Vulnerability Analysis of the US Rail Infrastructure using Network Analysis

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Introduction

The United States rail network has 140,000 miles of track (FRA, 2025), it is one of the most efficient ways to transport freight and passengers, making it a crucial part of infrastructure. Rails are prone to failure due to extreme weather. Heatwaves can cause thermally induced buckling and extreme cold can cause cracking in the rails (Yang and Bradford 2018). Research has investigated the risks of rail buckling using methods such as finite element analysis, methods to measure the rail neutral temperature (RNT), or prediction of accidents using machine learning. These approaches investigate rails on individual rail elements rather than treating rails as a network. This network approach helps to investigate the vulnerability of rails against the effects of weather and help decision makers plan the future of the railroads.

Methodology

The methodology consists of three main parts: data collection and preprocessing, calculating the probability and impact, and finally calculating the severity. Data about the rail, weather, and county GIS are collected. As shown in figure 1, the probability is calculated using a normal distribution with the rail neutral temperature being the point where it is assumed the rail is at its safest. The impact is calculated by finding the difference between the shortest path and an alternate path after simulating failure along the original path. The severity is calculated by multiplying the probability and impact of the rails together, which is done along every rail edge to quantify the vulnerability of the entire network.

Results

Figure 2 shows the mean temperature of the network. Extreme deviations from the mean values were used to calculate the probability of failure. Figure 3 shows severity of the network, which considers both probability and impact. The results show that some areas of the network, such as Midwest and some parts of the South are particularly vulnerable. The Midwest/Northwest has temperate weather and, as such, is susceptible to extreme differences in temperatures. The South is primarily vulnerable during extreme cold, the region is generally very hot and may be susceptible to cracking during cold snaps. The lack of alternative routes along both of these paths makes the rails have a very high impact. Both of these factors combined lead to the rails have a high severity.

Conclusions

The vulnerability of the network is assessed using the probability of failure and impact of the rail. The results show that the probability of failure increase the greater the difference is between the extremes of temperature and the average temperature. Additionally, having many alternate paths decreases the individual impact of the rails. The model can support decisions to prioritize maintenance to certain parts of the rail and build alternative routes that reduce the impact of failures.

References

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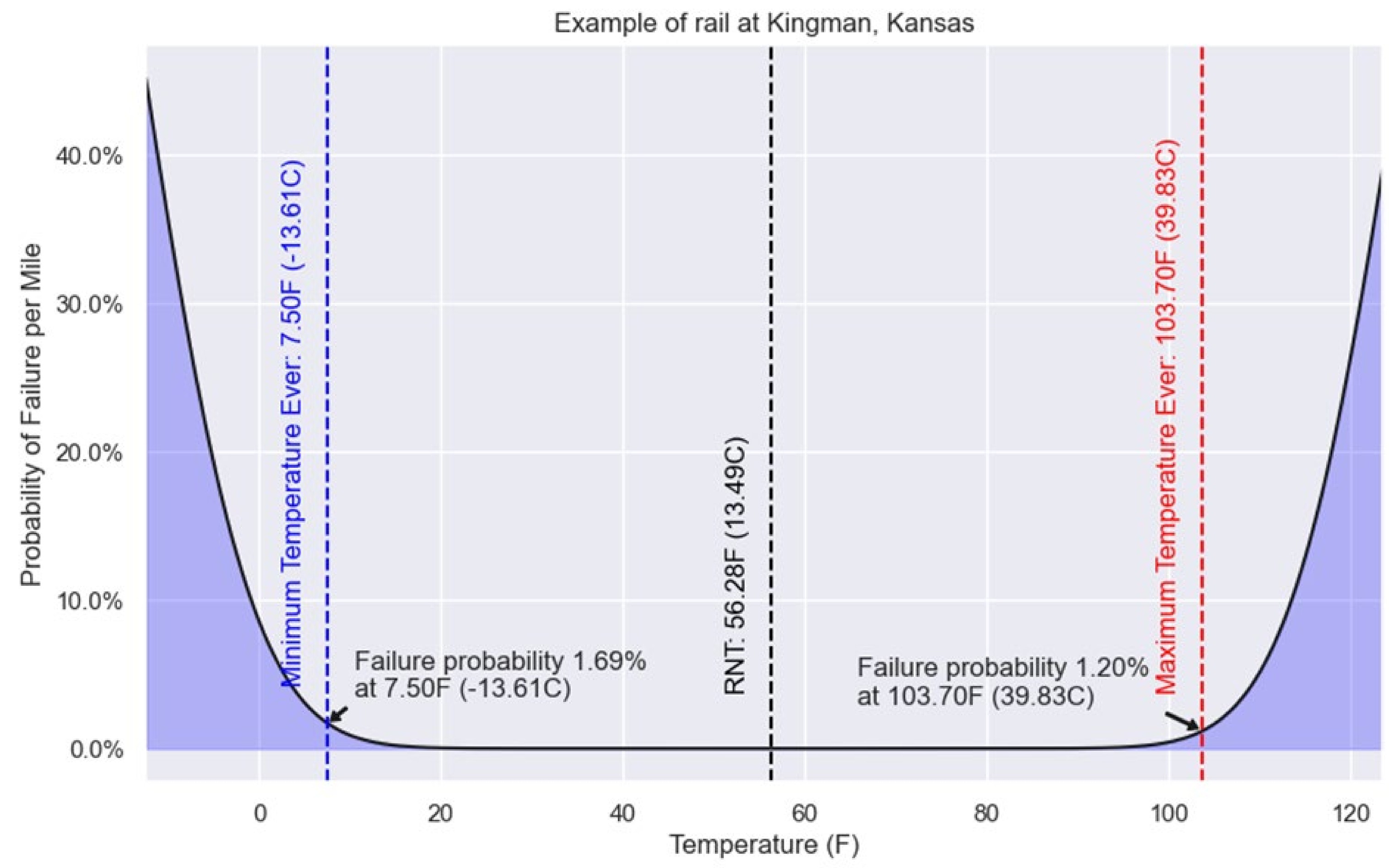

Figure 1: Probability Function

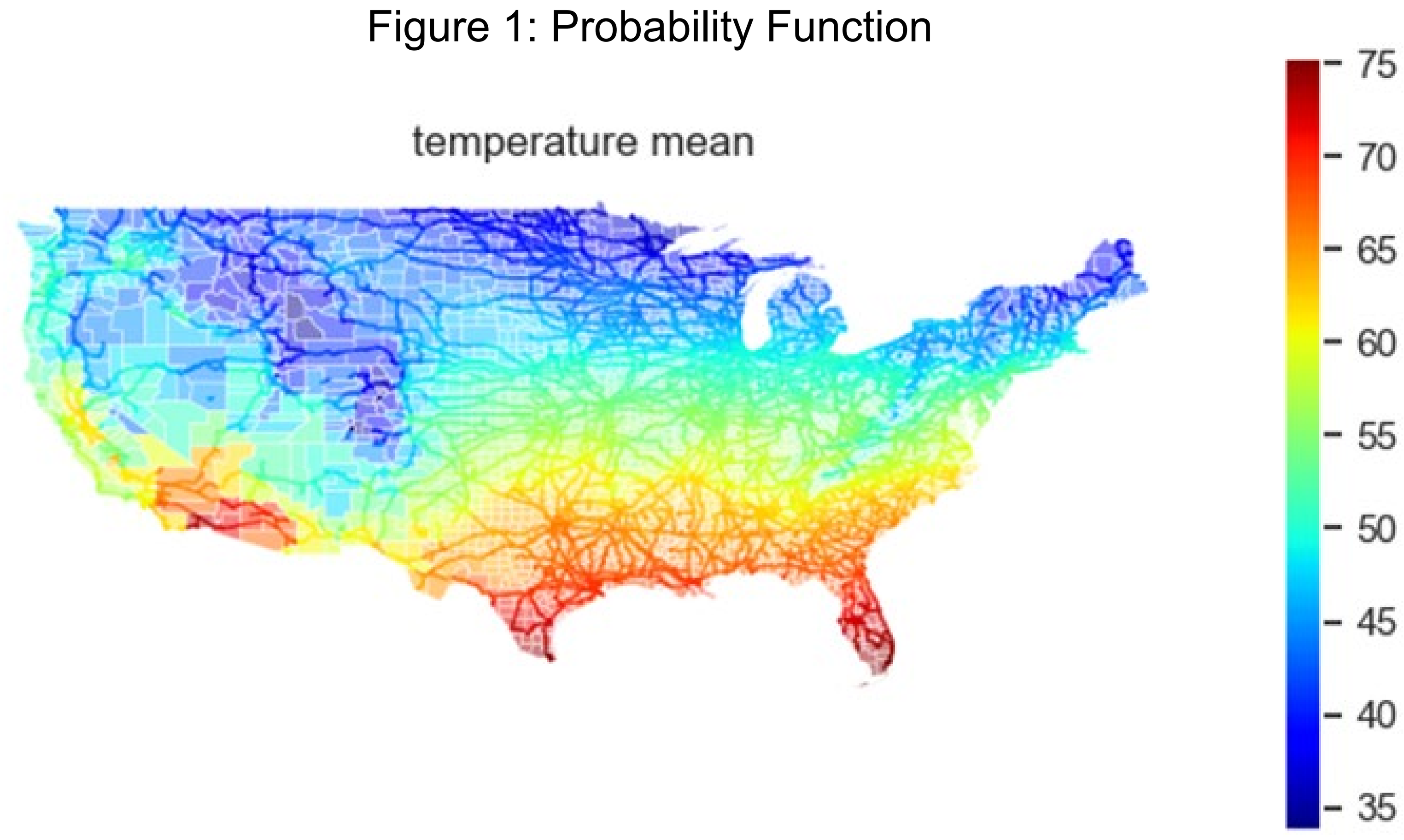

Figure 2: Rail Network Temperature

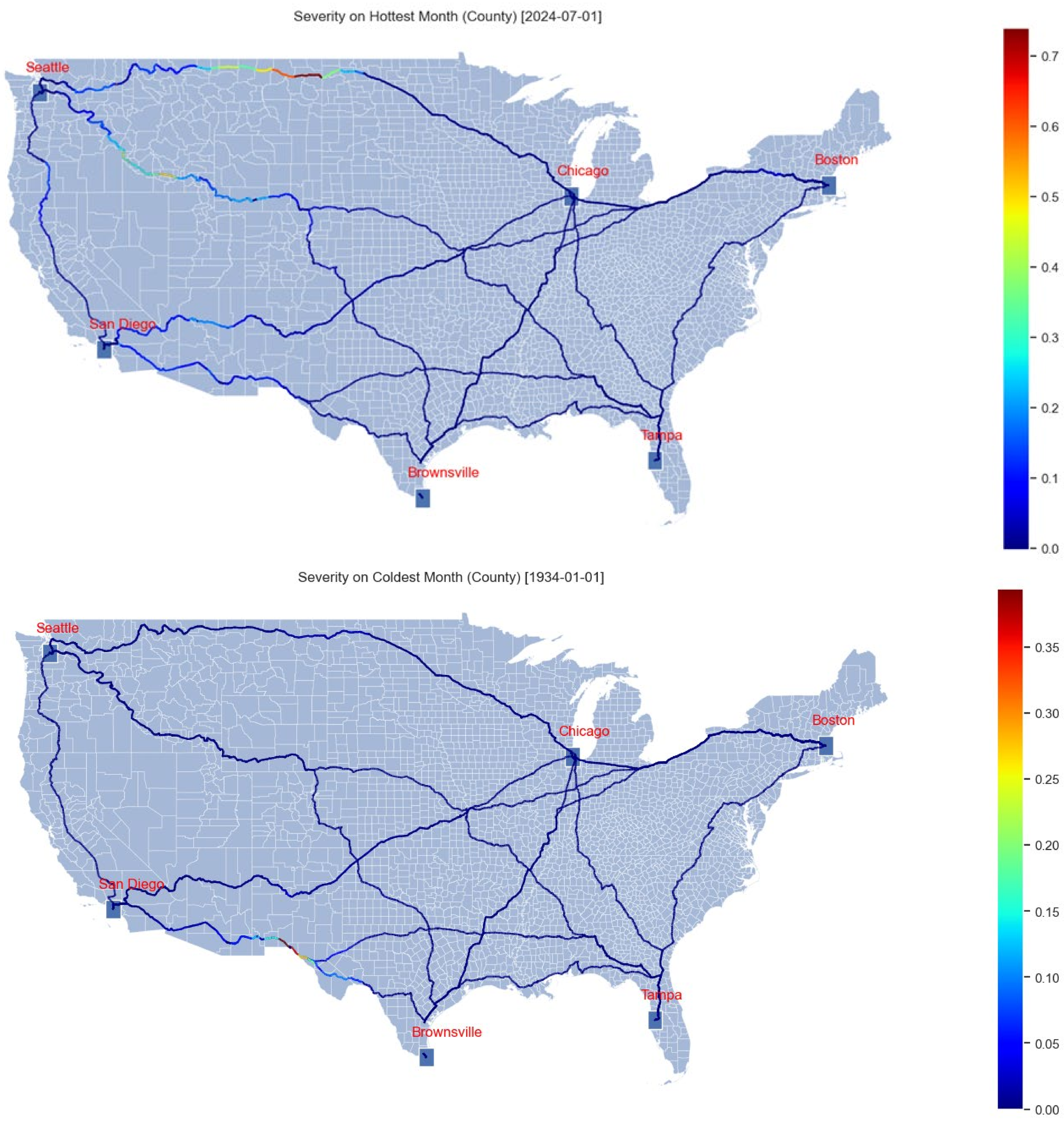

Figure 3: Severity of the rail network on the hottest and coldest days

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