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Overview Paper

Evacuation transportation modeling: An overview of research, development, and practice

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ABSTRACT

This paper presents a review of highway-based evacuation modeling and simulation and its evolution over the past decade. The review includes the major components of roadway transportation planning and operations, including the current state of modeling in the forecasting of evacuation travel demand, distribution and assignment of evacuation demand to regional road networks to reach destinations, assignment of evacuees to various modes of transportation, and evaluation and testing of alternative management strategies to increase capacity of evacuation networks or manage demand. Although this discussion does not cover recent work in other modes used in evacuation such as air, rail, and pedestrian, this paper does highlight recent interdisciplinary modeling work in evacuation to help bridge the gap between the behavioral sciences and engineering and the application of emerging techniques for the verification, validation, and calibration of models. The manuscript also calls attention to special considerations and logistical difficulties, which have received limited attention to date. In addition to these concerns, the following future directions are discussed: further interdisciplinary efforts, including incorporating the medical community; using new technologies for communication of warnings and traffic condition information, data collection, and increased modeling resolution and confidence; using real-time information; and further model refinements and validation.

1. Introduction

Evacuations, while often thought of as rare events, are in reality more common. A study conducted by the Sandia National Laboratory for the United States (US) Nuclear Regulatory Commission (NRC) showed that, on average, an evacuation of 1000 or more people occurs about once every two to three weeks in the US (Sandia National Laboratories, 2004). Also notable in the NRC data is the high frequency (nearly 75% of the total sample) of small-scale evacuations involving less than 5000 people. These data, along with the range of hazards for which evacuations are ordered, suggest that evacuations can be needed virtually anywhere and must often be carried out with little advanced warning time to mobilize and implement traffic control and management measures. The realization of these trends led to an increased level of involvement from transportation professionals in emergency planning and response over the past 10–15 years. Today, the roles and responsibilities of transportation during emergencies have been formalized in the National Response Framework (Department of Homeland Security, 2008).

Among transportation's numerous roles is the planning of transportation assets and infrastructure to respond to major emergencies, including the management of evacuation and detour routes; utilization of mass transit systems; movement

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and distribution of relief supplies; and the restoration of damaged transportation systems. Transportation engineers have also been involved in the development and application of modeling and simulation systems to support the development of evacuation plans. The past several decades have seen significant advances in both the number and sophistication of systems adapted for and dedicated specifically to the purpose of evacuation modeling and simulation. Several of the earliest efforts evolved from the analysis of nuclear power plant emergencies in the aftermath of the Three Mile Island emergency then continued to evolve in detail and complexity throughout the next two decades, particularly for hurricane evacuations. Most recently, and in parallel with enormous advances in the computational speed and power of computers, the history altering events of September 11, 2001 and Hurricanes Katrina and Rita in 2005 have led to a greatly increased level of interest and involvement in evacuation modeling from within the transportation research community.

This paper presents a review of highway-based evacuation modeling and simulation and its evolution over the past decade. The review includes the major components of areas of roadway transportation planning and operations, including the current state of modeling in the:

- forecasting of evacuation travel demand;
- the distribution and assignment of evacuation demand to regional road networks to reach destinations;
- assignment of evacuees to various modes of transportation; and
- evaluation and testing of alternative management strategies to assess and increase capacity of evacuation networks.

Although this discussion does not cover recent work in other modes use in evacuation such as air, rail, and pedestrian (each of which has garnered increasing levels of attention and have seen significant advancements of their own), this paper does highlight recent interdisciplinary modeling work in evacuation to help bridge the gap between the behavioral sciences and engineering and the application of emerging techniques for the verification, validation, and calibration of models.

The discussion is organized into seven additional sections. The first provides an overview of evacuation warnings and information dissemination. Section 3 discusses zoning for evacuation warning dissemination and demand modeling. Section 4 presents a wide perspective on demand modeling, including social and threat factors influencing the decision to evacuate, trip generation techniques, departure time modeling, and mode split/choice. Section 5 provides an overview of route selection and traffic assignment. Section 6 discusses a selection of strategies to make evacuations more efficient. Section 7 describes some special logistical considerations that further complicate the evacuation process. Finally, Section 8 presents future needs and directions.

2. Warning and information

Among the most critical needs in carrying out an evacuation is the clear and effective communication of evacuation orders. This communication must overcome the disbelief that is typically the initial response to disaster warnings (Drabek, 1999; Tierney et al., 2001). The wording and content of evacuation orders (message), person delivering the message (source), and distribution medium (channel) (Lindell and Perry, 2004, 2012), can heavily influence not only the number of people that evacuate, but also the urgency at which they leave, the areas from which they depart, and the destinations that they chose. Drabek (1999) suggests that effective messages answer the questions "(1) Who is issuing the warning? (2) What is threatening? (3) What exact geographical area is threatened? (4) When is it coming? (5) How probable is the event? (6) Are there high risk locations, such as people in automobiles, that require special actions? (7) What specific protective actions should be taken?" (p. 520).

Interestingly, there is little consistency in terminology from location to location and, often, wide variation within a single location. Acronyms and jargon used in social media and the Internet may further cause consistency issues. A recent study of evacuation practices showed the range of wording used by public officials when issuing evacuation orders (Wolshon, 2009) as well as the intended meaning they are meant to convey. Among survey respondents, the terms "Mandatory" and "Voluntary" evacuation were the most common. It is notable, however, that the definition of "mandatory" is legally unclear (Baker, 1991) because emergency management and law enforcement agencies realize that it is not realistic to enforce an order that compels people to evacuate. However, the term "mandatory" carries significant weight with potential evacuees in recommending that they evacuate.

Disaster warnings are considered a social process, involving the interaction of warning sources and message receivers and receivers with each other and others in their social networks (e.g., family). For example, the messages can reach the ultimate receivers either directly from the source or through intermediate sources via a diffusion process. The information must be received and understood before action is likely to occur (Lindell and Perry, 2012), particularly in the absence of environmental or social cues. People interpret messages differently and vary in their beliefs of the messages and subsequent actions (Drabek, 1986). Personal characteristics and those of the channel, source, and message have a complex relationship that affects how the information is perceived and understood. People often seek confirmation of the information from other sources (e.g., friends, relatives, neighbors, coworkers (Tierney et al., 2001)) or additional warning messages (Drabek, 1986). In ambiguous situations, people may be guided by reference groups and even strangers (Lindell and Perry, 2004). This confirmation helps overcome initial inertia or disbelief. Perry (1985) presents a sequential flow chart of the decision making process for responding to natural disaster warnings that involves (1) receiving an initial message, (2) interpreting the message, (3) assessing personal risk, (4) determining whether protection is feasible, (5) determining whether protective action can be