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# Understanding and managing disaster evacuation on a transportation network

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ABSTRACT

Uncertain population behaviors in a regional emergency could potentially harm the performance of the region's transportation system and subsequent evacuation effort. The integration of behavioral survey data with travel demand modeling enables an assessment of transportation system performance and the identification of operational and public health countermeasures. This paper analyzes transportation system demand and system performance for emergency management in three disaster scenarios. A two-step methodology first estimates the number of trips evacuating the region, thereby capturing behavioral aspects in a scientifically defensible manner based on survey results, and second, assigns these trips to a regional highway network, using geographic information systems software, thereby making the methodology transferable to other locations. Performance measures are generated for each scenario including maps of volume-to-capacity ratios, geographic contours of evacuation time from the center of the region, and link-specific metrics such as weighted average speed and traffic volume.

The methods are demonstrated on a 600 segment transportation network in Washington, DC (USA) and are applied to three scenarios involving attacks from radiological dispersion devices (e.g., dirty bombs). The results suggests that: (1) a single detonation would degrade transportation system performance two to three times more than that which occurs during a typical weekday afternoon peak hour, (2) volume on several critical arterials within the network would exceed capacity in the represented scenarios, and (3) resulting travel times to reach intended destinations imply that un-aided evacuation is impractical. These results assist decisions made by two categories of emergency responders: (1) transportation managers who provide traveler information and who make operational adjustments to improve the network (e.g., signal retiming) and (2) public health officials who maintain shelters, food and water stations, or first aid centers along evacuation routes. This approach may also interest decisionmakers who are in a position to influence the allocation of emergency resources, including healthcare providers, infrastructure owners, transit providers, and regional or local planning staff.



## 1. Introduction

Considerable attention has been focused on plans for sheltering and evacuation in response to a regional emergency such as a natural disaster or terrorist attack. Knowledge of population behaviors and resulting impacts on the evacuation efforts provide emergency managers with crucial formation for improving the planning efforts for such incidents. Evidence-based projections of population evacuation behaviors provide opportunities for analysis of evacuee behaviors in the event of a regional disaster, specifically a dirty bomb attack. By utilizing survey findings of expected population behavior, we can estimate the origins and destinations of evacuees in the event of a regional emergency. The use of publicly available data, clear assumptions, and quantitative analysis provides a data-driven repeatable methodology that can be shared among diverse agencies without the need for custom software. The approach will allow emergency planners and transportation agencies to develop

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plans for how to allocate resources throughout the region based on the projected evacuation patterns and traffic flows.

In order to better understand the behavioral data and analysis needs of emergency planners, the authors completed telephone interviews with researchers acting under FEMA's Regional Catastrophic Planning Grant Program starting in 2009. Program research was focused on resource management, public preparedness, mass care, modeling and simulation, and transportation. All five groups stated that they have a need for and an interest in evacuation behavior data and analysis, for the following reasons: (1) *resource management* for identifying resource gaps such as shelter availability and shelter capacity in the region, (2) *public preparedness* for determining short term and long term housing needs, (3) *mass care* for effectively assisting people with special needs and people that require specific health services, (4) *modeling and simulation*—for determining temporary fuel, water, and first aid locations as well as shelter space and commercial food vendors, (5) *transportation*—for validating some assumptions that have been made regarding the number of people on the roads.

The purpose of this paper is to explore and characterize the impacts to the transportation network of an evacuation resulting from a regional emergency. To achieve this purpose, the study has four objectives: (1) *estimate the number of evacuees that would use the transportation network in the event of a regional emergency*, (2) *estimate the resultant delays on the transportation network*, (3) *identify other performance measures, besides travel delay, to make the results understandable*, and (4) *quantify the differences and implications among the emergency scenarios*.

The methods will be demonstrated with a recent survey dataset of population behaviors associated to a hypothetical radiological emergency in the Washington, DC (USA) National Capital Region. The University of Virginia Center for Survey Research completed a telephone survey with 2700 National Capital Region residents in 2009 in order to understand their behaviors in the event of a Radiological Dispersion Device (RDD), or "dirty bomb", attack to the region. The survey revealed *evacuation versus shelter-in-place* behaviors and *origins and destination* preferences of residents following a dirty bomb attack in the National Capital Region with respect to different levels of hazard. The survey provides emergency and transportation officials with valuable information on public actions during emergencies. Results from the survey help refine emergency response, traffic movement, and evacuation plans. The survey data may also benefit planners and government officials in the National Capital Region, as well as surrounding states, that would potentially provide shelter, transportation, and public information to people in need (Guterbock et al., 2010).

## 2. Background

Significant research about radiological attacks and the resultant sheltering and evacuation behaviors of affected populations utilizing physical models has been undertaken. Wein et al. (2010) analyze the impact of shelter-in-place evacuation decisions following an improvised nuclear device attack to the Washington, DC area. Carter et al. (2007) analyze the implications of a hypothetical improvised nuclear device attack on Washington, DC from multiple perspectives based on a workshop. Dombroski and Fischbeck (2006) assess the risks of RDD events by considering both the physical effects of RDD's and the behavioral response factors in such an attack in Pittsburgh, PA. Dombroski et al. (2006) predicted compliance with shelter-in-place directions in case of a RDD event in Pittsburgh, PA, based on expert elicitation.

If emergency plans for sheltering and evacuation following a regional emergency are to be realistic, they must be based on projections of how citizens obtain their information in an emergency. These projections should include what sources they trust, the degree to which they have planned or prepared in advance, and the decisions and actions they will make under various possible emergency scenarios (Guterbock et al., 2010). However, emergency planners and researchers have little reliable guidance in terms of how they should expect residents to behave in the event of a regional disaster.

Behavioral surveys have been useful for collecting data and helping emergency planners and government officials refine emergency response in the following areas: traffic movement and evacuation plans, sheltering and transportation resource management, and public information (Guterbock et al., 2010). A 2010 University of Virginia behavioral survey of 2700 National Capital Region residents was conducted to increase the understanding of emergent public behavior following an emergency incident. Each respondent completed a 30-min telephone interview. Respondents were distributed across over 20 county and city jurisdictions of the region and were randomly sampled from both cell phone and landline telephone households. The survey report Population Behaviors in Dirty Bomb Attack Scenarios: A Survey of the National Capital Region addresses a radiological dispersion device (dirty bomb) event at three different hazard levels: minimum, moderate, and maximum. The survey asks various behavioral questions about what people would do, how prepared they would be, whether they would comply with instructions, how they would perceive the threat of the event, whether they trust various information sources, whether they are confident in existing infrastructure, and, the most critical of all, whether they would shelter in place (Guterbock et al., 2010). The findings of the survey provide a basis for understanding population behaviors in the event of a dirty bomb attack.

*Shelter-in-place* or *evacuation* behaviors have significant impacts on the decisions of many emergency planners in the fields of mass care, resource management, transportation, public preparedness, simulation and modeling, etc. (Parlak et al., 2012). *Shelter-in-place* or *evacuation* behaviors are uncertain in the sense that they are affected by many factors. Survey findings revealed that over 70% of the respondents would stay in place under the three different hazard levels when they are told to imagine themselves at home at the time of the event and are told to shelter in place. When the respondents are told to imagine themselves at work, the percentages are observed to be significantly lower. This finding indicates that the unpredictability of compliance with shelter-in-place directions is a major issue in emergency planning in terms of estimating capacities, managing shelters and traffic patterns, and assessing the availability of various resources. Moreover, less compliance with shelter-in-place directions while in work places presents a problem in terms of lacking critical personnel at the work place.

By integrating the previously mentioned behaviors highlighted by the survey, the relevance of behaviors to the emergency planning process is better understood. A dirty bomb attack is a random event that causes a random exposure to radiation. Dirty bomb exposure is also affected by the behaviors of the population such as deciding to shelter in place or evacuate. Population behaviors in this case are also one of the uncertainties that are considered in the decision making process in terms of which initiatives should be applied. Together, the decisions of emergency managers and the exposures of populations to the impacts of the dirty bomb affect the number of lives saved, the quality of life of the affected population, and how efficiently the resources are allocated. By these and similar results of the survey for understanding the major behaviors of an affected population and related uncertainties, emergency managers will have more effective and robust plans that can accomplish their overall objectives. These and other selected details of the literature and survey results will be used in the demonstration of methodology below.