ABSTRACT

Hsu, Yu-Ting, Ph.D., Purdue University, Aug 2013. A Generalized Operational Framework for Mass Evacuation Integrating Demand, Supply and Disaster Characteristics.
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There has been an increasing focus in recent years on efficient response to large-scale disasters due to the severity of devastation under several natural and man-made disasters. From a transportation perspective, a key objective in this context is disaster-related mass evacuation to avoid/mitigate the potential loss of life. It addresses the movement of people (demand) from the region affected or threatened by a disaster to areas of safety using the available transportation system (supply). In an operational context, the mass evacuation problem is shaped by the dynamics of three underlying aspects: demand, supply, and disaster. Hence, it is critical to integrate the time-dependent effects, and consequent interactions, of these three aspects to determine effective evacuation strategies within a deployable framework. However, most current studies focus primarily on the supply-side management, while addressing the other two aspects in a comparatively notional or simplified manner. Additionally, there is the lack of systematic paradigms for real-time operation that capture the dynamics of the evacuation network resulting from the intricate interactions between these three aspects, especially evacuee behavior, evolving traffic conditions, and disaster spatio-temporal characteristics.

This dissertation proposes the concept of evacuation risk and behavior-consistent information strategies to develop a stage-based operational framework for mass evacuation that integrates the dynamics of demand, supply and disaster characteristics. Evacuation risk, a measure based on whether the population at a location in the affected region can be safely evacuated before the disaster impacts it, uses the estimated time-dependent lead time to disaster impact at a location and the estimated time-dependent clearance time based on evolving traffic conditions, to characterize the time-dependent risk associated with that location. Thereby, it factors the time-dependent effects of the supply and disaster characteristics to prioritize locations in terms of when they should be recommended to evacuate to mitigate the substantial impact of a large demand impinging on a finite transportation capacity in a short duration as is common under a

mass evacuation scenario. The prioritization of the locations is done by determining evacuation risk zones (ERZs) based on their time-dependent evacuation risks. An innovative aspect of the concept of evacuation risk is that it enables the proposed framework to be independent of the specific characteristics of a disaster or disaster type. This feature enables the operational framework to be generalized relative to the disaster type and/or its characteristics, and represents a key departure from existing approaches in this domain.

The behavior-consistent information strategies of the disaster response operator provide evacuation recommendation and route guidance information to people in the disaster-affected region to minimize the total system travel time in that region. The strategies are behavior-consistent because they explicitly factor the disaster response operator's objectives and the estimation of evacuee response behavior to the provided information in the determination of the information strategies. This entails the consideration of the time-dependent interactions of the demand and supply characteristics. The evacuee behavior is modeled with several elements of realism. It factors emergent behavioral processes as the problem is characterized by a potential threat from the extreme event, time pressure, and herding mentality. It uses fuzzy logic to capture subjective and qualitative elements that govern evacuee decision-making under information provision. Due to limitation on the data availability in real-world operations, the associated behavior models are developed at an aggregate level, which allow model calibration based on measurable traffic data. A mixed logit structure is applied to accommodate the behavioral heterogeneity across individual evacuees. Together, this fidelity and realism in modeling the behavioral aspects of evacuation represent a key new capability to address disaster-related evacuation operations.

To enable real-time deployment from a computational standpoint, the stage-based framework is implemented using a rolling horizon approach by identifying an ERZ in each stage. The ERZ is a spatially bounded subzone of the affected region encompassing the population currently with the highest evacuation risk in which the limited evacuation response resources (such as personnel and equipment) can be deployed to synergistically aid system performance under the information strategies adopted for that stage. Thereby, the ERZ-based strategies seamlessly integrate demand, supply and disaster characteristics to foster a generalized evacuation operational framework.