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Effect of overlay thickness, overlay material, and pre-overlay treatment on evolution of asphalt concrete overlay roughness in LTPP SPS-5 experiment: A multilevel model approach

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HIGHLIGHTS

- A multilevel model was developed to model evolution of asphalt overlay roughness.
- Clustered longitudinal structure of overlay roughness was fully captured.
- Interactive effects between factors on roughness were systemically investigated.
- Overlay material and overlay thickness affect roughness after overlay.
- Overlay thickness have a significant effect on roughness evolution.

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ABSTRACT

The objective of this study is to investigate the effect of overlay thickness, overlay material and pre-overlay treatment on roughness evolution of asphalt overlay in the Long-term Pavement Performance (LTPP) SPS-5 experiment. Roughness data collected from SPS-5 experimental sites has a clustered longitudinal structure. A multilevel model is established to simultaneously account for measurement correlation within the same test section and roughness evolution correlation within the same experimental site. It was discovery that while as-built roughness depends on overlay material and overlay thickness, roughness growth rate only depends on overlay thickness.

1. Introduction

The Long-Term Pavement Performance (LTPP) program is a study of the behaviour of pavement test sections located on in-service roadways constructed using highway agency specifications and contractors, and subjected to real-life traffic loading throughout the United States and Canada [1]. As the largest pavement performance research experiment ever undertaken, LTPP is designed to monitor and collect data from over 2500 in-service pavement test sections over a 20-year period [2]. A key aspect of the LTPP project is to investigate the specific effects on long-term pavement performance of various design features, traffic and environment, materials, construction quality, and maintenance practices based on systematic, exhaustive, and in-depth analysis of sufficient data.

The Specific Pavement Studies Experiment 5 (SPS-5) in the LTPP program was designed to study the effects of overlay thickness, overlay material, and pre-overlay treatment on the performance of asphalt overlay [3,4]. There are 18 experimental sites throughout the United States and Canada. At each site, there are eight 150 m test sections built side-by-side and monitored for long-term pavement performance development. All the eight type of treatments are commonly used by highway agencies in practical [2].

The primary objective of this study is to investigate the effect of overlay thickness, overlay material and pre-overlay treatment on roughness evolution based on the IRI data collected in the LTPP SPS-5 experiment. As shown in Fig. 1, the IRI data used in this study, which was collected from 18 experimental sites, has a clustered longitudinal structure. Repeated measures of pavement

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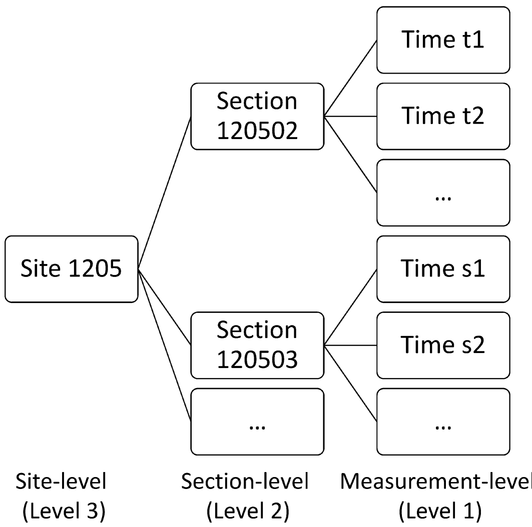

Fig. 1. Clustered longitudinal structure of pavement performance data for site 1205 in the LTPP SPS-5 project.

performance are collected on each test section over time while multiple test sections are nested within each experimental site. As a consequence, multiple measurements of IRI over time for the same test section are likely to be correlated. In addition, IRI evolution of several test sections nested within the same experimental site may tend to be similar because these test sections are subject to the same in-situ conditions (hereinafter referred to as site effect) such as pavement structure, climate and traffic loads. The above-mentioned clustered longitudinal structure must be well accounted in the analysis process in order to capture the effect of overlay thickness, overlay material and pre-overlay treatment on roughness evolution accurately. Table 1 presents the factors for performance development of the SPS-5 test sections.

In this study a multilevel model is established to account for such a clustered longitudinal data structure. Multilevel models, also known as hierarchical linear models, nested data models, mixed models, random coefficient models, random-effects models, random parameter models, individual growth models, or split-plot designs, are statistical models of parameters that vary at more than one level. [5,6].

The multilevel model for IRI evolution developed in this study includes sub-models at three levels: (1) a level-1 sub-model that describes how IRI of pavement sections change over time; (2) a level-2 sub-model that describes how these changes vary across pavement sections within the same experimental sites; and (3) a level-3 sub-model that describes how these changes vary across experimental sites [5]. It can embody three type of research questions regarding to roughness evolution: level-1 questions about within-section roughness evolution over time, level-2 questions about between-section within-site differences in roughness evolution resulted from different overlay thickness, overlay material and pre-overlay treatment, and level-3 questions about between-site differences in roughness evolution resulted from in-situ conditions such as pavement structure, climate and traffic loads. It can be used to compare the expected roughness evolution of overlay over time on the basis of various attributes such as overlay thickness, overlay material, and pre-overlay treatment.

Table 1
Factors for performance development of the SPS-5 test sections.

Level	Factors on each level
Site (Level 3)	In-situ conditions such as pavement structure, climate, and traffic loads
Section (Level 2)	Section-level design factors (i.e., overlay thickness, overlay material, and pre-overlay treatment
Measurement (Level 1)	Time elapsed after overlay

2. Literature review

Thus far, several studies have been conducted using the LTPP SPS-5 data.

Hong and Chen [7] investigated effects of overlay thickness, material and pre-overlay treatment on transverse crack propagation of asphalt pavement overlay based on LTPP SPS-5 test sections in Texas. They employed sigmoid or S-shaped models to study the development of transverse cracking. Hong, Chen and Mikhail [8] conducted a similar but more comprehensive study in which transverse cracking length, rut depth, and ride quality of SPS-5 test sections were evaluated, respectively. In regard to roughness, it was found that there was no statistical difference between the recycled (RAP) and virgin (non-RAP) test sections according to paired-*t* test.

Carvalho, Shirazi, Ayres and Selezneva [9] analyzed the impact of reclaimed asphalt pavement (RAP) on the performance of flexible pavement overlays based the LTPP SPS-5 project. Statistical methodology used in their study was repeated measures analysis of variance. They compared roughness, rutting, fatigue cracking, and deflection of the recycled (RAP) and virgin (non-RAP) test sections subjected to the same traffic and environment. For roughness, it was suggested that there was no significant difference between roughness of the RAP sections and that of non-RAP sections for the majority of sites. However, non-RAP sections tend to perform slightly better than the RAP sections when the overlay was thin.

West, Michael, Turochy and Maghsoodloo [3] compared pavement performance of the SPS-5 test sections with and without RAP using paired *t*-test. International roughness index (IRI), rutting, fatigue cracking, longitudinal cracking, transverse cracking, block cracking, and ravelling were chosen as indicators for pavement performance. They also investigated the effect of location, age, overlay thickness, and pre-overlay milling on the performance of the overlays using analysis of variance (ANOVA). It was shown that thicker overlay performed better in terms of IRI. The effect of milling on roughness was found to be significant. However, no evidence of the effect of overlay material was detected.

Dong and Huang [10] investigated the effectiveness and cost-effectiveness of typical asphalt pavement rehabilitations and identified major influence factors through multiple regression. Logarithmic transformation and square root transformation were utilized to normalize response variables in the multiple regression models. Their study was conducted using IRI data collected from the LTPP SPS-3, SPS-5 and GPS-6B test sections. Analyzed factors included specific rehabilitation methods, pre-overlay pavement condition, traffic volume, and overlay thickness. The results indicated that pavement with thicker overlay, milling, and low pre-overlay roughness were smoother after rehabilitation. It should be noted that, apart from the data of the LTPP SPS-5 test sections, their study utilized the pavement performance data from the SPS-3 and GPS-6B test sections.

Ahmed, Labi, Li and Shields [2] analyzed the effectiveness of pavement rehabilitation treatments based on LTPP SPS-5 test sections in west region. Effectiveness was measured in both short term (roughness reduction) and long term (estimated treatment service life and area bounded by the performance curve). Ordinary least square regression was employed in their research to develop treatment effectiveness models. It was found that overlay thickness and pre-overlay treatment have a profound effect on roughness performance. There were generally no difference between