Development of Pavement Structural Analysis Tool (PSAT) for Iowa Local Roads

tech transfer summary

This study developed a user-friendly tool that allows local agencies to understand the current structural capacities of their pavement assets, prioritize their preservation and rehabilitation needs, and make better-informed pavement infrastructure decisions.

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RESEARCH PROJECT TITLE
Development of Pavement Structural Analysis Tool (PSAT) for Iowa Local Roads

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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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Background and Problem Statement

Many Iowa county pavement systems have multilayered pavement structures of varying ages, thicknesses, stress levels, materials, conditions, and past traffic impact resulting from multiple cycles of pavement construction and renewal. Such complex pavement structures challenge Iowa county engineers' efforts to estimate the structural capacities of in-service pavements and to develop cost-effective decision-making strategies for the management, maintenance, and rehabilitation of county pavement systems.

This challenge creates a need to establish reliable and accessible methods and tools for Iowa county engineers to use in routine pavement analysis, design, and asset management applications, as well as to facilitate effective communication with the public and elected officials regarding pavement needs.

Key Objectives

- Develop a Pavement Structural Analysis Tool (PSAT) for county engineers to use in routine pavement analysis, design, and asset management practices on Iowa's local roads and to support effective communication regarding pavement needs to both the public and elected officials
- Analyze structural capacity for multilayered pavement systems in which each layer has a unique age, thickness, material, physical condition, modulus, and prior traffic carriage impacts
- Develop a systematic approach for generating a highly realistic annotated synthetic database representing the characteristics of county-level field data
- Utilize artificial intelligence methods such as artificial neural networks (ANNs) to develop surrogate pavement response modeling
- Propose an equivalent layer thickness theory to simplify multilayered pavement systems into three-layered pavement systems with one asphalt concrete (AC) layer, one base layer, and one subgrade layer
- Develop algorithms and approaches for estimating the current and future structural capacity and remaining service life (RSL) of pavement systems

Research Description

The research team conducted an initial review of the equivalent layer theory (ELT) concept, including an evaluation of different ELTs and a comparison in terms of pavement responses and a review of mechanistic- and ANN-based pavement structural analysis models.

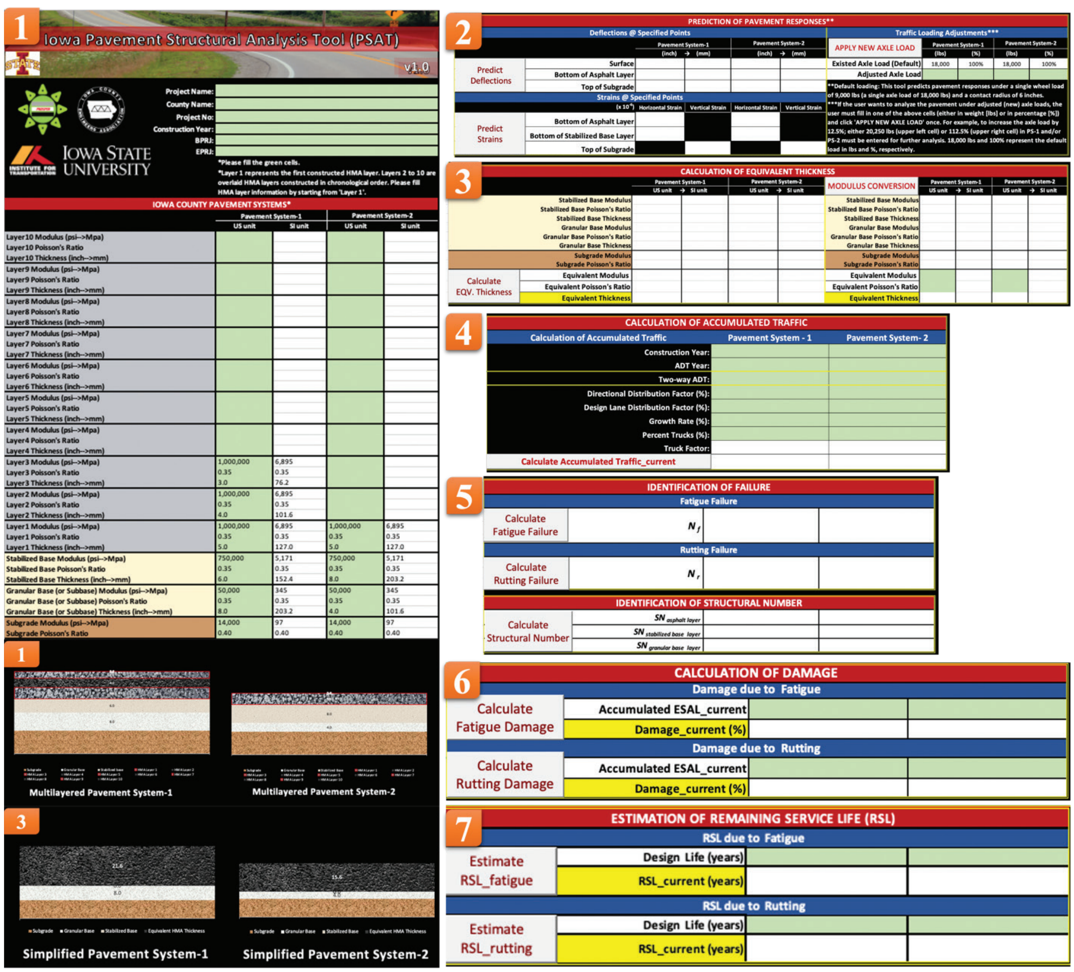
The team established a detailed step-by-step methodology for developing a synthetic database derived from real pavement data obtained from the Iowa Department of Transportation and the Iowa County Engineers Association Service Bureau. The synthetic database includes inputs and outputs for developing the ANN models. Input parameters consist of structural design and mechanical properties including modulus of elasticity, Poisson's ratio, and thickness of pavement layers. Outputs parameters, which are critical pavement responses consisting of deflection and strain, were computed using the MatLEA (MATLAB Layered Elastic Analysis) software program.

ANN-based pavement response prediction models were then developed using the generated synthetic database.

A total of six ANN models were developed (i.e., for pavement systems with a (1) stabilized base, (2) granular base, and (3) stabilized base and granular base/subbase, (a) deflection and (b) strain predictive models were developed).

The research team proposed a variety of algorithms and approaches to estimate the current and future structural capacities of Iowa county roads using the primary structural failure modes of flexible pavement (e.g., fatigue and rutting).

Finally, the researchers developed a macro-enabled Microsoft Excel spreadsheet and Visual Basic for Applications-based tool, the PSAT, to assist engineers in estimating structural capacity, damage, and RSL of Iowa county pavement systems in terms of fatigue and rutting failures. The tool provides analysis options for AC pavement systems with 1 to 10 layers including those on a stabilized base, on a granular base, and on both a stabilized base and granular base.



PSAT tool interface including panels for (1) input, (2) pavement response prediction, (3) equivalent thickness calculation, (4) traffic calculation, (5) failure identification, (6) damage calculation, and (7) RSL estimation

Key Findings

- A synthetic database was successfully developed and statistically evaluated for three major groups of flexible pavement systems.
- The ANN-based models provided high accuracy in predicting horizontal strains at the bottom of the asphalt layer and vertical deflections and strains on the surface and at the top of the subgrade.
- The mechanistic-based failure models developed in this study are capable of estimating the structural capacities of pavement systems by identifying fatigue and rutting damage and their RSLs. The developed empirical-based model provides a structural number (SN) that indicates the overall structural requirement needed to sustain the design's traffic loadings.
- A simple method was developed to combine multiple overlaid pavement layers with different thicknesses and moduli into a single layer with an equivalent thickness, which facilitates an understanding of the structural capacities of pavement systems.
- The PSAT developed in this study is a user-friendly tool that provides a range of options for analyzing different types of flexible pavement structures.

Implementation Readiness and Benefits

The PSAT developed as part of this project is beneficial to Iowa county engineers responsible for pavement management.

The tool offers users the ability to predict critical pavement responses, calculate equivalent thickness, compute current traffic load repetitions, detect fatigue and rutting failures, compute the SN of each layer, determine damage, and estimate the RSL.

The tool thus helps users make informed decisions about managing paved county roads. This leads to an increase in the overall performance of the pavement network and improvements in pavement preservation and rehabilitation practices.

Recommendations for Future Research

Future phase(s) of this work are recommended to further meet county engineers' needs.

Short-term actions include developing the following:

- A structural performance tool for rigid (concrete) pavements
- A structural overlay design tool

Long-term actions include developing the following:

- An approach for relating mechanistic-based failures to pavement distresses
- A smartphone application version of the PSAT tool
- A platform integrating the Iowa Pavement Analysis Techniques (IPAT), PSAT, and CyROID (for road performance data collection) tools
- A functional overlay design tool