Construction and Building Materials 116 (2016) 281–288

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Performance models for hot mix asphalt pavements in urban roads

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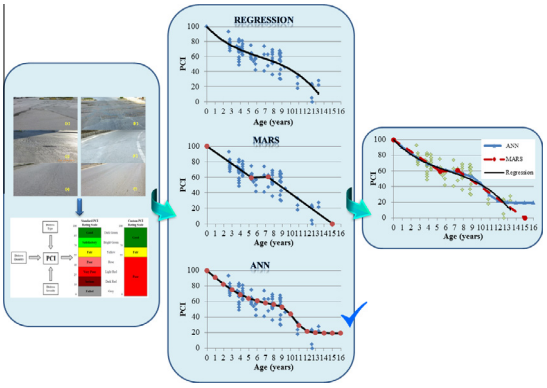
HIGHLIGHTS

- Pavement deterioration models were developed for HMA paved road sections in urban roads.
- The models used were deterministic regression analysis, MARS and ANN.
- The ANN method was found to be the most appropriate model for predicting deterioration.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 November 2015
Received in revised form 14 April 2016
Accepted 26 April 2016

Keywords:
Flexible pavement
Deterioration model
Performance prediction
PCI
Hot mix asphalt

ABSTRACT

The correct budget allocation for road maintenance, which represents a significant infrastructure investment in urban roads, requires the accurate prediction of the deterioration of bituminous hot mix asphalt (HMA). In this study, three different deterioration models have been developed that can predict the future performance of pavements in urban HMA paved roads. First, the current condition of the pavements was measured by using the pavement condition index (PCI), which is approved by the PAVER system. Then, three different models were developed to predict deterioration in the PCI as a function of pavement age, and applied to urban road networks in Samsun (Turkey). The models used were deterministic regression analysis, multivariate adaptive regression splines (MARS) and artificial neural networks (ANN). Variations of each model were explored and the one with the highest computational efficiency was employed for ranking pavement sections with respect to rehabilitation needs. Results indicated that the three approaches had comparable prediction accuracies and R-squared values, although predictions provided by the ANN model were more accurate compared with the other models. The article provides a detailed comparison of the performance of the three models.

1. Introduction

Pavement management, in its broadest sense, encompasses all the activities involved in planning, design, construction, maintenance, evaluation, and rehabilitation of the pavement portion of a public works program [1]. The Pavement Management System (PMS) concept that has been in place since the 1950 s has been adapted over time in line with new innovations and technological

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http://dx.doi.org/10.1016/j.conbuildmat.2016.04.118
0950-0618/

developments. In the 1990 s in particular, several books and research reports were published explaining the theory of the PMS concept, its levels, and its data collection and assessment techniques. This period also saw the publication of a PMS standard, known as the American Society Testing and Materials (ASTM) E1889-97(2009). Due to limitations in annual budgets for the execution of pavement rehabilitation projects, the authority must choose first those alternatives with highest priority, in order to supply the demands of optimization in the network [2]. As a key component of pavement management, pavement performance models play a crucial role in PMS, where forecasting results provide key information for highway agencies to make decisions on the overall maintenance and budget plan [3]. The effectiveness of the strategies is therefore highly dependent on the accuracy of the predictions [4]. The development of good models for predicting performance, in terms of some indexes versus age or accumulated axle load applications, has been a major challenge for pavement engineers [5].

Information on several pavement condition characteristics is critical to performing management functions. The characteristics include roughness, skid resistance, structural capacity, and distress [6]. The performance of a pavement, as presented herein, is measured by the PCI, which indicates the present condition of pavement in terms of structural integrity and surface operational condition [7]. The PCI provides an indication of the current performance of a pavement using pavement distress data, which includes different distress types, severity levels, and densities, and takes the form of a numerical rating, with 0 being the worst possible condition and 100 being the best. This study made use of PAVER software to obtain PCI values for twenty road sections, which experience different volumes of traffic, in the Samsun region. This study aimed to develop and compare deterioration models using three different modeling techniques (deterministic regression analysis, MARS and ANN) for HMA paved urban roads. These models are to be used in the planning resurfacing maintenance priorities at network level and to forecast the outcomes under different maintenance strategies and budget scenarios [8].

2. Review of deterioration models

The accuracy of these models depends on the type of algorithms, number of effective variables, number of measured data and accuracy of the instruments and measurements. Various algorithms and statistical methods have been developed to predict pavement condition [9].

The main factors influencing the loss of performance (serviceability) of a pavement are traffic loads, age, and climate effects (change in temperature and humidity) [1]. The age of the pavement in a road section is the single most important variable in explaining the loss of performance of the pavement, because it also serves as a summary indicator of all traffic and climate effects. This is why there are many studies in the literature, which model pavement deterioration over time, using deterministic and stochastic methods. The methods used in these studies include, linear or non-linear regression [10–13], autoregression and time series [4,14] methods, MARS method [15], artificial intelligence modeling techniques, specifically the ANN method [16], and stochastic methods, and the Markov chain [17–19] and Bayesian theory [16,20] in particular [21]. Research usually focuses on the development of models that can predict deterioration over time in an index, such as the PCI, which measures the current condition of the pavement, the international roughness index (IRI), or the pavement serviceability index (PSI). Most of these studies use data collected within the framework of the Long-Term Pavement Performance (LTPP) Program, run by the Federal Highway Administration (FHWA), which contains data on more than 2000 pavement sections, mostly from the United States, that has been collected over a period of more than 20 years and shared with researchers. There are also studies that compare results obtained using the multiple deterministic and/or stochastic modeling approaches [8,9].

Most researchers focus on forecasting models that use, as inputs, multiple independent variables developed with the purpose of predicting the future value of a pavement performance index. Some of the independent variables used among others, include the age of the pavement, environmental factors, different types and severities of pavement cracks, patching, pavement deformations of different types and severities, traffic loads, pavement design, pavement thickness, and rut depth. Because there are many variables that potentially affect pavement performance, and because some of the variables are not quantifiable, most forecasting models use artificial intelligence methods. Those frequently used are, Fuzzy logic [22,2,23] and ANN [3,24,25], which facilitate the combined use qualitative and quantitative data, and ANFIS [26], which is a combination of these two methods. MARS, which facilitates modeling the relationship between multiple independent variables, is another method preferred by researchers [27]. On the other hand, there are also studies that use linear or nonlinear regression methods to predict pavement performance [28–30].

The World Bank's Highway Design and Maintenance Models (HDM) are comprehensive models for prioritizing pavement maintenance and rehabilitation. These models simulate total life-cycle conditions and costs, and provide economic decision criteria for multiple road design and maintenance alternatives [31]. Each country has unique local conditions, including climatic, technological, operational and traffic conditions, as well as differing standards and measuring units; therefore, the adaptation and calibration of pavement deterioration models to local conditions are indispensable [32,33]. Some studies adapt HDM models by taking local construction materials and environmental conditions into account [34–36].

It is well known that predicting the future performance of pavements has multiple benefits in the allocation of a limited budget. The proper allocation of the budget requires identifying the optimum mathematical solution for the performance of the pavements on the road network. There are thus many studies that aim to optimize the parameters that describe pavement performance on road sections. In these studies, researchers use methods that are based on soft computing evolutionary computation, fuzzy decision tree, logistic regression method, data-mining, multi-criteria decision making applications, genetic algorithm, deterministic and stochastic approaches and hybrid techniques [37–40]. As prioritization is a decision making process, the statistical models are not very responsive. Therefore, in the future, highway agencies will become open to adopting new Decision-Aid Tools (DATs) that minimize the costs relating to their field of activity [41].

3. Pavement performance

The availability of a reliable index, which is capable of reflecting the actual conditions of distress on a pavement section, is essential for pavement management, decision making, prioritization, planning etc. The PAVER system is an evaluation procedure for the assessment of the current performance of the pavement by evaluating data gathered according to the identification guide with the code ASTM D 6433-11 in sample areas of $225 \pm 90\ m^2$ ($2500 \pm 1000\ ft^2$), chosen randomly in line with distribution principals [6]. The evaluation is made by reading the resulting values from the deduct value tables, which were prepared in accordance to the deterioration type and with the help of the value derived