The University of Texas Rio Grande Valley
Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS)

Vulnerability Analysis of US Rail Infrastructure Using Graph Theory Network Analysis

National Science Foundation

NSF Award No. 2112650

Gabby Gutierrez, Gasser Ali, Ph.D., Constantine Tarawneh, Ph.D.

Abstract

Railway networks are prone to failures of many kinds. Extreme weather tends to cause wear and tear on the rail, resulting in eventual failure. The goal of this paper is to present the absence of research in the area of predictive rail scenario analysis. To achieve this goal, the authors implement a framework to build a graph representation to analyze the rail network of the US, explore the connectivity of the network using node centrality, and perform large scale scenario analysis to study disruptions in the network and their consequences. Knowing when a rail might fail or being able to estimate the cost of failure can put more control into railway owners to properly maintain their tracks and take preventative action rather than wait until something goes wrong.

Introduction & Background

- 328,000 train-delay minutes in 2021 [1]
- Lack of a proper tool to predict potential failures throughout the rail network on a large scale
- **Goal:** Investigate the vulnerabilities of the rail network and potentially develop a tool to analyze it in real time
- **Objectives:**
  - Create a graph network of US railway
  - Perform scenario analysis to estimate impact of natural disasters on train travel time

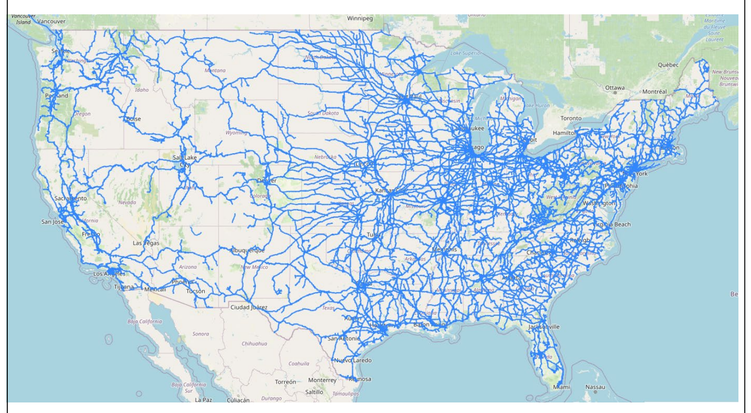


Figure 1:A map of the US rail network About 140,000 freight miles [2]

Methodology

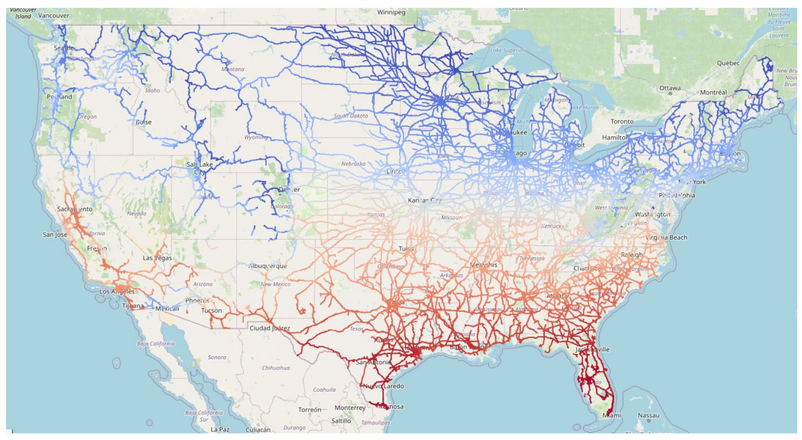
Extract data
- Gather weather data from NOAA (National Oceanic and Atmospheric Association)
- Gather rail data from FRA (Federal Rail Association)
- Gather accident reports from FRA

Implement into model
- Convert the data into a graph network
- Merge weather and rail data
- Analyze all the accident data

Use model to make predictions
- Find alternative shortest paths
- Predict accident chance and possible delay time

Data and Results

Generated maps of the rail network:



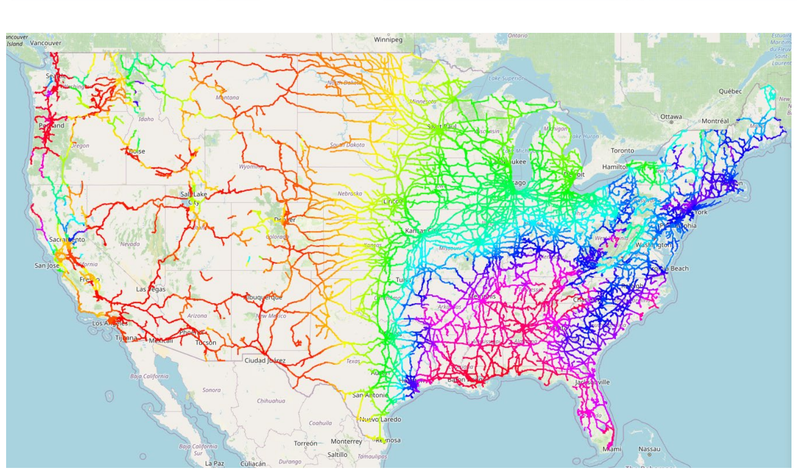


Figure 2: Map of the US rail network with each rails associated average yearly temperature (above) and precipitation (below)

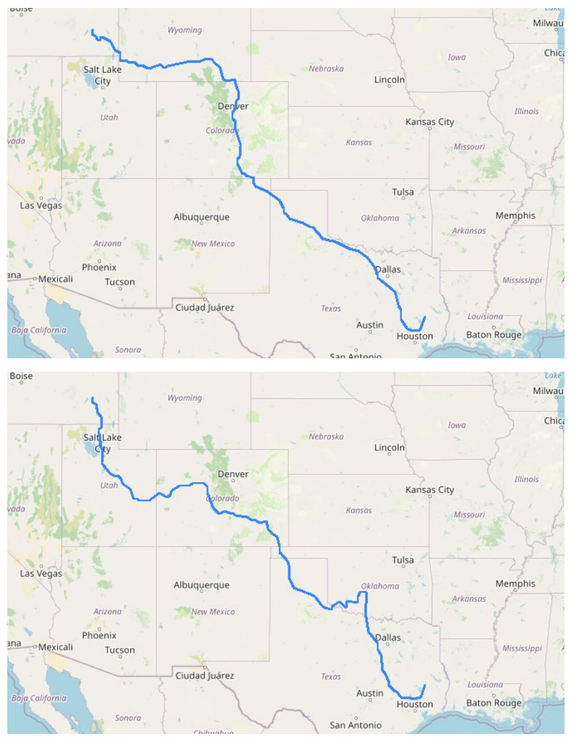


Figure 3: Recalculated shortest path after having removed random rail nodes between start and end points

Map 1 ETA: 35.5 hours traveling at 96km/h
Map 2 ETA: 38.6 hours traveling at 96hm/h

Conclusions & Future Work

- A model to calculate shortest path has been created
- This tool could potentially be useful for rail planners in case of emergencies that a train might need to pass through or encounter
- **Future Work:**
  - Improved vulnerability estimates
  - Traffic analysis

Acknowledgments

We acknowledge the financial support provided by the NSF CREST Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS) through NSF Award No. 2112650.

References

[1]"Rail," ASCE's 2021 Infrastructure Report Card |. Accessed: Mar. 25, 2024. [Online]. Available: https://infrastructurereportcard.org/cat-item/rail-infrastructure/
[2]"Freight Rail Overview | FRA." Accessed: Nov. 12, 2024. [Online]. Available: https://railroads.dot.gov/rail-network-development/freight-rail-overview