Estimation of logistic transportation system performance under extreme weather condition: A data-driven approach – Project 1

Deliverables and Reporting Requirements for UTC Grants Awarded in 2023 (June 2023)

Exhibit D

Recipient/Grant (Contract) Number: The University of Tennessee; Texas A&M University, Grant No. 69-A3552348338

Center Name: Center for Freight Transportation for Efficient and Resilient Supply Chain (FERSC)

Research Priority: Improving Mobility of People and Goods

Principal Investigator(s): Yunlong Zhang (TAMU), Lee Han (UTK), Bruce Wang (TAMU)

Project Partners: Oak Ridge National Lab

We have included some partners to seek feedback. The project team member had prior research collaborations with project partners and will continue to identify critical research needs and develop solution strategies.

Research Project Funding: $217,400 Federal and $108,700 non-Federal funding

Project Start and End Date: 08/01/2024 – 07/31/2025

Project Description: This is the year two effort of the 2-year project. The objective is to utilize a data-driven approach (e.g., Machine Learning and Deep Learning) to robustly, proactively, and trustworthily estimate the impact of impending extreme weather events (e.g., tropical cyclones) on key logistical infrastructure elements, including ports and highways. Beyond the first year's research, we plan to broaden our objectives from focusing on the port system (multiple points) to encompassing the interconnected network of the highway system. The highway network will be conceptualized as a graph in which intersections and roads are nodes and edges, respectively. A Graph Neural Network (GNN) equipped with temporal attention will be utilized to estimate the impact of tropical cyclones on highway operational performance, leveraging its ability to process complex spatial and temporal dependencies within the highway network.

In Year 1, the research is focused on robustly estimating the impact of tropical cyclones on port operations. From the data perspective, we select the Gulf of Mexico as the case and utilize five-year Automated Identification System (AIS) data from 2017 to 2022 to evaluate the port performance. Moreover, we collect explanatory features of port infrastructure and hurricane records from the database of the Department of Transportation (DOT) and National Hurricane Center (NHC), to enhance the model performance. Therefore, we can construct a comprehensive dataset to describe the impact of each hurricane on ports in the Gulf of Mexico with abundant features included. Additionally, the modular time-series regression model is used to determine the duration of port impacts due to tropical cyclones.

In the proposed methodology, we conceptualize the problem of estimating port performance under impending tropical cyclones as analogous to a recommendation system. Recommendation algorithms traditionally estimate a user's preferences based on their historical interactions with various items. Adapting this framework, we designate tropical cyclones as the 'users' and ports as the "items", with the "interactions" quantified by the number of impact days at each port attributable to specific cyclones. This recommendation algorithm is trained on historical data to estimate the likely interactions between impending cyclones and ports. The anticipated outcome of this model is an impact ranking, which will provide stakeholders with crucial insights for optimizing disaster preparedness and thereby mitigating potential losses as effectively as possible. After validation, the results indicate that the proposed algorithm outperforms existing distance-based approaches in both ranking accuracy and robustness against uncertainties arising from weather forecasting models.

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network's topology.

The primary activities/deliverables toward this goal are listed below:

- Reviewing the literature on existing highway performance estimation under extreme events and identifying research gaps (deliverable: literature review report).
- Reviewing and processing available data, including operation data from highway and extreme weather events for the research
- Designing a feasible GNN with a temporal attention framework
- Validating the proposed framework and fine-tuning it
- Documentation (deliverable: final report)

In parallel to the maritime traffic resiliency analysis, we will continue to look at the resilience of Mississippi River freight traffic over two major Interstate bridges with one (I-40) shut down suddenly and unexpectedly and the other (I-55) shut down with some advanced warnings, both for weeks or even months. Detailed lane-by-lane traffic data for before, during, and after periods have been collected and processed during Year 1 of this effort.

US DOT Priorities: The project will directly support the USDOT strategic goal of Improving Mobility of People and Goods by analyzing and improving freight network resiliency. In addition, this project will help the USDOT strategic goal of Climate and Sustainability through analyzing the impact and develop solutions for intermodal facilities under extreme weather conditions. Specifically, the proposed research responds to the RD&T priorities of "Multimodal System Planning," "Network Accessibility," "Rural Transportation Infrastructure," "Mode Shift," and "Resiliency and Climate Adaption."

This project will perform transformative research to study existing datasets for higher resolution enhancement potentials for freight network analysis. Innovative advanced AI models will be developed to assess the impact of and response to inclement weather events for intermodal facilities including ports and waterways.

Outputs: The objective of this project is to employ a data-driven approach, utilizing advanced machine learning and deep learning techniques, to proactively and robustly estimate the impact of impending extreme weather events on critical logistical infrastructure elements such as ports and highways. By doing so, the project aims to develop integrated strategies that enhance the resilience and reliability of the entire logistics network, ensuring the seamless transition of goods even during extreme weather-induced disturbances. This proactive and trustworthy analysis will enable the formulation of adaptive measures to mitigate risks and losses, as well as safeguard continuity in the supply chain.

Outcomes/Impacts: The necessity to enhance the resilience of our infrastructure of logistic transportation systems compels us to expand our research scope. In recognizing that the seamless transition of goods from sea to land is pivotal, our research focus will include the highway network – the critical link that ensures the continuity of the supply chain when maritime transport faces challenges. The extension of our research to the highway network is motivated by the need to develop a comprehensive understanding of how climate-related disruptions affect the entire transportation matrix and to design more robust and adaptable systems. This broader approach will allow for the development of integrated strategies to mitigate risks and enhance the resilience of the entire logistics network against future climate-induced disturbances.