# Modeling Multi-modal Freight Transportation Network Performance under Disruptions: Iowa Case Study

Micah Makaiwi, Jing Dong, and Navid Shafieirad
Institute for Transportation at Iowa State University

## Introduction

Freight transportation is a major source of traffic on our roads and greatly affects the entire economy. Disruptions—both short and long-term—to the transportation network can directly impact freight, causing an increase in the price of goods and increased congestion. Compared to passenger traffic, much less research on freight transportation exists, partly due to the proprietary nature of the industry. This research presents a simple multi-modal model to measure the performance and characteristics of regional freight flows when parts of the network face disruptions.

A case study using cereal grains shipped from Iowa was used to create the model. The model assumes that total origin-destination flows are constant before and after the disruption in the long-term. The Federal Highway Administration's Freight Analysis Framework 3 data-set for 2007 was used to determine the volume of cereal grains from Iowa. Similar FAF3 destinations were grouped together in order to simplify the model. A GIS model was used to create multiple routes to each destination on the available modes: road, rail and inland waterway.

## Methodology

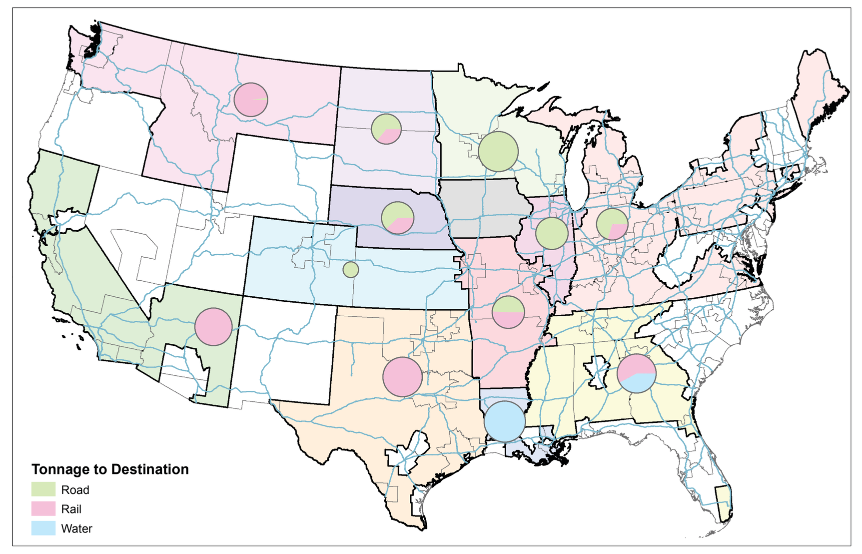
1. A GIS basemap was created using the following layers:
   - The FAF3 shipping regions
   - The National Highway Planning Roadway Network (joined to the FAF3 traffic data)
   - The Rail Network (National Geospatial Data Asset [NGDA] Database)
   - Commercially Navigable Waterways (NGDA)
   - Digitized rail terminal points (from railroadpm.org performance data)
2. The FAF3 geographic regions were aggregated into 11 regions based on the shipment volume of cereal grains from Iowa
3. For each region, between 4 and 7 alternate routes on multiple modes were created manually.
4. A generalized linear regression model using a logistic regression was created to estimate modal share during disruptions.
5. A terminal delay model was used to model the delay at locks, dams and railroad terminals along the network.
6. Three different disruptions were then hypothesized and modeled.

## Acknowledgments

The initial literature review and setup for this project was done by Yundi Huang. All shape data is from the federal government: Freight Analysis Framework 3, Commodity Flow Survey, TIGER/Line, National Highway Planning Network, National Railway Network and the National Navigable Waterway network.

## Route Aggregation

Due to the immense number of FAF3 regions Iowa Ships cereal grain to, the routes were aggregated my geographical regions. Pains were taken to ensure that each route has similar tonnage shipped and comprise of similarly made up states. The final route aggregation is below. (White indicates regions that do not receive cereal grain shipments from Iowa)




## Mode Choice Model

A small generalized linear model was used to determine what factors influence modal share for cereal grains shipped from Iowa. The model is a nested logit. The top nest estimates the percent of tonnage using inland waterways (for routes where that is available). The second nest takes the remaining tonnage and determines the share of rail vs. road.

Nest 1 (if applicable)
- % share of Water
- % share of Land
  - % share of Rail
  - % share of Road

**Water vs. Land Mode Share Model**

| | Estimate (error) | t-value | p-value |
|---|---|---|---|
| Constant | -9.72 (0.428) | -22.66 | 0.0019 |
| Total Tonnage to Destination | 0.0036 (0.0001) | 26.50 | 0.0014 |

**Road vs. Rail Mode Share Model**

| | Estimate (error) | t-value | p-value |
|---|---|---|---|
| Constant | -14.47 (4.48) | -3.22 | 0.0104 |
| Average Road Speed | 0.250 (0.073) | 3.43 | 0.00747 |

## Literature

Assad, A. A. (1980). Models for rail transportation. Transportation Research Part A: General, 14(3), 205–220.

Huang, Y. (2014). A Case Study of Freight Network in Iowa. Internal Document.

Lingaitien, O. (2006). Modelling the demand for vehicles in the logistic chain of freight transportation. phd, Vilnius Gediminas Technical University.

Ortúzar, J., & Willumsen, L. G. (2001). Modelling transport (3 ed.). Chinchester, UK: Wiley.

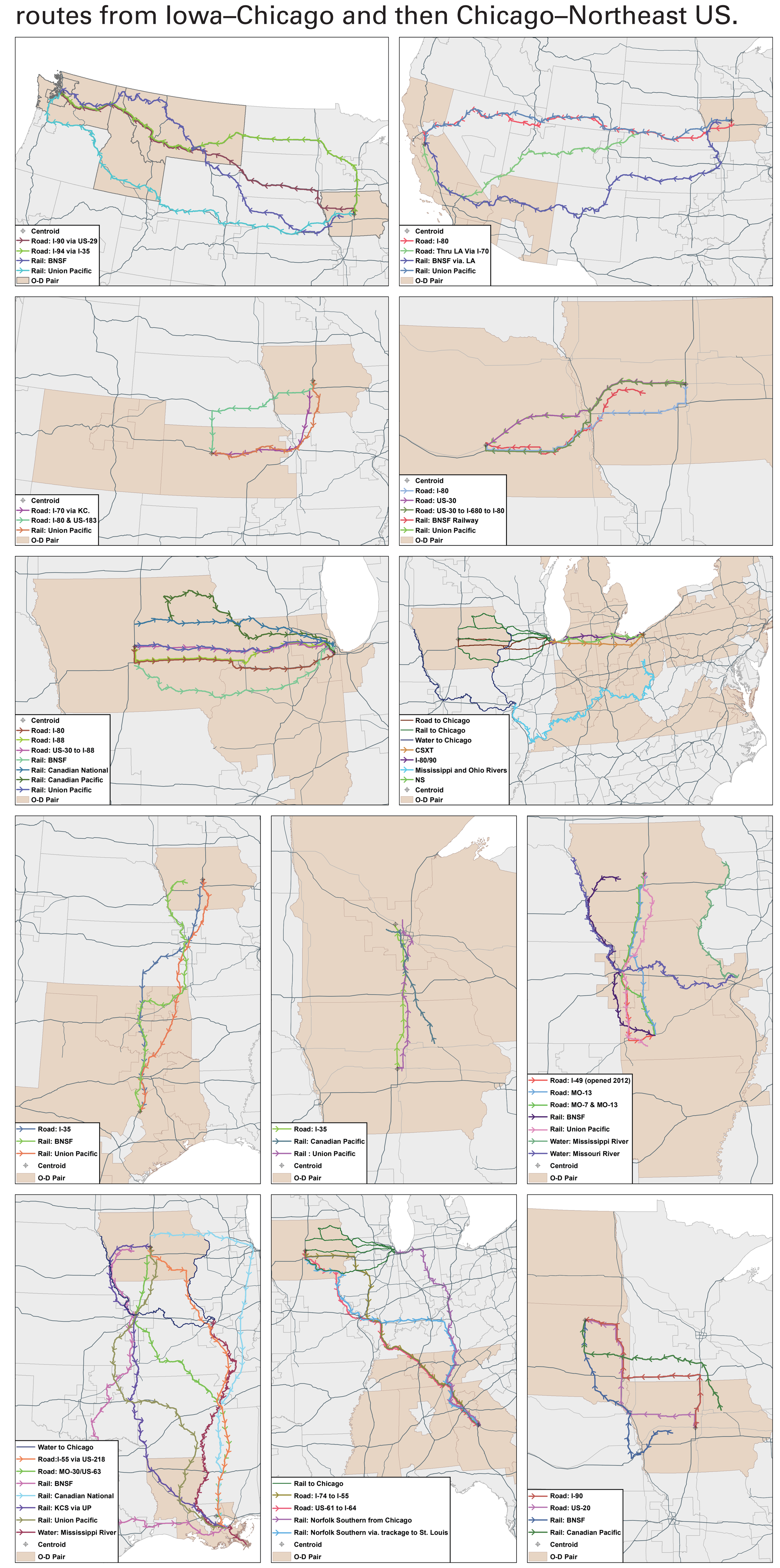
Oum, T. H., & Waters III, W. G. (2000). Transportation Demand Elasticities. In D. A. Henser, & K. J. Button (Eds.), Handbook of Transport Modeling (pp. 192–210). Amsterdam; New York: Pergamon.

## Creating Routes

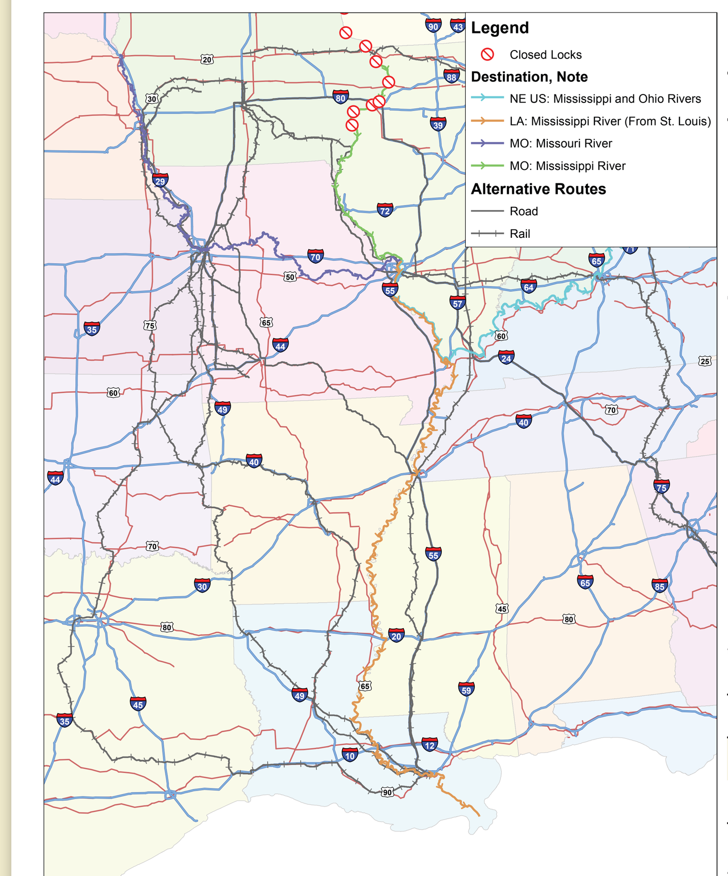
For each destination, between four and seven routes were created on different modes. Each route runs between the centroid of Iowa and the weighted centroid of the destination region.

The road routes mostly run on Interstate Highways with a small amount of US and State Highways. The rail routes are organized by Class I carrier. Where possible, track owned by the carrier was used, otherwise where they had trackage rights. Only a few destinations have plausible water routes.

In many cases, Chicago (for road and rail) and St. Louis (for water) are used as hubs. For instance, to get to the Northeast US centroid from Iowa, all valid routes enter through Chicago. Therefore, the routes to the Northeast are a combination of routes from Iowa–Chicago and then Chicago–Northeast US.



## Disruption 1: Mississippi River Lock Delays



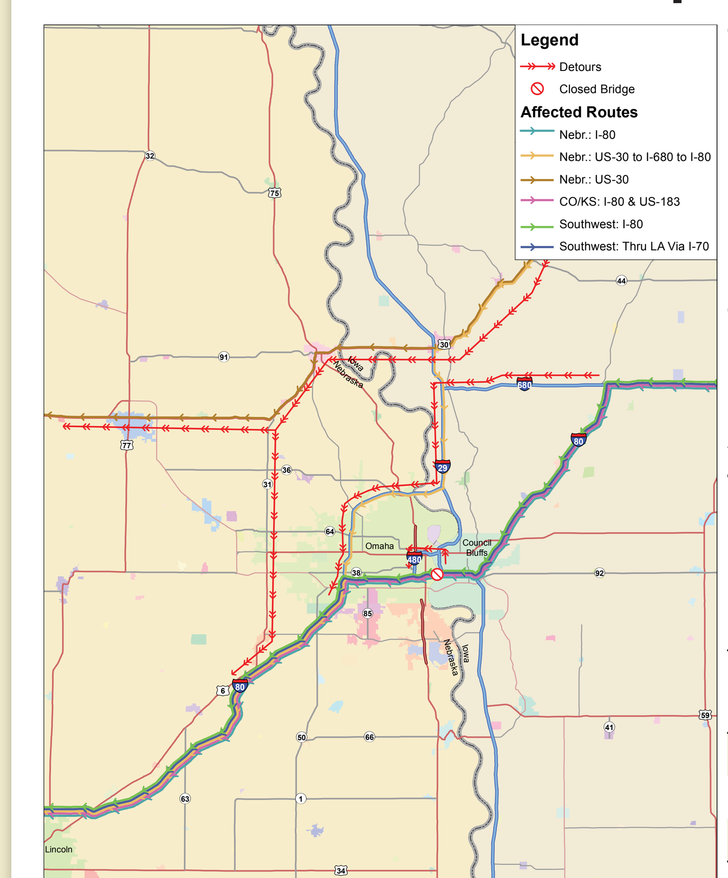
It is not unprecedented for the Mississippi River to be closed to barge traffic for extended periods of time due to either water flows that are too high or two low for operating the locks. In this situation, shippers have a few options. The first is to delay shipping until the disruption clears. This will cause delays in waiting and delays in congestion once the river is opened. The second option is to divert to road or rail. This is likely to have increased costs but reduced time. The third option is to use another water route. This option isn't always available, but there are ports farther downstream and the Missouri River is also an option.

For Louisiana, which is 100% on water, the mode choice logit model predicted that rail would account for 94% of shipments when water was not available.

| River (to St. Louis) | Length (mi) | # Locks | Travel Time |
|---|---|---|---|
| Mississippi | 358.30 | 14 | 125:30 |
| Missouri | 719.23 | 0 | 143:50 |

All times above are average travel times, which vary greatly depending on traffic.

## Disruption 2: I-80 Bridge Closure



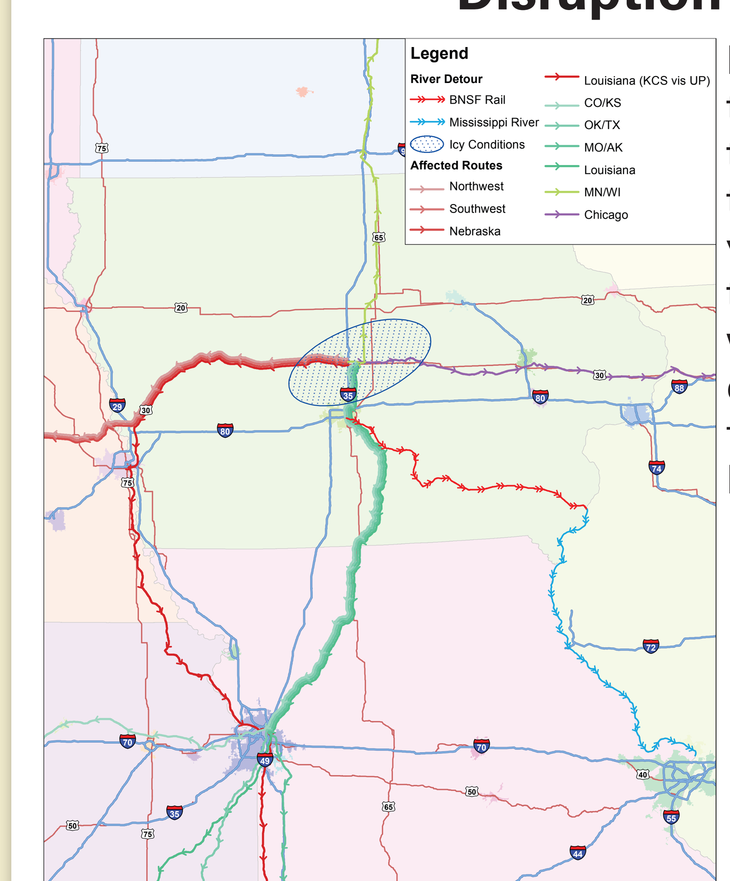
The I-80 bridge over the Missouri River is the major crossing of I-80. The other major crossings in the Omaha–Council Bluffs area are I-480, I-680 and US-30. These crossing are eight, four and two lanes, respectively. I-80 currently has 7 lanes (one axillary). Since the model is for a single commodity only, it does not have the ability to calculated congested travel time. Therefore, the 2007 and 2040 peak values can be used to calculate ranges of travel time during congested periods.

As seen below, US30 to NE31 is the best route under congestion. This is because the route has low traffic and low congestion to begin with; it likely will not preform as well under heavy saturation but likely will work better than I-80.

| Detour | No disruption Length (mi) | No disruption Travel Time Free-flow | No disruption Travel Time '07 Peak | No disruption Travel Time '40 Peak | Detour Length (mi) | Detour Travel Time Free-flow | Detour Travel Time '07 Peak | Detour Travel Time '40 Peak |
|---|---|---|---|---|---|---|---|---|
| I-480 | 3.33 | 0:03 | 0:55 | 8:32 | 7.25 | 0:08 | 2:30 | 12:39 |
| I-680 | 37.17 | 0:35 | 7:19 | 10:52 | 42.49 | 0:38 | 2:21 | 10:43 |
| NE31 | 184.58 | 2:45 | 11:57 | 19:15 | 173.77 | 3:30 | 3:37 | 3:58 |

Note that the NE31 route uses US30, causing the longer travel time and lengths.

## Disruption 3: Central Iowa Rail Closure



Rail is easily susceptible to ice. The Union Pacific railroad's two main lines in Iowa intersect in the center of the state. In the event of a large storm preventing trains' passage through this area, there are a few possibilities. First, freight can be diverted to another railroad in the state. Second, it could divert to another mode. Roadways are more expensive and likely will face delays in central Iowa anyways. Third, grains can be diverted to the Mississippi River using BNSF rail and transfered south away from the weather disruption. The graph below details the delays at a typical lock on the Mississippi.