Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(4) (2021) 285-288
DOI: 10.22060/ceej.2019.16072.6116

Analysis of Uncertainties in Deterioration Process of Asphalt Pavements based on Roughness Index Using LTPP Data

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ABSTRACT: Pavement deterioration models are the most important components of any Pavement Management System (PMS). These models could predict pavement conditions at any time in its service life. Pavement deterioration is a very complicated and uncertain process. Probabilistic deterioration models in comparison with deterministic ones could take into account these uncertainties. One of the most important probabilistic pavement deterioration models is the trend curve model that is based on pavement roughness. In this research, roughness data of GPS-1 and GPS-2 pavement sections, which are in-service asphalt pavements respectively with granular base and stabilized base layers, have been extracted from the Long-Term Pavement Performance (LTPP) database. These data then were used for analyzing pavement deterioration uncertainties. For this purpose, Chi-square ($\chi 2$) and Kolmogorov-Smirnov (K-S) statistical tests were used to determine the probability distribution of pavement future condition over its current condition ratio in different years. Results showed that lognormal distribution is more fitted with actual data in long-term pavement life. Having this distribution, the pavement deterioration model was developed based on the roughness index using the trend curve model. Utilizing the proposed model, the pavement management system could predict pavement future conditions taking into account uncertainties of the deterioration process and with optimal budget assignment, could maintain the network condition at a specified risk level. This could prevent any future risk regarding the pavement deterioration uncertainties.

Review History:

Received: Apr. 04, 2019
Revised: May. 17, 2019
Accepted: Jun. 10, 2019
Available Online: Jul. 04, 2019

Keywords:

Pavement Management System (PMS)
Pavement Deterioration
International Roughness Index (IRI)
Uncertainty
LTPP

1. Introduction

The development of reliable pavement deterioration prediction models is valuable for transportation policymakers and will lead to more economical highway management. Performance models are key components of any Pavement Management System (PMS) which may be utilized during maintenance and rehabilitation analysis and subsequently budget optimization to identify the cost-effectiveness of different rehabilitation alternatives [1]. Pavement roughness is the major factor influencing pavement riding quality. It can be directly related to pavement performance and road network costs, through such factors as dynamic pavement loading, vehicle operating costs, and vehicle fatigue [2]. AASHO Road Test indicated that about 95 percent of the information about pavement serviceability is contributed by surface roughness [3].

2. Pavement Deterioration Prediction

Pavement performance or deterioration prediction models can be either deterministic or probabilistic, depending on the method employed to simulate the deterioration or aging process. Deterministic models predict the condition based on mathematical functions of observed or measured deterioration without taking into account the uncertainties associated with the deterioration process. On the other hand, probabilistic models consider uncertainties and predict the condition as the probability of occurrence in a range of possible outcomes [4]. Various models are introduced for pavement deterioration prediction which the most important of them are [3, 5-7]:

* Empirical (Regression);
* Survivor curve;
* Markov chain;
* Semi-Markov;
* Bayesian;
* Trend Curve; and,
* Artificial Neural Network (ANN).

3. LTPP Program

The Long-Term Pavement Performance (LTPP) program was initiated in 1987 as a part of the Strategic Highway Research Program (SHRP). The main objective of LTPP is to establish a national long-term pavement database to support SHRP objectives and future needs [8]. The database includes information that has been systematically collected throughout

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the project for about 2,500 pavement sections for the past 30 years. Collected data includes construction information, pavement structure, material properties, maintenance and rehabilitation activities, pavement condition, pavement loading, as well as environmental condition information. LTPP database can be used to develop base deterioration prediction models for developing PMS in any state that can then be adjusted using agency-specific experience and/or data. In addition, LTPP data is a major source for calibrating Mechanistic-Empirical Pavement Design Guide (MEPDG) models [9].

The LTPP test sections are classified into some studies; General Pavement Studies (GPS) and Specific Pavement Studies (SPS) sections. A GPS test site typically would have one in-service test section, while an SPS test site would have multiple test sections incorporating a controlled set of experiment design and construction features [8].

4. Data Extraction

In this research, in-service flexible pavement sections from the LTPP database are adopted for analysis. When determining the data set for this analysis, all available information on GPS-1 and GPS-2 sections (GPS-1: asphalt pavement with granular base, GPS-2: asphalt pavement with stabilized base) are scrutinized in the LTPP Standard Data Release (SDR v.23) database [10]. As a result, sections with at least one IRI evaluation after its first inspection were considered in this analysis. The sections selected the cover the four representative regions of the United States according to LTPP [8].

5. Pavement Deterioration Modeling and Uncertainty Analysis

The trend curve model [7] was utilized for pavement deterioration modeling based on the IRI roughness index. This model is shown in Equation 1.

$$s = s^0 \exp(\xi\tau) \tag{1}$$

$$P_\eta(y) = \frac{1}{y\tau\sigma\sqrt{2\pi}} \exp\left(-\frac{(ln(y)-\tau\mu)^2}{2(\tau\sigma)^2}\right) \tag{2}$$

where ξ is the deterioration parameter, s^0 is the initial pavement roughness, s is the final pavement roughness, and τ is the total period of prediction in years ($t>t_0$, $\tau=t-t_0$). In this model, the deterioration parameter, ξ, is considered as a random variable with a normal distribution ($\xi \sim N(\mu,\sigma^2)$). Hence, $\eta=s/s^0$ would have lognormal distribution with density function as stated in Equation 2:

where μ is the average value and σ is the standard deviation of deterioration parameter, ξ.

To determine the distribution of deterioration parameters on LTPP data, two statistical tests, i.e. Chi-square (χ^2) and Kolmogorov–Smirnov (K-S) were used. Results showed that lognormal distribution is very well fitted in long-term prediction with a 99.9% confidence level. In Fig. 1 and Fig. 2, final pavement roughness over initial roughness ratio during pavement life is shown based on developed deterioration model for GPS-1 and GPS-2 sections, respectively.

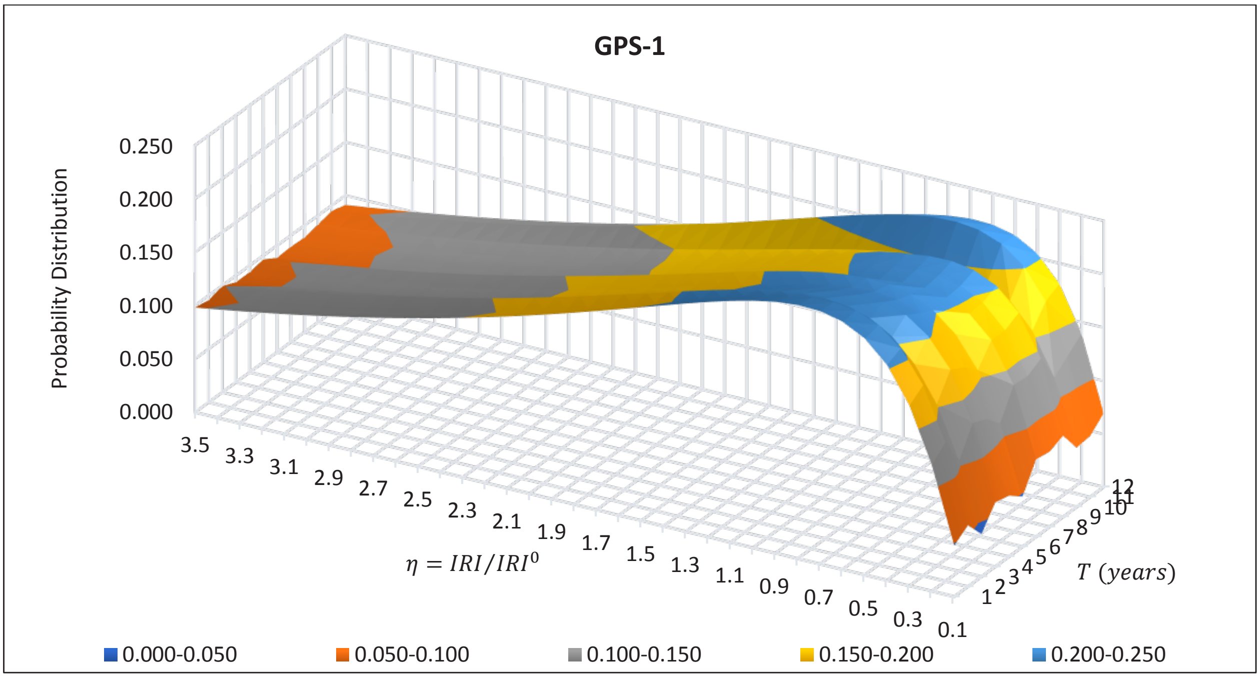

Fig. 1. Roughness deterioration model for GPS-1 pavement sections considering prediction uncertainties for different years

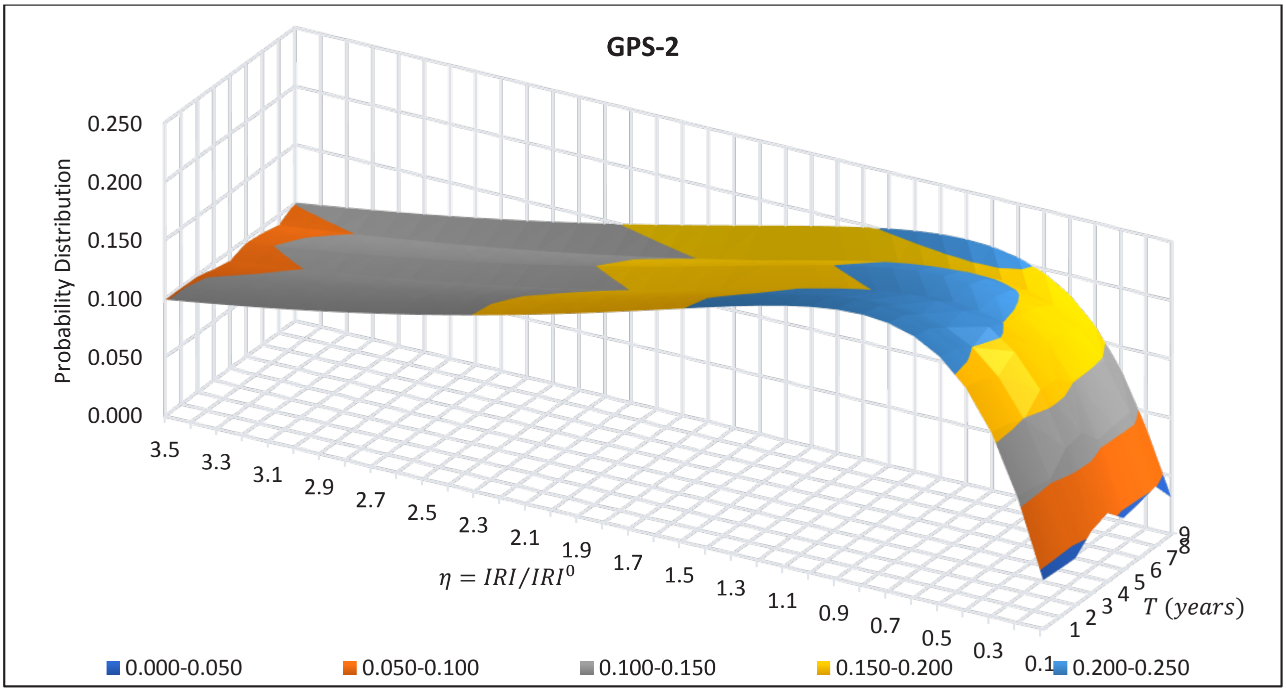

Fig. 2. Roughness deterioration model for GPS-2 pavement sections considering prediction uncertainties for different years

6. Conclusions

In this research, the trend curve model was utilized to predict roughness deterioration of GPS-1 and GPS-2 pavement sections from the LTPP database. This model could take into account prediction uncertainties. After applying Chi-square and Kolmogorov–Smirnov statistical tests, lognormal probability distribution was fitted in prediction distribution for long-term performance of pavement sections. Having this distribution, the pavement deterioration model based on the roughness index has been developed using the trend curve model. Using statistical parameters for different years, it is possible to predict pavement conditions at any time with desired uncertainty level. One of the most important benefits of considering uncertainties in the pavement deterioration process is the possibility of using risk models in pavement condition prediction and as a result, using these models in budget allocation in pavement network service life.

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HOW TO CITE THIS ARTICLE:

N. Solatifar, Analysis of Uncertainties in Deterioration Process of Asphalt Pavements based on Roughness Index Using LTPP Data, Amirkabir J. Civil Eng., 53(4) (2021): 285-288.

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