Asset Management, Extreme Weather, and Proxy Indicators

tech transfer summary

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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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Predicting the vulnerability of transportation assets to flooding can help decision makers better allocate resources and funding for maintenance, repairs, and future construction.

Project Goal and Objective

The objective of this project was to develop a suite of methodologies and proxy indicators to assess the risk of bridges and pavements to flooding. This pilot project is part of ongoing efforts by the Iowa Department of Transportation (DOT) and the Iowa Highway Research Board (IHRB) whose shared goal is to develop the state's risk-based transportation asset management plan (TAMP).

Problem Statement

In light of the growing risk of severe weather events, the Iowa DOT needs to assess the potential exposure of the state's transportation assets to flooding, define appropriate vulnerability measures or proxy indicators, and develop suitable mitigation strategies and response plans.

Background

As the most common natural disaster in the United States, floods pose a serious threat to the transportation network, often impairing travel mobility and damaging infrastructure assets. In Iowa, for example, the 2008 Cedar and Iowa River floods resulted in the closure of multiple Interstates, bridges, and major highways.

Climate models predict that the frequency and intensity of precipitation in Iowa will increase in the coming years, leading to an increasing number of severe flood events and greater stresses on transportation assets.

Iowa Civil Air Patrol
Flooding of the Cedar River in downtown Cedar Rapids in 2008

Following the requirements of Moving Ahead for Progress in the 21st Century (MAP-21), the Iowa DOT is developing a risk-based TAMP for the state's portion of the National Highway System (NHS). A key consideration for the TAMP is to incorporate the risks associated with extreme weather events, including flooding, into asset management tools and decision making processes.

Research Methodology

Proxy indicators that can help predict the vulnerability of transportation assets to flooding include locations of frequent flooding, an asset's structural condition, an asset's criticality to the transportation network, and historic flood-related damage to the asset.

Two sets of methods for developing proxy indicators were used in this study, one for bridges and one for roads.

Bridges

A bridge sensitivity index was developed using National Bridge Inventory (NBI) data for state-maintained bridges over waterways in Iowa (1,869 bridges). Bridges were rated according to indexes developed for stream channel instability, structural condition, and criticality to the transportation network. The indexes were then weighted and combined to determine an overall sensitivity rating for all bridges in the sample.

An analysis using historical data collected for the Federal Highway Administration's (FHWA's) Emergency Relief program from 1998 to 2014 was conducted to identify the probability of flood-related damage to bridges based on prior damage. Relationships were examined between various bridge parameters and the probability of and cost of repair for three types of flood damage: abutment/berm erosion, pier scour, and pier debris.

To determine the effects of different flooding scenarios on the transportation network, flood elevation data for 2-, 50-, 200-, and 500-year floods were overlaid on the primary road network of Iowa DOT District 6. Overtopping was used to indicate bridge closures and thereby the impacts of flooding on the network.

Roads

Flood elevation data for 2-, 10-, 100-, and 500-year flood period scenarios were overlaid on the road network in Linn County, Iowa, to determine the effects of road closures due to overtopping on the transportation network. The base and surface pavement type of each road was then overlaid on the flooded segments to determine which pavements would suffer the most flood-related damage.

Key Findings

Bridges

- Bridge sensitivity index scores can be used to determine whether specific bridges are at the maximum or minimum of the sensitivity range and can be used as proxy indicators to monitor and evaluate bridges before flooding occurs.

- A statistically significant difference was found among the mean bridge sensitivity index scores for the six Iowa DOT districts.

- Bridge length was a significant predictor for the probability of abutment/berm erosion during a flood event. Significant relationships were also found between the cost of repairing abutment/berm erosion and bridge age, bridge seat elevation, streambed elevation, abutment type, channel rating, and scour rating.

- Bridge length, pier foundation type, and substructure rating showed a statistically significant relationship to the probability of pier scour during a flood event. Bridge bent had a statistically significant relationship to the cost of repairing pier scour, but significant differences were not found between the different bent types and the overall cost of repairs.

- Pier width and bent type showed a statistically significant relationship to the probability that debris would accumulate during a flood event. No parameters showed a statistically significant relationship to the cost of repair for this type of damage.

- Assuming that the transportation network performs at 100% when no flooding is present, performance decreases to 84.7% during a 2-year flood event and continues to decrease with higher intensity flooding. Similarly, both traffic delay times and travel times increase as flood intensity increases.
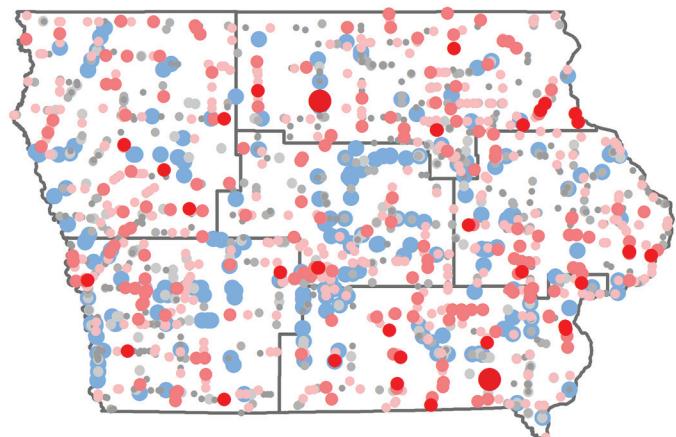
Heat map showing bridge sensitivity index scores for bridges across Iowa, with the darkest red and lightest blue dots indicating the most and least sensitive bridges, respectively
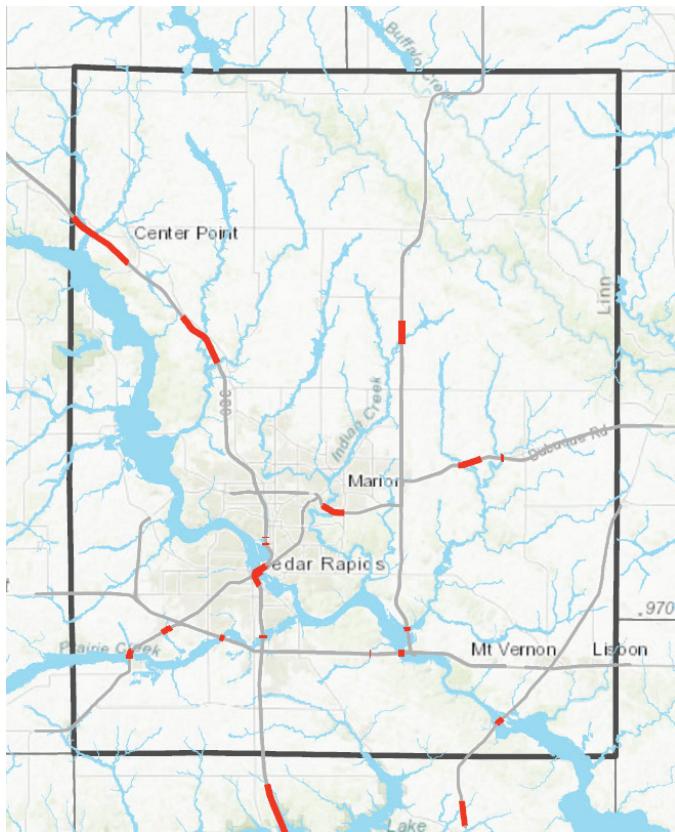
Anticipated road closures (marked in red) in Linn County, Iowa, for a 100-year flood

Roads

- Because most of the pavements in Linn County had portland cement concrete surfaces, flooding could be expected to accelerate the deterioration of the road system if the flooded pavements already show signs of transverse cracking or distortion.

- Because the base layers for most of Linn County's pavements were hot mix asphalt, flooded roads could be expected to lose strength within two hours of submersion.

Recommendations for Future Research

- The bridge sensitivity index can be much improved by incorporating additional geomorphic information about the waterways into the stream channel instability index. Qualitative data from the SIIMS database could be extracted and coded to meet this need.

- The bridge sensitivity index might be more appropriately presented as a matrix rather than a linear scale, with the bridge sensitivity index score along one axis and minimum structural rating along the other. This would ensure that the bridge sensitivity index does not overshadow any structural deficiencies with the bridge.

- The analysis estimating the probability of flood damage based on historical data would be much improved by a larger sample size. Future analyses should use flood elevation and bridge parameter data for the entire state of Iowa rather than only District 6.

- The sample size can be further increased by making additional efforts to match these damage reports to bridge records, perhaps using other databases or enhancing the existing ones.

- The analysis can also be refined by using water elevation and water velocity data to determine the relationships between these parameters and the costs of repairing flood damage.

- Flooding can damage bridges before overtopping occurs. Hence, this analysis could also be expanded by examining the probability of flood-related damage at lower flood stage elevations.

Implementation Readiness and Benefits

The proxy indicators identified in this study—such as the bridge sensitivity index, various bridge parameters, and pavement type—can be used to identify vulnerable assets and target them for appropriate monitoring and maintenance. Being proactive on inspections and maintenance can help agencies avoid more costly repairs after flood events.

The methods for identifying these proxy indicators can be integrated into the development process for the Iowa DOT's TAMP to create a more resilient, cost-effective, and better quality transportation network that is prepared for future flooding events.

In addition to contributing to a risk-based TAMP, the methodologies and proxy indicators developed in this research can complement parallel efforts to assess and enhance the resiliency of Iowa's transportation infrastructure.