Investigation on Pavement ME Design Reflective Cracking, Faulting, IRI Prediction Models, Concrete Overlays Design Tool, and Performance Threshold Levels for Iowa Pavement Systems

tech transfer summary

The local calibration factors proposed in this research can help improve the accuracy of the performance predictions made by AASHTOWare Pavement ME Design in Iowa and facilitate implementation of the latest version of the software.

Problem Statement

Research has shown that different versions of AASHTOWare Pavement ME Design (PMED) yield different performance predictions and design recommendations when the same local calibration coefficients are used. An urgent need exists to recalibrate the performance prediction models in PMED version 2.5.5 for use in Iowa.

Key Objectives

- Evaluate the new features added to PMED version 2.5.5
- Review the modifications made to the performance prediction models in PMED version 2.5.5 to assess the need for recalibration
- Use advanced optimization tools to calibrate PMED version 2.5.5 for Iowa's flexible, rigid, and composite pavements

Background

The American Association of State Highway and Transportation Officials (AASHTO) PMED version 2.5.5, released in June 2019, features several enhancements and updates.

Newly integrated climate data sets include Modern Era Retrospective Analysis for Research and Applications (MERRA) for the design of flexible pavements and North American Regional Reanalysis (NARR) for the design of rigid pavements. New models have been added to address reflective cracking and short-jointed plain concrete pavement over asphalt concrete (SJPCP/AC). The software's pavement performance prediction models have also been modified to improve overall performance.

The performance prediction models in PMED were calibrated nationally based on the results of National Cooperative Highway Research Program (NCHRP) Project 1-37A, Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures.

AASHTO recommends that state highway agencies (SHAs) calibrate the performance models to local conditions. Calibration involves minimizing the bias and standard error between field-observed pavement distresses and PMED-predicted pavement performance.

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RESEARCH PROJECT TITLE
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The Program for Sustainable Pavement Engineering and Research (PROSPER) is part of the Institute for Transportation (InTrans) at Iowa State University. The overall goal of PROSPER is to advance research, education, and technology transfer in the area of sustainable highway and airport pavement infrastructure systems.

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Research Description

This project consisted of five main tasks.

Evaluation of Four Climate Data Sources and the Impact of Surface Shortwave Radiation on Iowa's Pavement Systems

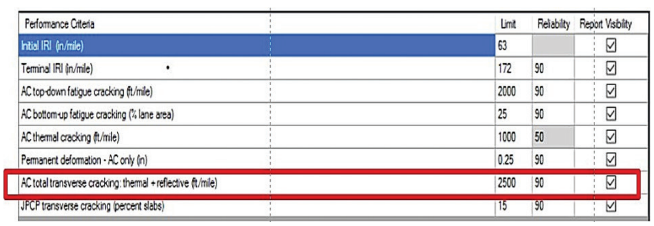
Performance predictions made by PMED for composite pavement systems in Iowa were compared using four climate data sources: ground/airport-based weather stations (GBWS), NARR, and two versions of MERRA (MERRA-1 and MERRA-2).

Significant differences in hourly measurements of percent sunshine among the different climate data sources were accounted for by compiling a database of "synthetic" percent sunshine using surface shortwave radiation (SSR) estimates from MERRA.

Sensitivity Analysis of PMED Inputs for New Reflective Cracking Model

The sensitivity of reflective cracking predictions to PMED design inputs and material properties was assessed. To study the effects of climate, six representative locations distributed across different US climate zones were considered.

One-at-a-time (OAT) sensitivity analyses were performed to determine normalized sensitivity index (NSI) values under two scenarios: short-term reflective cracking prediction (i.e., the year when the predicted distress is 4,000 ft/mile) and long-term reflective cracking prediction (i.e., for a 20-year design life).

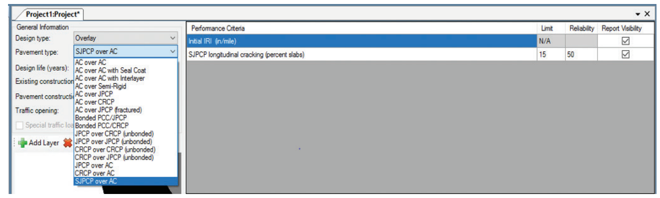


Perfomance Criteria	Limit	Reliability	Report Visibility
Initial IRI (in/mile)	63		☑
Terminal IRI (in/mile)	172	90	☑
AC top-down fatigue cracking (ft/mile)	2000	90	☑
AC bottom-up fatigue cracking (% lane area)	25	90	☑
AC thermal cracking (ft/mile)	1000	50	☑
Permanent deformation - AC only (in)	0.25	90	☑
AC total transverse cracking: thermal + reflective (ft/mile)	2500	90	☑
JPCP transverse cracking (percent slabs)	15	90	☑

PMED version 2.5.5 screenshot of AC total transverse cracking criteria for AC over JPCP

Sensitivity Analysis of PMED Inputs for Assessing Short-Jointed Bonded Concrete Overlay of Asphalt Pavement

A sensitivity analysis was conducted for a method recently added to PMED that assesses SJPCP/AC. The sensitivity of longitudinal fatigue cracking predictions to PMED design inputs was evaluated for five locations representing different climate conditions. NSI values were obtained through OAT sensitivity analyses.

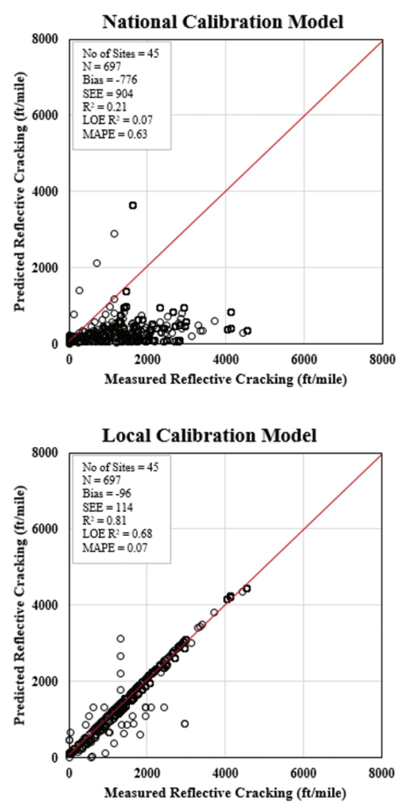


PMED version 2.5.5 screenshot of performance criteria for SJPCP/AC

Local Calibration to Iowa's Flexible, Rigid, and Composite Pavements

Local calibration was performed for flexible, rigid, and composite (asphalt concrete [AC] over jointed plain concrete pavement [JPCP]) pavements in Iowa. A complete set of revised calibration coefficients appropriate for PMED version 2.5.5 was developed.

Multiple optimization and resampling approaches were evaluated for their ability to improve predictive accuracy. Approaches included sensitivity analyses, a Microsoft Excel solver, a LINGO optimization tool, genetic algorithms, SciPy optimization, bootstrapping, and jackknifing.



Measured versus predicted reflective cracking for a nationally calibrated model (top) and a locally calibrated model (bottom)

Data-Driven Determination of Optimal Pavement Thickness

During pavement design using PMED, each potential distress that a pavement may be subjected to is assigned a reliability level that indicates the probability that the predicted distress will not exceed the established design limit during the design period considered. A balance between design criteria and reliability is needed to achieve the thinnest (i.e., lowest cost) pavement that will experience the lowest amount of distress.

The sensitivity of reliability level to flexible and rigid pavement thickness was analyzed for all distresses listed in PMED. An additional analysis was performed to evaluate the impact of joint spacing on the final pavement thickness.

Additionally, a survey was distributed to SHAs, pavement engineers, and researchers across the United States and Canada to determine the variety of design criteria and reliability levels employed by PMED users. In total, 26 responses were received from US SHAs (22), a Canadian SHA (1), US consultants (2), and a US pavement industry group (1).

Key Findings

Evaluation of Four Climate Data Sources and the Impact of Surface Shortwave Radiation on Iowa's Pavement Systems

- The diurnal variations in percent sunshine from the four climate data sources showed substantial and nonsystematic differences, and a sensitivity analysis of climate inputs showed that percent sunshine significantly impacts pavement performance.
- To use the MERRA-1 and MERRA-2 SSR values in environmental calculations, "synthetic" percent sunshine values were backcalculated for use in PMED. These backcalculated values replaced the percent sunshine values in the climate data provided with PMED.
- Comparisons of predicted pavement performance using the MERRA climate data and the "synthetic" percent sunshine values showed dramatically improved agreement for all pavement types, with the predictions clustered tightly along their respective lines of equality.

Sensitivity Analysis of PMED Inputs for New Reflective Cracking Model

- Reflective cracking distress was most sensitive to joint spacing, JPCP layer thickness, transverse load transfer efficiency (LTE), and alpha and delta in the AC sigmoidal curve.
- Reflective cracking distress was moderately sensitive to annual average daily truck traffic (AADTT), AC surface shortwave absorption, effective binder content, air voids in AC, tensile strength, AC thickness, ratio of distressed slabs before and after restoration, and portland cement concrete (PCC) thermal conductivity.
- The other design inputs considered had little to no impact on reflective cracking.
- At one test location (International Falls, Minnesota), most of the PMED inputs were found to significantly impact reflective cracking. A reason may be that extremely cold winter temperatures and extensive snow accumulation in states like Minnesota could result in excessive infiltration of moisture through cracks and premature overlay failure.

Sensitivity Analysis of PMED Inputs for Assessing Short-Jointed Bonded Concrete Overlay of Asphalt Pavement

- Longitudinal fatigue cracking was sensitive to layer thickness in all cases. Field surveys should be performed carefully to collect information on the existing AC and base layer thicknesses, and the SJPCP layer should be optimized appropriately.
- Longitudinal fatigue cracking was moderately sensitive to AADTT, transverse LTE, and PCC modulus of rupture.
- Longitudinal fatigue cracking was not observed to be sensitive to joint spacing and coefficient of thermal expansion (CTE) due to the limited range of input options in PMED.
- All other inputs considered had little to no impact on longitudinal fatigue cracking.

Local Calibration to Iowa's Flexible, Rigid, and Composite Pavements

- The SciPy optimization tool produced the best results, although it requires some basic knowledge of programming. The genetic algorithm tool in MATLAB may be a better alternative for engineers who choose not to use programming-dependent tools.
- A new set of coefficients based on conditions in Iowa was developed and is recommended for use in design practice. This is the first study in which the reflective cracking model has been locally calibrated since the model was added to PMED.

- Minimizing overestimation and underestimation of pavement distresses is crucial for local calibration, and the results of this study provide comprehensive guidance on how to modify coefficients based on comparisons of measured and predicted pavement performance data. These guidelines can be implemented by any SHA that uses PMED.

Data-Driven Determination of Optimal Pavement Thickness

- Final design, long-term performance, initial construction costs, and life-cycle costs are greatly affected by the chosen design criteria and reliability levels.
- Optimal layer thicknesses for use in the design of flexible and rigid pavement systems in Iowa were determined based on the survey responses and AASHTO guidelines. Recommended thicknesses vary significantly for different pavement systems and traffic levels.
- The approach developed in the study to determine layer thicknesses can also be used to evaluate and validate final or earlier designs. The selection of a given reliability level can have a significant impact on optimal thickness.

Recommendations

- The use of MERRA-2 climate data is recommended for Iowa pavement design.
- The sensitivity analysis results from this research must be carefully reviewed to mitigate the frequently observed issues with reflective cracking and the distresses associated with bonded concrete over asphalt (BCOA) pavement.
- For AC pavements in Iowa, the locally calibrated prediction models developed in this study for rutting, longitudinal (top-down) cracking, thermal cracking, and International Roughness Index (IRI) are recommended as alternatives to the nationally calibrated models.
- For JPCPs in Iowa, the locally calibrated performance models (including those predicting faulting, transverse cracking, and IRI) developed in this study are recommended as alternatives to the nationally calibrated models.
- For AC over JPCPs in Iowa, the locally calibrated prediction models developed in this study for rutting, longitudinal (top-down) cracking, thermal cracking, reflective cracking and IRI are recommended as alternatives to the nationally calibrated models.

Future Research

- The results of this research can be used to develop a lookup catalog/table for mechanistic-based pavement thickness design for Iowa pavement systems. While PMED could improve the efficiency of pavement analysis and design, the software has limitations, and many design decisions could be better addressed through an Iowa-specific lookup catalog/table.
- Based on the analysis of the climate models in the current software, it is recommended that short-wave and long-wave radiation models be evaluated and included as direct climate inputs in future versions of the software.
- The current SJPCP/AC model in PMED predicts only longitudinal fatigue cracking. If other distress types are added, PMED predictions should be compared to field-observed distresses before the model is implemented.
- Local calibration is a complex and time-consuming process, but a recently released calibrator tool could save considerable time and effort. This new tool should be evaluated and compared to previously used local calibration methods in future research.

Implementation Readiness and Benefits

A properly designed pavement structure can lead to significantly reduced construction and lifecycle costs and a longer service life for the pavement.

The results of this research, which evaluated the latest features of PMED version 2.5.5 and recalibrated the software's performance prediction models for Iowa pavement systems, are immediately implementable by the Iowa Department of Transportation (DOT).

The proposed local calibration factors can facilitate the implementation of PMED version 2.5.5 in Iowa, and the recommendations summarized above have the potential to significantly improve the accuracy of performance predictions for Iowa's pavement systems.