

## ABSTRACT

In the face of intensifying natural hazards, the need for resilient transportation infrastructure and an equity-aware understanding of disaster impacts has become increasingly urgent. Tornadoes and hurricanes pose distinct challenges: tornadoes often produce highly localized, severe damage with sharp spatial contrasts, while hurricanes generate widespread exposure and prolonged disruption that can constrain mobility and access to essential resources. As such, this dissertation develops a spatially explicit and data-driven framework to quantify disaster exposure, impact, and evacuation-related disruption across both tornado and hurricane contexts. The research is structured as a collection of three related studies that collectively advance understanding of how hazards interact with demographic vulnerability, the built environment, and transportation system performance.

The first study establishes a foundational approach to characterizing tornado exposure and transportation vulnerability by examining how tornado density varies across space and how it relates to demographic, socioeconomic, and transportation-related factors at the U.S. Census Block Group scale in Kentucky. Tornado exposure is quantified using spatial analysis methods, including kernel density estimation and zonal statistics, applied to historical tornado records. To account for spatial heterogeneity, the study employs multiscale geographically weighted regression, enabling relationships between explanatory factors and tornado exposure to vary across the state rather than assuming a single global effect. In addition to community exposure, the study quantifies tornado impacts on roadways using two complementary approaches and maps impacted areas to support transportation-focused preparedness and response planning.

Building on this foundation, the second study shifts from exposure to a more comprehensive representation of localized tornado consequences by introducing an integrated tornado impact metric that combines tornado risk and exposure. Focusing on Florida's Panhandle, the study investigates how built-environment characteristics, including urban form efficiency, network connectivity, housing density and affordability, interact with demographic and socioeconomic attributes to shape impact intensity. Multiple global and local spatial models are compared to address spatial autocorrelation and non-stationarity, with multiscale geographically weighted regression providing the strongest representation of spatially varying relationships. Findings highlight that built environment factors can either mitigate or amplify tornado impacts depending on location, offering actionable insights for planners seeking to reduce vulnerability through land-use and transportation system interventions.

The third study transitions to hurricane evacuation conditions and examines how Hurricane Milton altered mobility and fueling dynamics in Sarasota County. Using INRIX trips and trajectories, the study compares two different time periods (October 2023 and October 2024) to quantify evacuation-driven mobility disruption, including shifts in internal–internal and internal–external travel patterns over time. A central contribution of this chapter is a trajectory-based method to infer gas-station–related trips directly from raw trajectories, enabling measurement of fueling stress as an operational constraint on evacuation. Station-level congestion is assessed through

spatiotemporal patterns of queuing and slowdown in the immediate vicinity of gas stations, revealing when and where refueling bottlenecks were most severe.

Taken together, these three studies provide a holistic view of disaster impacts across hazards with fundamentally different spatial footprints, and operational consequences. By integrating multiscale tornado exposure and impact modeling with trajectory-based measurement of hurricane evacuation mobility and fueling stress, this dissertation contributes scalable, and spatially precise methodologies for disaster preparedness and response. The findings offer practical guidance for transportation engineers, emergency managers, and policymakers seeking to strengthen infrastructure resilience, improve situational awareness, and support more equitable disaster planning in an era of climate-driven extremes.