, with acceptable results, but the study did not analyse directly the correlation between roughness and SN.

In this paper, the authors propose a different approach to attest the relationship existing between roughness and structural performance on asphalt pavement. In detail, analysing and combining a large set of data from the LTPP program, the authors have trained an Artificial Neural Network (ANN) to find an analytical and reliable correlation between roughness and structural capacity. Roughness has been measured using IRI, while the structural performance of the pavement has been evaluated through the effective SN (SN_{eff}). According to the procedure proposed in the AASHTO Guide [1], SN_{eff} has been calculated from deflection measurements. The ANN has been trained using a large data set of input parameters, to differentiate various scenarios and take into account numerous relevant aspects, such as traffic, weather, and structural conditions. In the paper, for more clarity, various networks are presented, considering several data samples and different groups of sections. For all the networks, training results and numerical validations are provided. In general, the numerical outcomes are useful to analytically demonstrate the connection between structural performance and roughness and the ANN resulted an adequate method for studying the problem, with better results than a classical linear regression approach.

2. Theoretical notes on ANNs

ANNs are recent computational models defined in analogy with the biological characteristics to simulate the decision process in the brain. They are useful to approximate and estimate unknown functions depending on various and numerous input values. One of the main characteristics of this approach is that it represents a way to solve very complex and nonlinear problems using only very simple mathematical operations [25,18]. In particular, ANN can be considered as a “black-box” approach, since the results are produced with no regards to the causal relationships between input

and output [28]. The method potentiality is fully exploited when adopted for big data analysis and it can be used to develop generalized solutions to problems using large set of example data [15]. Like the brain, the ANN is made up of various interconnected neurons, which receive input, process the information, and produce output for other linked neurons.

Many papers presented application of ANNs in different areas of civil engineering with good results. Among all, ANNs were adopted for structural, construction, environmental, geotechnical and infrastructure engineering. Adeli [2] reviewed the ANN state of the art in the 90's. Concerning the infrastructures, Ceylan et al. [10] presented a recent survey on ANN application in pavement engineering. Eldin and Senouci [13] proposed an ANN for rating highway pavement conditions, while Terzi [30] presented a model for predicting PSI considering distresses. Roberts and Attoh-Okine [27] used different kinds of ANNs to produce prediction of pavement performance in terms of IRI, while Kirbaş and Karaşahin [20] compared ANN to regression analysis and multiadaptive regression slides for determining pavement performance models in terms of PCI. Attoh-Okine [5] adopted an ANN model to evaluate pavement conditions from distresses grouping different relevant pavement condition variables, while Owusu-Ababia [22] suggested a procedure to estimate evolution of crackings. Plati et al. [24] adopted an ANN to evaluate pavement structural condition from FWD data. La Torre et al. [21] tried to predict roughness on highway pavements by means of ANN, but this technique can be also adopted for crack recognition [35]. Other interesting approaches in infrastructure engineering were proposed for the analysis of the factors influencing the compaction phase [4], for the evaluation of the driver's visual perception [8], for maintenance cost estimation and prioritization [16,9,33], for pavement friction management of airport runways [17], and for the aging analysis of asphalt binders [34].

Multilayer Feed-forward Neural Network (MFNN) is the most widely used type of ANN. An MFNN is characterized by three kinds of layers of interconnected neurons: input, hidden, and output layers (Fig. 1a). Each neuron processes the received inputs and, according to a properly defined activation function, produces an output (Fig. 1b) that is transmitted to neurons in the following layer through specific connections defining the network topology. Each connection is associated to a specific weight (w_i) that amplifies or reduces the input. For the single neuron, the relationship existing between inputs (x_i) and output (y_i) is defined using a specific transfer function that usually has the logistic sigmoidal shape (Eq. (1), Fig. 1c).

$$f(I) = \frac{1}{1 + e^{-I}} \quad (1)$$

where $I = \sum w_i x_i$ is the sum of the weighted inputs x_i produced by the previous neurons.

In a “supervised approach” – such as MFNN –, given a large set of input and output data, the training procedure consists in the modulation of the various weights to produce acceptable outputs. The results should be very similar to the output provided for training. Usually, the training phase is performed using a back propagation model [19,12] that allows the network to adjust the weights in a reverse direction, distributing the error among the various neurons and minimizing it after each iteration. Levenberg-Marquardt is the most used training algorithm and, generally, the error is evaluated in terms of Mean Square Error (MSE). If a set of N records is considered MSE can be evaluated using Eq. (2).

$$MSE = \frac{1}{N} \sum_{i=0}^n (e_i)^2 = \frac{1}{N} \sum_{i=0}^n (t_i - p_i)^2 \quad (2)$$

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