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EMBLEM2: An empirically based large scale evacuation time estimate model

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Abstract

This article describes a simple, rapid method for calculating evacuation time estimates (ETEs) that is compatible with research findings about evacuees' behavior in hurricanes. This revision of an earlier version of the empirically based large scale evacuation time estimate method (EMBLEM) uses empirical data derived from behavioral surveys and allows local emergency managers to calculate ETEs by specifying four evacuation route system parameters, 16 behavioral parameters, and five evacuation scope/timing parameters. EMBLEM2 is implemented within a menu-driven evacuation management decision support system (EMDSS) that local emergency managers can use to calculate ETEs and conduct sensitivity analyses to examine the effects of plausible variation in the parameters. In addition, they can run EMDSS in real time (less than 10 min of run time) to recalculate ETEs while monitoring an approaching hurricane. The article provides an example using EMDSS to calculate ETEs for San Patricio County Texas and discusses directions for further improvements of the model.

Keywords: Emergency management; Hurricanes; Evacuation modeling; Evacuation time estimates; Traffic management

1. Introduction

Recent research has increasingly sought to analyze the performance of transportation networks during off-normal conditions. One strand in this line of research has sought to develop models for assessing network vulnerability to the disruption of individual links. Such methods can be used to assess the economic impacts of disasters (Chang, 2003) and set priorities for repairing damaged links or constructing additional redundant links (Jelenius et al., 2006; Sohn, 2006; Sohn et al., 2003). Another line of research has addressed methods for re-routing trains after disruptions have occurred (Törnquist, 2007) and managing flows of evacuating vehicles before disaster strikes (Cova and Johnson, 2002, 2003). The evacuation management problem is particularly significant because communities on the US Atlantic and Gulf coasts are vulnerable to hurricanes and

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need to evacuate large populations when a major storm approaches. The large volume of vehicle traffic involved in mass evacuations consistently exceeds the capacities of local road networks, causing traffic jams. To avoid the large numbers of casualties that could occur if the impact area is not cleared in time, public officials need accurate evacuation time estimates (ETEs). Such ETEs allow them to decide between waiting long enough to avoid the economic cost of an unnecessary evacuation and evacuating early enough to avoid a loss of life (Lindell and Prater, 2007a). The complexity of this decision is compounded by major uncertainties about a hurricane's forward movement speed, intensity, and track – all of which make it difficult to determine when and where to initiate an evacuation.

The amount of time needed to clear a risk area is determined by the capacity of an evacuation route system (ERS) to handle the demand that is placed upon it. Basic principles for analyzing daily traffic demand (e.g., Homberger et al., 1996; Transportation Research Board, 1998) are needed to compute ETEs, but must be adapted to the special conditions existing in evacuations (Urbanik, 1994, 2000). Daily traffic demand is determined by daily cycles of travel to work and then back home that provide drivers with hundreds of opportunities per year to learn their optimal travel routes. However, hurricane evacuations are so rare that drivers cannot learn from experience which route will minimize their evacuation times. Thus, it is not possible for an equilibrium to emerge that will distribute demand evenly across the evacuation routes.

Many analysts have proposed methods for computing ETEs (e.g., Abkowitz and Meyer, 1996; Barrett et al., 2000; Hobeika and Kim, 1998; Safwat and Youssef, 1997; Tweedie et al., 1986). However, Lindell and Prater (2007b) found these analytic methods to be problematic because of incorrect assumptions about 16 behavioral variables affecting hurricane evacuations. The need for real time operational tools is becoming increasingly apparent from the finding that risk area residents respond to approaching hurricanes in ways that can invalidate ETEs calculated in advance. For example, as many as two-thirds of risk area residents have evacuated before an official warning is issued (Lindell et al., 2005; Lindell and Prater, 2006). Thus, ETEs computed before the hurricane season on the basis of peak populations could significantly overestimate actual clearance times. Moreover, many models require trained analysts to run and take too much time to use during large scale evacuations. For example, Chen et al. (2006) reported an average of 56 h for each of 10 simulation runs in their analysis of ETEs for the Florida Keys. The computational burden would be even greater for more densely populated areas such as the Galveston/South Harris County ERS, which must transport more than 175,000 evacuating vehicles over official routes having a capacity of 5800 vehicles/hour (Lindell et al., 2002b). Consequently, macroscopic models are needed to compute ETEs on the types of desktop computers that are available in most local emergency operations centers.

This article describes a procedure that explicitly addresses the behavioral variables identified by Lindell and Prater (2007b) and incorporates them into a menu-driven computer program that is suitable for operational use by local emergency managers. An earlier version of this procedure, the empirically based large scale ETE method (EMBLEM), was implemented as a spreadsheet to generate the hurricane ETEs used by the state of Texas (Lindell et al., 2002a,b). It included many of the behavioral variables but was designed for use by trained analysts, not local officials. The current algorithm, EMBLEM2, is theoretically and empirically more sophisticated, yet is simple enough for emergency managers to use in revising their ETEs as a hurricane approaches. EMBLEM2 also uses concepts from decision analysis (Clemen, 1996) to show the effects of parameter uncertainties on ETEs. The presentation of the EMBLEM2 algorithm in the next two sections is followed by a discussion of sensitivity analysis, an example of EMBLEM2's application, a discussion of its limitations, and recommendations for further research and development.

2. A model of hurricane evacuation

The factors determining the time required to clear an evacuation area can be described by the model depicted in Fig. 1. Storm characteristics such as forward movement speed, intensity, size, and track affect ERS capacity through high wind, debris, heavy rain, and flooding that decrease roadway capacity. Current and forecast storm conditions also affect the response of residents, transients, and special facilities. Residents are households that permanently inhabit the risk area and transients are those who are only there temporarily (e.g., business travelers and tourists). Special facilities include schools, hospitals, nursing homes, and jails (for a detailed list, see Lindell et al., 2006, Table 6-2). Although not explicitly depicted in Fig. 1, storm conditions