

ABSTRACT

The intersection of natural disasters and infectious disease outbreaks presents complex challenges for public health, evacuation planning, and the allocation of emergency resources. This is illustrated by Hurricane Sally's September 2020 landfall during the COVID-19 pandemic. Three gaps in existing literature limit current decision support. Disease transmission models define geographic coupling using fixed, time-invariant weights that cannot capture abrupt, mobility-driven shifts. Evacuation planning models treat epidemic risk as a fixed parameter or a competing objective, rather than a system-level constraint. Finally, most demand estimation approaches cannot use mobility data to inform shelter capacity design. This dissertation develops data-driven decision models that integrate spatiotemporal mobility data, epidemic forecasting, and optimization methods to support informed response strategies in compound emergency settings.

Using connected-vehicle mobility data, COVID-19 infection case counts for ZIP Code Tabulation Areas (ZCTAs), and inventories of congregate shelters and non-congregate lodging facilities across three counties in the Florida Panhandle (Escambia, Santa Rosa, and Okaloosa), this dissertation makes three contributions. (1) Time-segmented origin-destination (OD) mobility matrices are used to estimate time-varying geographic coupling weights for an endemic-epidemic (EE) model, first assuming homogeneous temporal changepoints across the study region. This homogeneity assumption is then relaxed to heterogeneity through spatially constrained (SKATER) clustering with cluster-specific temporal changepoints. Mobility-derived coupling weights improved forecast accuracy over the univariate ZCTA-level time-series segmentation baseline while remaining interpretable through self-, neighbor-, and environmental-transmission components. (2) A mixed-integer shelter allocation model is proposed to enforce a dynamically

recalculated system-level effective reproduction number as a constraint. The shelter allocation model relocates part of the at-risk population to receiving regions that can accommodate them while keeping post-evacuation transmission risk within a specified threshold, outperforming a logistics-only benchmark. (3) A Generalized Additive Model (GAM) is investigated to forecast congregate and non-congregate shelter capacity demand, supporting shelter planning and the strategic deployment of non-congregate facilities during a geophysical hazard under public health constraints. This model was benchmarked against a Generalized Linear Model (GLM). The proposed GAMs substantially outperformed the GLM and revealed contrasting effects of school closures on shelter and lodging demand.

These findings show that one class of mobility data can drive a coherent pipeline for quantifying how movement shapes transmission, routing evacuations without amplifying it, and forecasting the shelter capacity demand that these evacuations create. This dissertation provides practical tools for epidemic-aware disaster response while advancing spatiotemporal modeling and decision-making methodologies.

Keywords: compound emergencies; human mobility; connected-vehicle data; endemic-epidemic modeling; time-series segmentation; spatial clustering; effective reproduction number; evacuation optimization; shelter demand forecasting; generalized additive models