Joint Transportation Research Program

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SPR-3805 2016

Long-Term Pavement Performance Indicators for Failed Materials

Introduction

State Transportation Agencies (STAs) use quality control/quality assurance (QC/QA) specifications to guide the testing and inspection of road pavement construction. Any pavement section that does not pass the testing is viewed as failed materials. Although failed materials rarely occur in practice, it is critical to have a sound decision framework to assist in making data-driven, informed decisions because such decisions have profound impacts on the long-term performance of pavement and its operation and maintenance.

At the Indiana Department of Transportation (INDOT), the Failed Materials Committee makes decisions regarding whether failed materials should be considered for "removal and replacement" or be "accepted with a heavy penalty." Uncertainty about long-term pavement performance creates a dilemma for INDOT, and therefore a procedure is needed to assess long-term pavement performance based on the reliability of sub-standard pavement materials and to estimate the life-cycle cost (LCC) difference between as-designed and as-constructed pavement.

This study presents a newly developed decision framework to assist INDOT in making decisions regarding failed pavement materials. The framework is based on the long-term performance modules available from performance-related specification (PRS) tools. Pavement PRS tools can analyze input acceptance quality characteristics (AQCs) and predict the lifetime performance and LCC of pavement through computer simulations. Using the decision framework, INDOT can calculate the difference between the LCCs of as-designed and as-constructed pavement at various confidence levels and compare it to the contract price to decide which option (i.e., "removal and replacement," or "acceptance with a heavy penalty") is more economic.

The framework involves two PRS tools: PaveSpec for Portland cement concrete pavement (PCCP) and Quality Related Specification Software (QRSS) for hot mixed asphalt (HMA) pavement. The framework was tested and validated using design and construction data from an INDOT construction project.

Findings

Valuable findings regarding the use of PRS tools are summarized as follows.

Using PaveSpec to Develop the Decision Framework for Failed Materials of PCCP

- PaveSpec takes five AQCs for PCCP: concrete strength, slab thickness, air content, initial smoothness, and percent consolidation around dowels (optional). INDOT tests all four mandatory AQCs in its current practice.
- PaveSpec provides two levels of specification. Level 2 Specification considers the correlation between AQCs. It is more reflective of the reality and, therefore, is the level adopted in the decision framework.
- PaveSpec offers two approaches to estimate the LCC of as-constructed PCCP: the interpolation and the re-simulation approach. The re-simulation approach substitutes design targets with field-testing results to estimate the pavement LCC, enabling the calculation of the confidence level for a given LCC and vice versa (e.g., 90th-percentile LCC and 95th-percentile LCC). The re-simulation approach was adopted in the decision framework.
- According to INDOT specifications, a lot could contain both acceptable and failed sublots. Two different methods, the single lot method and the divide-estimate-sum method, were devised, and their simulation results were compared for various scenarios of the co-existence of both failed and acceptable sublots in a single lot. Simulation results illustrate that (1) for lot level failures (i.e., the lot average falls in the failed range), the single lot approach is more appropriate, and (2) for sublot level failures (i.e., the lot average is acceptable, but the lot contains failed sublot(s)), it reflects the reality better by separating the original lot into two new lots: one contains acceptable sublot(s) only and the other contains failed sublot(s) only.
- A large number of simulation scenarios of failed materials were designed for a three-sublot lot. Results show that higher mean values and lower standard deviations

always lead to lower LCCs. While this trend also exists with the air content AQC, it is not appropriate to use PaveSpec because a higher air content does not indicate better quality.

- Concerned with the air content AQC, additional simulation scenarios were designed to investigate the aggregate effect of multiple AQCs (focusing on air content) on the LCC. Results show that PaveSpec is not an appropriate tool for estimating the as-constructed LCC if materials fail because of the air content AQC.
- The LCC difference at various level of confidence can be statistically calculated. Consequently, the LCC difference at any confidence level can be calculated following the calculation methods for normal distributions.

Using QRSS to Develop the Decision Framework for Failed Materials of QC/QA HMA Pavement

- QRSS estimates the service life by predicting the distresses of rutting, fatigue cracking, and thermal cracking and comparing them to pre-set threshold values. It does not have a mechanism to incorporate maintenance strategies and costs to estimate the LCC.
- There is a misalignment between the AQCs specified in INDOT's QC/QA HMA specification and the AQCs required in QRSS.
- Because of the misalignment, a pairing mechanism was proposed to run QRSS simulations for INDOT QC/QA HMA pavement. A recommendation to INDOT is to collect the AQCs that are required in QRSS to adopt it in the decision framework.
- A challenge in applying QRSS to INDOT QC/QA HMA pavement is caused by the use of PWL as the criterion for failed materials in INDOT specification: many different scenarios could lead to the same PWL value.
- QRSS simulations yielded abnormal results when predicting the service life difference between the as-designed and the as-constructed pavement based on fatigue cracking and thermal cracking. This indicates that QRSS (in its current form) is not appropriate for estimating the shortened service life attributable to failed materials.
- The current version of QRSS executes Monte Carlo simulations to predict service life differences based on pavement performance estimates. In the results, QRSS provides means of the service life differences; however, it does not provide standard deviations of the service life differences directly. Therefore, to predict the service life difference at a user-specified confidence/probability (e.g., 90th-percentile or 95th-percentile service life difference), a statistical approach was devised to calculate the standard deviation based on individual pairs of the service life of as-designed and as-constructed.
- A large number of simulation scenarios for the only two common AQCs in QRSS and INDOT specification—binder content and roadway core density—were crafted in lieu of a five-sublot lot. The simulation results showed erroneous results when applying the PWL concept.
- Given the misalignment between INDOT AQCs and the AQCs required in QRSS, the limitations in QRSS, and the erroneous results from the QRSS simulations, QRSS is not being recommended as the PRS tool to be used for QC/QA HMA pavement at this time.

Implementation

The findings from this study were used to develop the decision framework for failed materials of PCCP. The framework was validated using the design and construction data of an INDOT highway construction project. The framework can be immediately implemented to assist INDOT in making informed decisions regarding failed PCCP materials while waiting for findings of the use of the Mechanistic-Empirical Pavement Design Guide (MEPDG) on PCCP.

For QC/QA HMA pavement, while the concept on comparing the long-term performance between as-designed and as-constructed pavements is still valid, QRSS is not an appropriate PRS tool to estimate the long-term performance because of its limitations and the misalignment between QRSS process and INDOT practice. Further study is needed to find an appropriate PRS tool, which could be a modified version of QRSS or a different tool such as the MEPDG.

Recommended Citation for Report

Park, J., Yuan, C., & Cai, H. (2016). *Long-term pavement performance indicators for failed materials* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2016/10). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284316333

View the full text of this publication here: http://dx.doi.org/10.5703/1288284316333

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