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Prediction of pavement roughness using a hybrid gene expression programming-neural network technique

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ABSTRACT

Effective prediction of pavement performance is essential for transportation agencies to appropriately strategize maintenance, rehabilitation, and reconstruction of roads. One of the primary performance indicators is the international roughness index (IRI) which represents the pavement roughness. Correlating the pavement roughness to other performance measures has been under continuous development in the past decade. However, the drawback of existing correlations is that most of them are not practical yet reliable for prediction of roughness. In this study a novel approach was developed to predict the IRI, utilizing two data sets extracted from long term pavement performance (LTPP) database. The proposed methodology included the application of a hybrid technique which combines the gene expression programming (GEP) and artificial neural network (ANN). The developed algorithm showed reasonable performance for prediction of IRI using traffic parameters and structural properties of pavement. Furthermore, estimation of present IRI from historical data was evaluated through another set of LTPP data. The second prediction model also depicted a reasonable performance power. Further extension of the proposed models including different pavement types, traffic and environmental conditions would be desirable in future studies.

1. Introduction

Performance indicators are widely used to evaluate pavement condition and serviceability. Most notably, parameters such as the Present Serviceability Index (PSI), Pavement Condition Index (PCI), and IRI are commonly used in performance assessment. IRI, in particular, is a primary performance measure that is often employed by highway agencies to predict pavement performance. The present study aims at employing LTPP data for the development of IRI prediction modeling through the use of a hybrid GEP-ANN technique.

The IRI is a World Bank sponsored performance indicator that was developed during the International Road Roughness

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Experiment (IRRE) in 1982. The IRI was conceived to provide a common global measurement for pavement roughness comparison. The IRI of a pavement is defined as the average rectified slope (accumulated suspension motion to distance traveled) as derived from a mathematical model of a standard quarter car passing over a measured profile at a speed of 50 mph (Ozbay and Laub, 2001). The roughness or smoothness of the pavement is a comprehensive assessment indicator that takes into account not only both ride quality and comfort of the pavement, but also serving as an indicator of the presence of collective distresses. As the pavement ages, the roughness or IRI of the pavement increases, representing deterioration. IRI is a primary mode of assessing pavement condition, as Wang et al. (2007) stated, and one of the main functional performance indicators used by the Mechanistic-Empirical Pavement Design Guide (MEPDG).

The health state of the pavement can be evaluated by closely observing the type and amount of present distresses, examining the material properties of the pavement structure, and estimating the construction quality. Unfortunately, this particular method of evaluation is neither practical nor cost-effective for both project and network level analysis of pavements. Therefore, models have been developed to forecast pavement performance using performance measures, such as IRI. Various methods of IRI prediction modeling have been practiced in the literature. Given the variable characteristics of pavement structures and data collection methods, it is understood that no single model can be successfully applied to all pavements. The structure of prediction model is dependent on the type and amount of historical performance data available.

Current MEPDG-IRI prediction models are actually a by-product of traditional regression statistical analysis (Wang et al., 2007). It is a function of traffic, material, geometric and climatic conditions derived from the LTPP database (Schram and Abdelrahman, 2006). There are some discussions that IRI prediction modeling through regression analysis may not be the ideal method, given the complex relationships between the model variables and actual pavement performance. Choi et al. (2004) discussed that the relationships between material, construction variables and pavement performance measures were too complex and poorly understood to be explained by traditional statistical methods.

Apart from traditional regression analysis, other techniques have been employed for pavement performance modeling. One example is the use of gray theory for IRI prediction. Jiang and Li (2005) employed LTPP datasets to perform a comparison between gray relational models and the MEPDG regression models. They found that in different cases, gray relational models offered better IRI predictions, while utilizing less distress parameters than the MEPDG counterpart. The use of artificial neural networks for modeling infrastructure deterioration is being popular and various studies have been performed to assess their effectiveness. A roughness prediction study by Attoh-Okine (1994) remarked that employing ANN roughness prediction models were feasible and could be the basis for developing a generic intelligent pavement deterioration process. Later, Attoh-Okine et al. (2003) developed a method for pavement roughness prediction using multivariate adaptive regression splines (MARS) which allowed finding the relative significance of pavement condition, traffic and environmental parameters. Kargah-Ostadi et al. (2010) developed an ANN-based pattern-recognition model to predict IRI for flexible pavement rehabilitation sections in a wet-freeze climate using LTPP database.

The World Bank has developed a roughness prediction model through the Highway Development and Management (HDM) program in which five factors contributed the most: cracking, rutting, potholes, environmental conditions and structural deterioration (Odoki and Kerali, 2000).

Von Quintus and Killingsworth (1997) conducted a study on LTPP data to find relationships between deflection time-history data and pavement conditions such as IRI. Rada et al. (2012) contained a comprehensive review of IRI prediction models while trying to correlate ride quality and structural adequacy of pavement structures using LTPP database. Stubstad et al. (2012) developed a stochastic approach for understanding and assessing deflection data for network-level pavement management systems (PMS) including IRI models.

The focus of this study is to couple genetic programming and artificial neural network for IRI prediction on a dataset collected from the LTPP database. The first part of this study includes developing a hybrid approach for prediction of IRI from pavement structure and traffic parameters. Thereafter, historical roughness data along with the traffic and structural conditions are employed to predict the roughness.

2. Methodology and database

The LTPP program was initiated as a part of the Strategic Highway Research Project (SHRP) in 1987 and was expanded to a twenty-year program under the coordination of the Federal Highway Administration (FHWA). The main objectives of this program are to improve and develop a designed process for new and rehabilitated pavements, evaluate existing pavement conditions, develop methodologies for improving existing design and maintenance processes, and determine the effect of the construction processes, environmental criteria, traffic and the materials properties on the structural performance of flexible and concrete pavements (Elkins et al., 2003).

The LTPP information management system (IMS) is a comprehensive pavement management database documenting historical performance data for over 2500 in-service and monitored test sections spanning across North America. Different types of information are stored within the database in the form of seven modules: inventory, maintenance, monitoring, rehabilitation, material testing, traffic, and climatic data. The datasets collected for this study was extracted from the LTPP data documented for states of Indiana, Iowa, Maryland, New Jersey, New York, Tennessee, Arkansas, and Oklahoma in the United States, New Brunswick and Prince Edward Island in Canada. From the extracted data, those sections with asphalt concrete over unbound granular layers were selected to analyze. Such database was extracted from the study performed by Ozbay and Laub (2001).