Development of a Life-Cycle Cost Analysis Tool for Improved Maintenance and Management of Bridges

tech transfer summary

Risk-based, probabilistic, life-cycle cost analysis yields a realistic understanding of the costs necessary to maintain a bridge over its service life and can help optimize maintenance plans.

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RESEARCH PROJECT TITLE
Development of a Life-Cycle Cost Analysis Tool for Improved Maintenance and Management of Bridges

SPONSORS
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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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Background

The 2012 Moving Ahead for Progress in the 21st Century (MAP-21) Act requires states to develop and implement a transportation asset management plan (TAMP) for their portions of the National Highway System (NHS). MAP-21 specifically mandates that each state's TAMP includes life-cycle cost (LCC) and risk management analyses.

To calculate the LCCs of its bridges, the Iowa Department of Transportation (DOT) currently uses a type of life-cycle cost analysis (LCCA) that involves determining the expected number of iterations of 10 typical maintenance activities over a bridge's lifetime. The number of iterations and their costs are fixed, but the model is tailored to the three main bridge types in Iowa: prestressed girder, steel girder, and reinforced concrete slab.

While the costs and iterations of these maintenance activities are based on experience, they are not directly tied to historical performance data. More importantly, the current model does not include uncertainty or risk in the input variables.

In contrast, risk-based, probabilistic LCCA relies heavily on historical bridge data to determine the probabilities of various costs that may occur throughout a bridge's lifetime and the potential uncertainties in those costs. Such a model can provide a more realistic understanding of the costs necessary to maintain a bridge and the ways different strategies may affect a bridge over its service life.

Typical corrective maintenance for damaged concrete: epoxy injection

Problem Statement

To help the Iowa DOT comply with MAP-21's risk management requirements, risk must be integrated into Iowa's LCCA method to develop Iowa-specific deterioration models and thereby determine maintenance and repair needs.

Objective

The objective of this project was to develop a user friendly LCCA software tool for Iowa's bridges based on a survival analysis of bridges at various condition ratings.

The tool was to cover the most common types of bridges in Iowa while integrating historical data from various sources into predictive models that account for the maintenance and repair costs incurred during a bridge's service life.

Research Description

The LCCA tool developed in this project focuses on bridge decks, with the possibility of potential extensions in subsequent implementation phases. Bridge decks were chosen due to the relatively abundant amount of data available for this component.

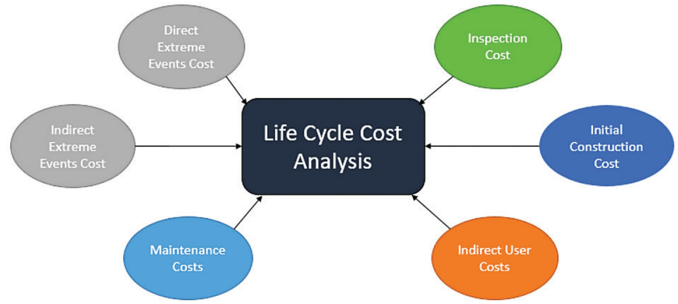
Bridge data were sourced from experts in the field, Iowa's Structure Inventory and Inspection Management System (SIIMS) database, and the National Bridge Inventory (NBI) database.

To create the software tool, an LCCA methodology was first developed that considers the deterioration rates specific to Iowa bridge decks over two-year inspection intervals and aims to predict the agency and user costs associated with preservation, rehabilitation, and repair.

The LCCA methodology involved determining the probability that a given bridge component will transition from one condition state to another over a certain period. To obtain this probability, more than 10 years of historical data were used to determine the hazard rates associated with different condition states and estimate hazard functions. Survival or failure probability distributions for different condition states were then derived, which yielded the average ages of condition ratings.

The software tool developed in this project is a MATLAB-based application called LCCAM. The application is built around a deterioration curve for Iowa's bridges that was derived using the LCCA methodology described above and data from 24,000 bridges in Iowa. The deterioration curve shows bridge deck deterioration over a period of more than 100 years.

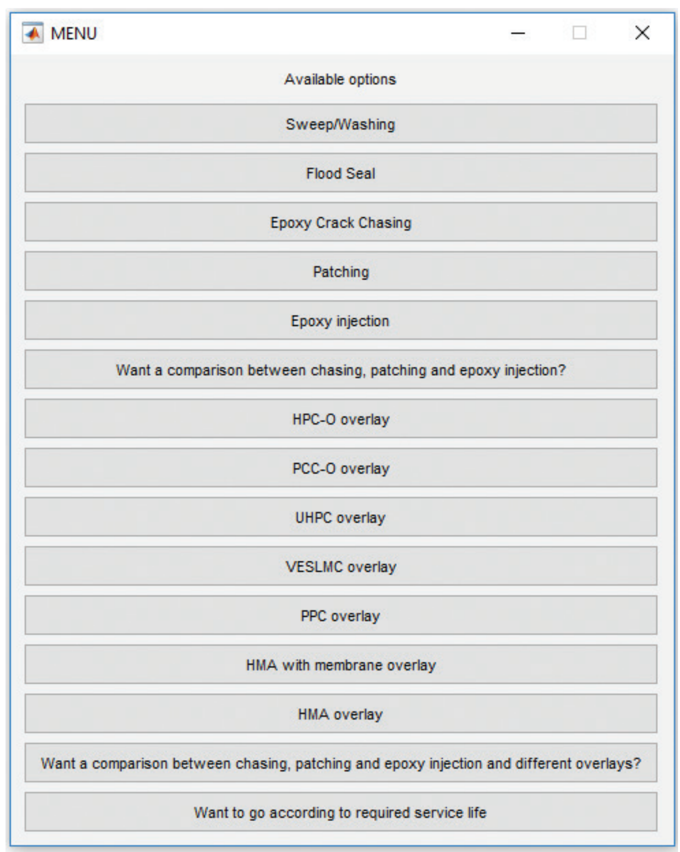
Possible ways that LCCAM can be utilized with other bridge management tools, such as SIIMS and AASHTOWare Bridge Management (BrM), were also investigated.



Life-cycle cost analysis cost inputs

Key Findings

- LCCAM is a user-friendly software tool that allows a user to select the optimal maintenance activity for a given bridge deck by inputting the bridge deck's current condition rating and the threshold rating at which maintenance is required.
- Based on the condition rating inputs, LCCAM presents a menu of all available maintenance options, from which the user can either select a specific activity or compare different activities.
- LCCAM also allows the user to determine the optimal maintenance activity given a required service life improvement.



LCCAM menu showing available maintenance options for an example condition rating input

- The maintenance options in LCCAM are compared in terms of the cost of the maintenance activity, the extension in service life, and the improvement in condition rating.
- LCCAM is able to integrate Iowa's available data and adapt as more data are added over time. As the database grows, so will the calculated confidence levels of the tool's output, allowing Iowa DOT and county engineers and planners to select the most cost-effective alternatives.
- LCCAM allows the user to input the average age of each condition rating as a variable instead of using the deterioration curve included with the application, thereby allowing AASHTOWare BrM-based condition rating predictions to be integrated into LCCAM.

Recommendations for Future Research

Future work on LCCAM can involve determining project selection criteria that optimize maintenance schemes. Consultations with Iowa DOT representatives may provide greater insight into the deciding factors between similar alternatives and help LCCAM provide results in a preferable decision making context.

Close work and interviews with Iowa DOT representatives can also help refine LCCAM's user interface so that it best suits users and explore where the tool can complement AASHTOWare BrM.

Ultimately, a more self-explanatory graphical interface and manual of practice can be developed to help make the tool more user-friendly. Workshops can also help potential users implement the tool.

LCCAM can be extended through the development of degradation curves for all bridge components in addition to the curves developed for bridge decks in this phase of the research. Additionally, the impacts of exposure conditions on the degradation curves can be refined.

LCCAM can further be extended through the inclusion of varying inflation rates and a feature that allows a database of new condition states to be loaded annually.

Implementation Readiness and Benefits

LCCAM provides a user friendly way to thoroughly and realistically evaluate and compare maintenance costs for bridge decks over a bridge's lifetime. With this information, investment decisions can be made in consideration of all maintenance costs during the period over which alternatives are compared.

In its consideration of the variability of future infrastructure investments, LCCAM has an advantage over Iowa's current system, which is to select projects based on the lowest bid or estimated initial costs.

The Iowa DOT's current plan for implementing LCCA in bridge management is to focus its efforts on bridge decks until sufficient data are available to expand the model to other bridge components.

Further efforts to integrate LCCAM with AASHTOWare BrM could lead to swifter and smoother assimilation of the tool among Iowa's agency personnel. Additional inspection data requirements can also be mandated and then input into AASHTOWare BrM to provide a crucial data source for LCCAM.