Assessing and Enhancing Transportation Resilience for the State of Iowa

tech transfer summary

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RESEARCH PROJECT TITLE
Assessing and Enhancing Transportation Resilience for the State of Iowa

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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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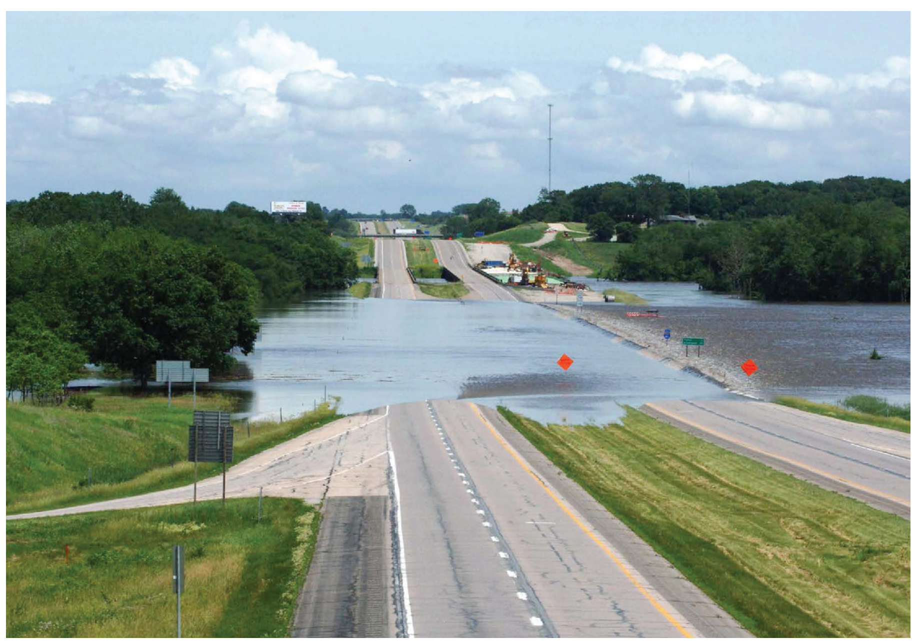
The results of this project are expected to help the Iowa DOT optimize and prioritize investments while enhancing resiliency of the transportation system in the long run.

Problem Statement

Flooding is a destructive hazard and can cause enormous direct and indirect losses to the transportation network, including closure of transportation assets, reduction of system connectivity and accessibility, extended traffic delays, and long out-of-distance miles that can result in the cancelation of trips. Inland regions, and particularly those in the vicinity of river basins, experience adverse impacts from intense flooding on an annual basis. Decision makers, designers, and planners are constantly required to improve the conditions of transportation assets to combat flooding in planning for the consequences of road and bridge closures.

Goal

The goal of this project was to develop a system-level resilience framework that can eventually be used as a tool by Iowa Department of Transportation (DOT) engineers to optimize and prioritize investments while ensuring that the transportation system is capable of absorbing shocks, adapting to changing conditions, and rapidly recovering from disruptions.



I-80 in eastern Iowa overtopping from floods in 2008

In this study, a robust pathway to achieving resilience was associated with three major components:

- Capacity of the system to absorb the shocks induced by flooding events either by having mitigative measures that make the transportation network less vulnerable to flood events (such as higher elevations of roads and bridges and scour mitigation strategies for bridges, to name a few) or by providing alternative routes to potentially vulnerable roads and bridges to maintain connectivity and accessibility after damages occur.

- Organizational capacity of the transportation agencies to restore the functionality of the network in the shortest possible time (and with minimum cost) after flooding events, to reduce the recovery time with pre-defined plans, emergency contracts, and budgetary and human resources ready to be deployed (and potentially using strategies such as accelerated bridge construction for faster recovery)

- Capacity to plan for failures with the goal of benefitting from the window of opportunity provided to build to a better standard in such a way that the vulnerability of the transportation asset to future events of similar or even higher scales is reduced in the long term

This study focused on the first component with established plans to address the other two components in future.

Objectives

- Define resilience goals or targets (e.g., functionality level after disruptive flood events)

- Understand system characteristics (e.g., resolution level on the network)

- Characterize disruption scenarios (e.g., extreme flood at various locations on Iowa road network)

- Estimate the consequences of failures (e.g., level of physical loss, traveler delay, economic loss, loss of accessibility)

- Develop a robust the multi-scale resilience index (MRI) to assess the impact of different failure consequences

- Find optimized solutions for possible mitigative impacts, especially in hotspot regions using an actual case study region

Background

Following the requirements of the Moving Ahead for Progress in the 21st Century Act (MAP-21), each state is required to develop a risk-based asset management plan for the National Highway System (NHS) to improve or preserve the condition of the assets and the performance of the system. One of the challenges of incorporating risk (and resilience) with asset management is the lack of a standard framework to identify and prioritize critical assets, and to quantify the impact of threats.

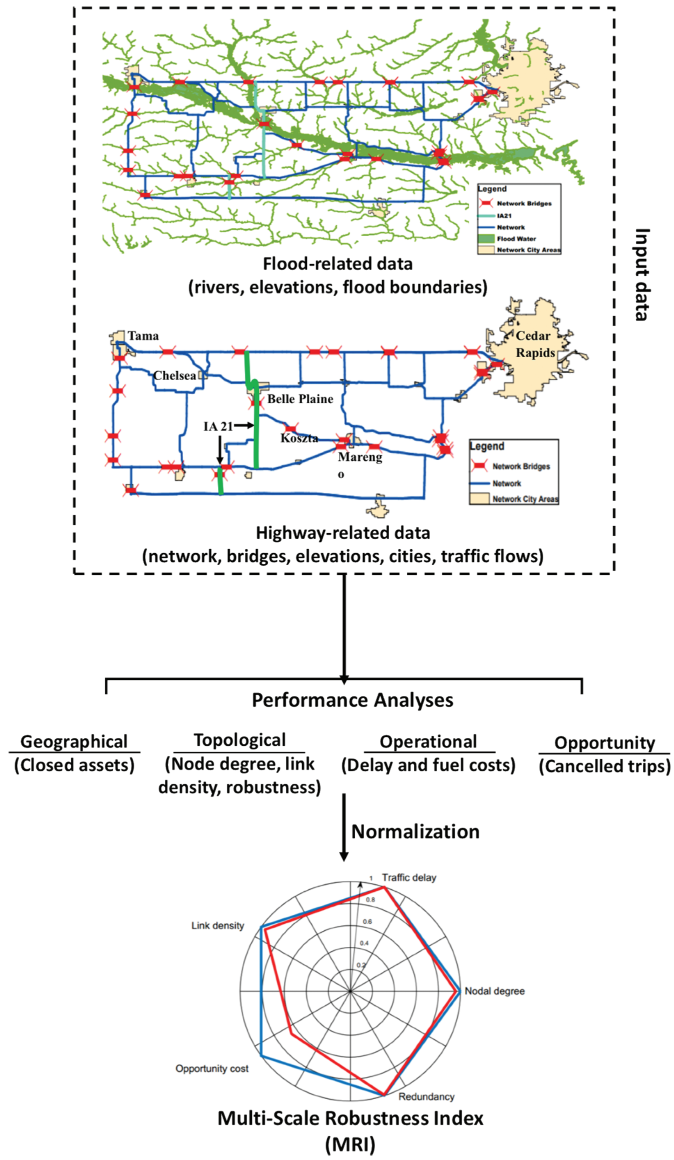
MAP-21 requires the enhancement of safety, infrastructure condition, system reliability, economic vitality, and environmental sustainability and also the reduction of traffic congestion. Implementing resilience, on the other hand, aims to design a system that can stay functional or return to functionality in a rapid manner when an operational disruption or an extreme event occurs.

The Iowa DOT is planning to include resilience indices as a factor for planning and investment purposes. One of the key measures used to evaluate the performance of transportation networks is to identify the extent of disruptions, where transportation network elements, including nodes and links, are disabled, degraded, or destructed either randomly or intentionally, hindering mobility and traffic flow.

Research Description

Considering the severe floods that Iowa has suffered in recent years, this project assessed and evaluated how to cost-effectively enhance transportation resilience for the Iowa highway network in mitigating flood-prone transportation assets. The research team worked on defining and validating appropriate procedures that will form the cornerstone of resilience assessment and enhancement strategies customized for Iowa's highway transportation network.

To address these issues, the MRI was developed and used to account for the impact of different measures on network performance after flood events. The MRI uses a radar chart to describe the robustness of each measure after the transportation network has been disturbed by flooding and uses a ratio of residual network functionality to intact functionality to describe the integrated network's ability to absorb and adapt to hazards. Development of the MRI was a unique endeavor that required use of data from multiple offices and bureaus within the Iowa DOT and beyond.



Flow chart illustrating the multi-scale resilience index methodology of this study

To prove the robustness of the developed MRI as a means to assess and enhance the resilience of a transportation network and use as a tool for prioritizing projects and strategizing pre-event mitigation and post-event recovery strategies, two different projects were undertaken.

The first project used the deployed MRI on the large network of Iowa Dot District 6. Under different flood scenarios with various return periods, the applicability of the MRI was highlighted as it provided a robust means to find hotspots. The available options to adjusting weights of different contributing measures in the MRI allows for inclusion of the DOT's missions and goals as they change for the purpose of decision making.

In the second project, the applicability of the MRI was examined at the project level. For this purpose, IA 21 in east-central Iowa, which has had multiple recurrent flooding events in recent years was chosen. This highway is an important part of the network because it is one of the few north-south roadways in the area. The problem is that, once IA 21 floods, there is no close travel route to the west or east that is usable given other roads also being flooded.

In this project, the MRI was used to measure the impact of different flood mitigation strategies considering different return periods for flood events. The considered mitigation strategy was to raise the roadway (which was a strategy being considered by Iowa DOT staff to prevent the recurrent closures on this road). A benefit/cost analysis based on the MRI concept was used to assess the best strategy under the variety of flood hazards.

Key Findings/Results

This project developed a holistic framework to assess the resilience of the transportation network in an area prone to inland flooding as a first component of achieving resilience for the Iowa DOT. The framework was unique as the different measures considered in its development account for different characteristics of a network and are not considered in silos. For instance, the framework is capable of considering loss of connectivity but at the same time accounts for the fact that some segments of the system may become isolated and, as such, cancels out traffic accordingly.

The framework integrates the direct damage analysis on the closure of roads and bridges based on flood water depth, a connectivity functionality analysis by using indices of graph theory, and a flow-based network performance analysis to capture the indicators associated with socio-economic losses. The composite action of these measures provides a holistic view of the transportation system, and one that was not developed before.

By application of the developed methodology on a large segment of the Iowa DOT primary system (in District 6), it was shown that the framework is capable of highlighting the hotspots in a system and provides a robust means to select locations of interest for pre- or post-event planning purposes. The framework consists of a composite of different measures that capture not only aspects such as connectivity and level of system redundancy, but also represent the level of loss to the traveling public. The framework was developed such that the weights for each of the measures can be adjusted to represent the specific transportation agency's needs, missions, and goals.

The applicability of the framework in a project basis context was tried out on a smaller road segment (IA 21) that was shown to be flooded on a regular basis in recent years. For this purpose, a proposed mitigation approach by Iowa DOT engineers was considered and the benefit/cost analysis of the mitigation strategy was assessed using the developed MRI.

The project was able to use the historical repair costs from past events—from a parallel project currently ongoing—to realistically approximate the cost to repair closed roads and bridges if they were to be damaged. Many parts to this study originated from actual events and data that the Iowa DOT and the research team have accumulated over the years. This strengthens the validity of the findings of the research.

This study was complex and thorough compared to other studies in the past. The holistic view of direct and indirect costs in addition to the performance and robustness of the network is a new methodology. The scale at which this was done is also innovative.

Implementation Readiness and Benefits

This project provides a meaningful and easy-to-implement procedure to evaluate the likelihood of damages to the transportation network due to flood events, estimate the direct and indirect losses associated with such closures, and use the results as a tool to prioritize different projects while considering the long-term implications of mitigation efforts on the life cycle of assets considering the likelihood of flood events.

The results of this project's systematic efforts are expected to eventually be integrated into a project prioritization tool (PPT), which the Iowa DOT is currently developing, and help optimize and prioritize investments while enhancing resiliency of the system in the long run. The PPT development team is considering different factors in decision making for ongoing and future DOT investments and it is expected that MRI will be one of those.

The discussions with the project technical advisory committee and the PPT development team provided a clear path for the implementation of the MRI as a factor in the decision-making process. It is expected that the current infrastructure developed for the PPT provides an excellent basis for the MRI to be further developed and ran as an add-on module to the PPT.

The team also foresees adding to the holistic nature of the MRI by including the other two components to achieve resilience: developing a methodology to assess the recovery rate of the damaged assets based on the extent of damage observed in them and using the framework as a means to prepare for potential failures (for those assets that were not mitigated) such that they are re-built to sustain future events of similar scale. On the first component, without consideration of the extent of damage and rate of recovery, the whole nature of resilience would not be achieved.