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# INTERNATIONAL JOURNAL OF MASS EMERGENCIES AND DISASTERS

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# Emerging Developments in Evacuation Methods, Planning, and Analysis

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Recent disasters—both natural and willful—have focused attention on the challenges of mass evacuation and the need for robust evacuation capability. Until recently, evacuation studies tended to be narrowly focused. Over the past decade, however, the conceptualization, modeling, and analysis of mass evacuation have advanced dramatically. Moreover, recent studies have drawn on a broader array of engineering and social science methods to permit a more sophisticated understanding of evacuation behavior and practice. That said, there remain substantial gaps in the developing evacuation literature. To forward the discussion of critical needs in evacuation and exchange ideas, practices, policies, and emerging knowledge from all fields involved in this subject, the Gulf Coast Research Center for Evacuation and Transportation Resiliency in cooperation with the Stephenson Disaster Management Institute at Louisiana State University co-hosted the Second National Evacuation Conference.

The conference, held in February 2012 in New Orleans, brought together hundreds of experts from government, private industry, academia, national laboratories, and non-profit organizations in the fields of emergency management; engineering; law; social and behavioral sciences; human and animal medicine; and law enforcement, among others, to foster an interdisciplinary exchange of ideas in evacuation planning and management. The event was sponsored by several private corporations and public sector agencies, including the Transportation Research Board of the National Academies. The conference included more than 100 speakers from throughout the United States and numerous other countries seeking ways to accommodate the needs of all affected people before, during, and after major disasters. Presentations covered an array of topics—from the specific challenges of evacuating during radiological emergencies, to the analysis of evacuee behavior and response, and effective communication of guidance and direction for evacuation.

The presentations at the conference illustrated the diversity of interests and needs that must be accounted for in evacuation settings, as well as the range of knowledge and expertise now focused on evacuation-related issues. Within this context, three themes emerged as motivations for emergent research: First, evacuation occurs in a variety of contexts and via a variety of modes that deserve careful empirical attention to identify commonalities and characterize nuances. Second, models, data, and empirical analysis must better inform evacuation policies and procedures. Third, public information and education programs would be more effective if they accounted for individual-level behaviors, preferences, and attitudes.

To more widely disseminate the emerging knowledge from the conference, and to highlight these themes, its organizers have partnered with the *International Journal of Mass Emergencies and Disasters* to develop this Special Issue. This edition includes six of the best-reviewed works from the conference that focus on topics ranging from analytical techniques for describing evacuee behavior and information needs, to computational processes for evacuation resource allocation, and the use of vertical evacuation as a protective action. The following discussion briefly summarizes the work included in this Special Issue and the contributions it makes to the field.

How and when evacuees respond to guidance information during emergencies impacts the timing and extent of evacuations. In addition to influencing if people will evacuate, guidance information can also be used to shape when they will leave, which routes they will use, and which destinations they will travel to. McCaffery and her coleagues used mailed surveys to examine how evacuees seek guidance information, the type of information they seek, and the sources they find to be reliable and trustworthy in the context of wildfire emergencies. The findings of this research are consistent with earlier work that shows the importance of timely dissemination of information, as well as the use of sources that permit substantial interaction with authorities.

Since the Three Mile Island emergency, considerable research efforts have targeted the development of mathematical methods to analyze the travel characteristics of evacuations ranging from evacuee decision-making behavior to the movement of evacuating vehicles through roadway networks. Over the decades, these techniques have grown in both complexity and accuracy and are now among the fundamental tools in the emergency planning toolbox. The papers by Vogiatzis et al., Ni and Rossetti, and Murray-Tuite and Wolshon all apply quantitative methods to analyze evacuation processes and examine how evacuations may be improved more effective modeling techniques such as optimization and control frameworks. The work by Vogiatzis et al. is novel in its focus on the evacuation of livestock during nuclear power plant emergencies. The authors used an integer programming algorithm to identify optimal evacuation plans for the Fukushima Daiichi power plant in Japan. The work by Ni and Rossetti uses traffic simulation to analyze a large retail area that includes a regional shopping mall. The simulation varied several key factors, including parking occupancy rates, traffic control plans, and destination assignments. A key finding of this work is how an optimized destination assignment policy can significantly reduce congestion and reduce the total evacuation time. In the last of the three evacuation modeling papers, Murray and Wolshon describe the essential features and assumptions that should be considered for the development of transportation simulation models. Included in this work are assumptions and conditions that can be taken into account for estimating demand, its loading on to the network, destinations, and modal splits for a no-notice evacuation condition in a large metropolitan region.

Although considerable attention has been paid to auto- and transit-based evacuations, other population protective actions should also be considered. The factors determining which protective actions to recommend for each population segment during an emergency include the size, movement, and amount of advance warning time given by a hazard. The paper by Velotti et al. describes techniques and applications of vertical evacuation strategies, including the social, scientific, and policy factors that should be considered when planning its use. Although vertical evacuations have been used throughout human history to protect from flooding, its use in modern cities has been only lightly studied. To address this lack of systematic study, this paper also proposes a research agenda to explore topics related to vertical evacuations.

The papers included in this Special Issue represent the several of latest discoveries and advanced thinking in the field of emergency evacuation. As they include both theoretical and practical findings, they will be of value to researchers, responders, and policymakers alike. And while these works discuss specific hazard and locations, they can be generalized to other locales and countries, and to other types of natural and man-made hazards. Finally, it should be noted that the products of 2012 National Evacuation Conference also yielded a related special issue of the American Society of Civil Engineers' *Natural Hazards Review* (*NHR*). The *NHR* Special Issue will feature several additional highly-reviewed papers that were submitted to the conference on engineering-oriented topics. This issue is expected to appear in print at about the same time as this issue of the *IJMED*.

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**Differences in Information Needs for Wildfire Evacuees and Non-Evacuees**

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*This paper examines whether evacuees from two wildfires displayed different information seeking behavior than non-evacuees. Findings are the results of a mail survey sent to residents affected by wildfires outside Flagstaff, Arizona and Boulder, Colorado in 2010. We found evacuees sought information more actively than non-evacuees and placed a greater emphasis on use of interactive information sources, which they also tended to see as more useful and trustworthy. Evacuees also expressed lower satisfaction levels for receipt of information items that were more important to them including evacuation and road closure information. Finally, evacuees differed significantly in their assessments of pre-fire information suggesting that experiences during a fire may retroactively influence views of pre-fire information needs. Overall, findings support that of previous work and highlight the importance of disseminating information in as timely a manner as possible and through sources that allow as much interaction as possible with information providers.*

**Keywords**: evacuation, disaster communication, risk communication, wildfire, sensemaking.

## Introduction

Recent years have seen large numbers of individuals affected by wildfires. Providing information to such populations during an event is an important, but challenging, part of minimizing negative outcomes and ensuring public safety. While fire managers have actively worked to provide information to the public for years, little empirical work has been conducted to understand whether managers are providing the affected public with the type of information they most want and through the channels they typically access and trust. The limited qualitative work conducted to date on wildfires suggests that evacuees have different information demands than other populations and that information needs change over the course of a fire (Cohn, Carroll, and Kumagai 2006; Taylor et al. 2007). To provide more in-depth understanding of the specific information needs of those more directly affected, this study assesses the differences in information needs and seeking behavior between evacuees and non-evacuees in two communities directly affected by fires in 2010.

## Literature Review

Literature from the fields of natural hazards, emergency management, public health, and risk communication provide insight into the potential information dynamics to consider for individuals and communities affected by natural or man-made disasters. In a brief assessment of the state of risk communication, Alaszewski (2005) challenges the traditional assumption that individuals would automatically use any risk information they received to reduce their exposure. Instead risk communication is best characterized as a two-way process that needs to take into account how people seek and interpret risk information. In emergencies, events are often chaotic and unpredictable: to reduce the uncertainty associated with such situations individuals actively search for information in an attempt to make sense of the situation (Hodgson 2007; Weick, Sutcliffe and Obstfeld 2005). How individuals search for and respond to risk information will be shaped by their particular context and viewpoints (Alaszewski 2005; Dash and Gladwin 2007; Hodgson 2007).

During a disaster, individuals turn to a large diversity of information sources as they try to decrease their uncertainty and determine which actions to take (Hodgson 2007). Public information sources in particular can have a significant impact on decision making (Baker 1991; Burnside, Miller and Rivera 2007; Fitzpatrick and Mileti 1994; Gladwin and Peacock 1997; Kumagai et al. 2004; Lindell, Lu and Prater 2005; Stein, Duenas-Osorio and Subramanian 2010). Family, friends and neighbors can also be important information sources during natural hazards events (Burnside, Miller and Rivera 2007; Fitzpatrick and Mileti 1994; Cretikos et al. 2008; Heath, Lee and Ni 2009). Media outlets such as television are another common source of emergency information but may not always be an effective information source. Several studies found radios to be among the most-used information sources in emergency situations, and that they were particularly useful in situations involving loss of electricity (Cretikos et al. 2008; Heath, Lee and Ni 2009; Rundblad, Knapton and Hunter 2010). Other studies found mass media to be subject to concerns of sensationalism (Becker 2004; Taylor et al. 2007) and general resident distrust (Wakefield and Elliott 2003). One study found that as radio stations continue to conglomerate and become centrally located in and around cities, their ability to provide community level coverage and information, especially in rural locations, is being diminished (Lowrey et al. 2007). Taylor et al. (2007) found the same to be true for television, and suggested that "when the public service function is subjugated to focus on the primary media market, television and newspapers can lose the function of informing a crisis situation" (p. 208). While gathering information is a key part of how individuals make sense of an uncertain situation, communication is another key aspect of sensemaking as individuals engage in iterative discourse to develop a plausible explanation for their situation (Hodgson 2007; Weick, Sutcliffe and Obstfeld 2005).

Several studies have found indications that those who feel more at risk seek information more actively than those at less risk. Hodgson (2007) describes the situation created by evacuations as "strip[ping] residents of almost all sense of control over the outcome of the situation" (p. 238). In response to such conditions, evacuated members of the public more actively and aggressively search for information and can at times be more critical of the information they find. Lindell et al. (2005) found that members of the public who lived in areas of the highest hurricane risk more actively searched for information and relied more heavily on local news media, the internet, and local authorities than those facing lower levels of risk. In a survey of Hurricane Katrina evacuees, Spence et al. (2007) found differences in the information desired and information seeking behavior of the disabled and non-disabled.

While only a few studies have examined risk information needs during wildfires, their findings support those of the larger field of work confirming the active information seeking behavior of individuals to reduce uncertainty and maintain a sense of normalcy (Cohn et al. 2006; Kumagai et al. 2004; Taylor et al. 2007). The same three studies also found that a high value was placed on receipt of real-time, place-specific information and that evacuees placed particular emphasis on timely provision of information about the status of their homes. When this need for information was not satisfactorily fulfilled by fire management agencies, members of the public turned to less official information sources such as television and friends and neighbors (Cohn et al. 2006; Taylor et al. 2007). Evacuees had an especially difficult time obtaining information that was up-to-date and locally accurate once their community had been dispersed by large scale evacuations (Cohn et al. 2006; Taylor et al. 2007). For this group in particular, lack of specificity or timeliness of information could lead to dissatisfaction and more critical assessments of fire authorities (Cohn et al. 2006; Kumagai et al. 2004). Cohn et al. (2006) found that a major issue for individuals was how to interpret information coming from multiple sources and how to determine the possibility of evacuation. In addition, Taylor et al. (2007) found that the information sought by both the public and evacuees changed over the course of the fire, shifting from wanting to know about the fire's location, size and direction at the onset, to whether evacuations would be necessary, to questions about the status of homes, road closures, and when re-entry would be allowed.

A number of authors have argued that pre-event collaboration and communication could contribute to effective communication during confusing situations (Cohn et al. 2006; Martin, Bender and Raish 2007; Queensland Police Service 2011; Taylor et al. 2007). In this respect, several studies have examined how people access wildfire management information in general. This work has shown that although interactive information formats are used less often, they tend to be seen as more useful (McCaffrey and Olsen 2012; Shindler, Toman and McCaffrey 2009; Taylor et al. 2007; Toman, Shindler and Brunson 2005). McCaffrey (2004) found that coupling educational materials with more individualized contact was the most effective method for providing information to residents on wildfire management and mitigation. Given the argument made by Weick, Sutcliffe and Obstfeld (2005) and Hodgson (2007) that communication and iterative discourse is an important aspect of how individuals make sense of uncertain situations, it is likely that interactive information sources will be equally valuable information sources during a wildfire.

In the remainder of the paper we use data from 2010 surveys to examine more closely information needs and dynamics during and prior to wildfires. The paper is organized into the following sections: methods and site characteristics, description of the two wildfire events, specific results, discussion of what these results may mean, and a conclusion.

## Methods

This paper reports on findings from a subsection of a larger study examining agency-community interaction before and during wildfires. The larger study used a combined method research approach with key informant interviews during the course of three 2010 wildfire events (Tecolote Fire in New Mexico, Schultz Fire in Arizona, and Bull Fire in California) followed by mail surveys of the affected local populations to assess their information needs both during and before the fire. For the survey, one additional fire was added that matched the basic criteria (Fourmile Canyon Fire in Colorado). This analysis focuses on the findings from the mail survey for two of the fire sites, Schultz and Fourmile Canyon, which had a significant number of respondents who evacuated. This enables a comparison of differences in information needs and information seeking behavior between evacuees and non-evacuees. The survey consisted of 22 pages divided into four sections focusing on respondent satisfaction with and views on the usefulness and trustworthiness of information sources and communication processes during and before the fire, opinions and knowledge about fire management, and demographic information. Terms, such as credible and trustworthy, were not defined in the survey and are reported here as they were used in the survey.

To generate the sample frame, geographic information system (GIS) maps highlighting a 5-mile area around the perimeter of each fire were created. These were used by the local assessors' offices to generate a list with the name and contact information for tax parcels within the specified perimeter. Public, corporate, and trust lands were then excluded from the list, as were duplicate ownership and those parcels with a mailing address outside the perimeter. In the fall of 2010, surveys were mailed to a random sample of the remaining names (1000 in each site) using Dillman's (2007) three-wave methodology. To ensure that sufficient evacuation responses were received for at least one fire, an additional 496 residents who were within the evacuation zone of the Schultz Fire were included in the survey mailing. Mail survey response rates were 18% for the Schultz Fire, 26% for the subset of Schultz Fire evacuees, and 16% for the Fourmile Canyon Fire. Due to the relatively low response rates, a follow-up telephone survey was conducted to test for non-response bias. Ten percent of non-respondents from the mail survey were contacted via telephone using an abbreviated version of the survey. Demographically, no differences were found for education or employment, but non-respondents were more likely to be younger, female, live in an urban area, and have lived in the community for less time. The primary information specific difference found was in relation to overall satisfaction with communication which respondents were asked to rate on a four-point scale from very dissatisfied to very satisfied. Non-respondents were more satisfied with information both before and during the fire, suggesting that our results may paint a more negative picture of communication response than may be the case. This is notable given that a common assumption is that non-respondents are the dissatisfied or uninterested group and consequently, survey results may underreport key negative views.

Although surveys were sent to a specific sub-population in the area affected by the Schultz fire, evacuee status was determined by respondents' self- reporting of their evacuation status. For both fires, a total of 274 respondents indicated that they did not evacuate (183 for Schultz, and 91 for Fourmile Canyon), and 158 reported that they did evacuate (109 from Schultz, and 49 for Fourmile Canyon). Quantitative statistical analysis comparing responses of evacuees and non-evacuees is reported below and reinforced with qualitative comments made by respondents in a write-in section of the survey. When not specified, the significance level we report in the results section is 0.05. Because ANOVA assumes an interval-level dependent variable and our Likert-type scales are ordinal but not truly interval, a nonparametric test is technically preferred. Because the comparisons are pairwise between evacuees and non-evacuees, the Mann-Whitney U Test is appropriate. However the vast majority of the results do not differ from ANOVA results, so ANOVAs are reported as they are the more prevalently reported test in the social sciences. ANOVAs were run using IBM SPSS Statistics 19 to make pairwise comparisons of whether evacuated and non-evacuated populations overall reported differing responses. To determine whether the experiences of respondents before or during the fire influenced assessments of satisfaction with information received we used ANCOVAs.

## Wildland Fire Events

The Schultz Fire started on the Coconino National Forest outside Flagstaff, Arizona on June 18, 2010, and resulted in no structural losses, although two thousand structures were threatened. During the peak of the event, Highway 89, a major thoroughfare, was closed and over 1,000 residences were placed under an evacuation order. Values at risk included residences, recreational sites, roads, power lines, threatened and endangered species, cultural resources, communication sites, the Flagstaff municipal watershed, and gas and water lines (Steelman et al. 2011b). After the Schultz Fire, seasonal rains caused severe flooding as a result of damage done by the fire and caused further property damage to many of the residents that were evacuated during the fire. The Fourmile Canyon Fire started in Boulder County, Colorado on September 6, 2010, and required evacuation of more than 500 residences. The fire resulted in the destruction of 168 residences and five additional structures. Values at risk included residences and public utilities infrastructure (Steelman et al. 2011a).

## Findings

### Information Seeking and Information Sources

Survey respondents were provided a list of 22 information sources, equally divided between unidirectional (e.g. radio, web sites) and interactive sources (e.g. meetings, conversations). During the fires, evacuees sought information more actively than did non-evacuees, matching findings from previous studies (Cohn et al. 2006; Kumagai et al. 2004; Taylor et al. 2007; Weick et al. 2005). Evacuees reported seeking information from an average of 9.7 sources, while non-evacuees reported seeking information from only 6.6 sources. Evacuees were also more likely to agree that they "used multiple sources of information to learn about the fire" and to indicate that it was important to them to access multiple sources of information. Along with using more information sources overall, evacuees were more likely to use interactive information sources. Survey respondents who evacuated reported obtaining information from an average of 5.3 of the 11 interactive information sources while non-evacuees obtained information from an average of 2.7 of these sources. There was a smaller difference, albeit still statistically significant, between the two groups for use of unidirectional information sources, with evacuees obtaining information from an average of 4.4 of the 11 unidirectional sources while non-evacuees used an average of 4.0 of these sources.

Respondents were also asked to rate how useful and trustworthy they found each information source during the fire (Table 1). There were few differences between the two groups for individual unidirectional sources, with the only significant difference being that evacuees were less likely to rate radio as useful and trustworthy.

**Table 1. Usefulness and Trustworthiness of Information Sources During the Fire: Unidirectional vs. Interactive Sources (Means)**

| | Usefulness | | Trustworthiness | |
|---|---|---|---|---|
| **Unidirectional Information Sources** | **Evacuees (n = 17-132)** | **Non-Evacuees (n = 44-222)** | **Evacuees (n = 18-125)** | **Non-Evacuees (n = 42-213)** |
| Maps | 2.46 | 2.53 | 2.56 | 2.61 |
| Inciweb | 2.32* | 2.07 | 2.52 | 2.34 |
| Websites other than Inciweb | 2.24 | 2.21 | 2.31 | 2.25 |
| Newspapers | 2.16 | 2.23 | 2.18** | 2.38 |
| Information billboard/kiosk | 2.12 | 1.84 | 2.32 | 2.02 |
| Radio | 2.08*** | 2.34 | 2.25*** | 2.45 |
| Scanners | 2.08 | 1.93 | 2.39 | 2.16 |
| Television | 2.07 | 2.14 | 2.11 | 2.21 |
| Twitter | 1.63 | 1.57 | 1.60 | 1.55 |
| Facebook | 1.62 | 1.57 | 1.77 | 1.64 |
| Blogs | 1.41 | 1.57 | 1.39 | 1.60 |
| **Interactive Information Sources** | | | | |
| Local fire department | 2.77*** | 2.34 | 2.86** | 2.53 |
| Family/friends/neighbors | 2.58*** | 2.39 | 2.51 | 2.41 |
| Conversations with IMT representative | 2.45** | 2.13 | 2.58 | 2.40 |
| Public meetings not led by USFS | 2.29*** | 1.77 | 2.36*** | 1.84 |
| Conversations with National Forest representative | 2.29 | 2.03 | 2.43 | 2.27 |
| Law enforcement | 2.23 | 2.16 | 2.52 | 2.38 |
| Public meetings by USFS | 2.21** | 1.90 | 2.41** | 2.14 |
| Call center | 2.21 | 2.00 | 2.41 | 2.16* |
| Meetings at ICP | 2.20 | 1.92 | 2.38 | 2.18 |
| Conversations with local government representative | 2.11 | 2.03 | 2.29 | 2.14 |
| Press conference | 2.09** | 2.34 | 2.22** | 2.46 |

1= Not Very Useful (Trustworthy), 2= Somewhat Useful (Trustworthy), 3= Very Useful (Trustworthy); Asterisks indicate significant difference at .01 (***), .05 (**) and .10 (*) levels.

The difference between groups is rather striking as, for evacuees radio was near the bottom quartile of sources in terms of useful and trustworthy ratings while it was in the top quartile of non-evacuee ratings for both categories. Evacuees also rated newspapers as less trustworthy, although there was no significant difference between groups in their perceived usefulness. More differences between the two groups were found for interactive information sources. Evacuees were more likely to report that they found the local fire department and public meetings by the US Forest Service and others to be both more useful and more trustworthy than did non-evacuees. Conversely, evacuees were less likely than non-evacuees to find one interactive source, press conferences, as either useful or trustworthy. This lower rating may reflect the fact that press conferences may not have been providing evacuees with information that was sufficiently specific to their needs. Interestingly, conversations with Incident Management Team representatives and family/friends/neighbors were seen as more useful by evacuees but not as more trustworthy.

The higher value placed on interactive information sources by evacuees is further demonstrated by the higher importance they placed on being able to interact with information providers and feeling that their concerns were being acknowledged. Although evacuees were no more likely than non-evacuees to report having been provided information by those they trusted or were familiar with, they were significantly more likely to report that it was important for them to have access to trustworthy and familiar sources during the fires (Table 2).

The survey also asked respondents about information sources they used prior to the fire. Interestingly, there were more differences found between the two groups for use of unidirectional sources before a fire (data not shown) than there were during the fire. Evacuees were significantly less likely to report using newspapers, television, Twitter, Facebook, and visitors' centers prior to the fire. Conversely, they were significantly more likely to report using several interactive sources before the fire, including conversations with local government representatives, the local fire department, and public meetings either by the US Forest Service or by other entities to get information about fire management prior to the fires. These findings are noteworthy given that there is no clear reason why the two groups would have used different information sources before a fire and begin to suggest that experiences during a fire may retroactively influence views of pre-fire information needs—a possibility supported in subsequent findings and discussed more fully in the discussion section. Evacuees also were more likely than non-evacuees to indicate that prior to the fire it was important to them to be provided information by people they trusted or were familiar with, have their concerns acknowledged, and to have opportunities to ask questions and to interact with information providers prior to the fire (Table 2). However, unlike during fires, evacuees were no more likely than non-evacuees to indicate accessing information from multiple sources was important to them.

**Table 2. Information Seeking Characteristics During and Prior to the Fire: Evacuees and Non-Evacuees (Means)**

| | Level of Agreement | | Importance | |
|---|---|---|---|---|
| **During the Fire** | Evacuees (n = 138-155) | Non-Evacuees (n = 157-255) | Evacuees (n = 129-145) | Non-Evacuees (n = 168-234) |
| I used *multiple sources* of information to learn about the fire. | 3.57** | 3.42 | 2.86** | 2.72 |
| I was provided information by people whom I *trusted*. | 3.22 | 3.17 | 2.77** | 2.63 |
| I was provided information by people who were *familiar* to me. | 3.01 | 2.92 | 2.47** | 2.30 |
| When providing information to me people *acknowledged my concerns*. | 3.01*** | 2.66 | 2.56*** | 2.07 |
| I had opportunities to *interact* with the people who were providing information. | 2.70*** | 2.40 | 2.36*** | 1.96 |
| | **Level of Agreement** | | **Importance** | |
| **Prior to the Fire** | Evacuees (n = 107-132) | Non-Evacuees (n=161-244) | Evacuees (n=98-111) | Non-Evacuees (n=172-224) |
| I used *multiple sources* of information to learn about wildfire risks. | 2.82 | 2.92 | 2.57 | 2.50 |
| I was provided information by people whom I *trusted*. | 2.95 | 2.90 | 2.63** | 2.44 |
| I was provided information by people who were *familiar* to me. | 2.56 | 2.56 | 2.29** | 2.06 |
| When providing information to me people *acknowledged my concerns* about wildfire risks. | 2.48 | 2.43 | 2.32*** | 2.04 |
| I had opportunities to *interact* with the people who were providing information. | 2.51 | 2.34 | 2.27*** | 1.94 |
| I had opportunities to *ask questions* about what I needed to do in response to wildfire risks. | 2.46 | 2.35 | 2.43*** | 2.07 |

Agreement scale: 1= Strongly Disagree, 2= Disagree, 3= Agree, 4= Strongly Agree
Importance scale: 1= Not Very Important, 2= Somewhat Important, 3= Very Important
Asterisks indicate significant difference at .01 (***), .05 (**) and .10 (*) levels.

## Information Content and Quality

Along with more active information seeking behavior and greater emphasis placed on interactive information sources, evacuees also wanted certain types of general fire information more than non-evacuees during the fire. For both groups the information most wanted was on the status of the fire and the least wanted information was on ecological conditions of the local forest. Those who evacuated were significantly more likely to report wanting information about evacuation, protecting home or property, road closures, and wildfire recovery (Table 3). Evacuees also gave significantly lower adequacy ratings for information about fire hazards, fire status, evacuation, and road closures.

**Table 3. General Fire Information During and Prior to the Fire: Want and Adequacy (Means)**

| | How much did you *want* this type of info? | | Was this info Adequate? | |
|---|---|---|---|---|
| **During the Fire** | Evacuees *n = 148-156* | Non-Evacuees *n = 248-259* | Evacuees *n = 117-143* | Non-Evacuees *n = 203-235* |
| Status of the fire | 2.96* | 2.91 | 2.43*** | 2.61 |
| Evacuation | 2.87*** | 2.54 | 2.48** | 2.65 |
| Where the fire is | 2.85 | 2.78 | 2.51 | 2.56 |
| Road closures | 2.76*** | 2.46 | 2.49** | 2.63 |
| Fire hazards/ concerns | 2.74 | 2.77 | 2.38*** | 2.65 |
| Protecting home or property | 2.55*** | 2.34 | 2.44 | 2.59 |
| Likely fire management strategies | 2.53* | 2.41 | 2.33 | 2.40 |
| Wildfire recovery | 2.43*** | 2.21 | 2.15 | 2.14 |
| Hazardous fuels reduction on the local national forest (mechanical thinning or prescribed burning) | 2.14 | 2.07 | 1.96 | 2.05 |
| Ecological conditions of local national forest | 1.89 | 2.03* | 2.10 | 2.19 |

| | How much did you *want* this type of info? | | Was this info Adequate? | |
|---|---|---|---|---|
| **Prior to the Fire** | Evacuees *n = 137-142* | Non-Evacuees *n = 244-254* | Evacuees *n = 126-135* | Non-Evacuees *n = 215-225* |
| Fire hazards/ concerns | 2.68* | 2.59 | 2.21 | 2.34 |
| Hazardous fuels reduction on the local national forest (mechanical thinning or prescribed burning) | 2.47*** | 2.26 | 2.02** | 2.21 |
| Defensible space/ FIREWISE | 2.47*** | 2.23 | 2.31 | 2.35 |
| Evacuation planning | 2.42*** | 2.21 | 1.93 | 1.98 |
| Likely fire management strategies | 2.31** | 2.15 | 1.85* | 2.02 |
| Ecological conditions of local national forest | 2.18 | 2.20 | 1.96** | 2.19 |

Want scale: 1= Did Not Want, 2= Wanted Somewhat, 3= Wanted Very Much
Adequacy scale: 1= Did Not Receive, 2= Not Adequate, 3= Adequate
Asterisks indicate significant difference at .01 (***), .05 (**) and .10 (*) levels.

Although evacuees had higher interest in topics that were directly related to their safety, we found few differences between the two groups in terms of ratings for receipt, importance, and timeliness of nine pieces of information specific to each fires' management. For both groups the most important information was about where the fire affecting them was going or likely to go and the least important was how much the fire cost (Table 4). The only significant differences between the two groups was that evacuees were more likely than non-evacuees to rate as important information about what fire management choices were being made, why these choices were being made, and why these were the best choices.

**Table 4. Specific Fire Information: "During the Fire, How Important Was it for You to Receive Information on…" (Means)**

| | Evacuees n = 152-155 | Non-Evacuees n = 252-260 |
|---|---|---|
| Where is the fire going? | 2.95 | 2.90 |
| Where is the fire likely to go? | 2.92 | 2.92 |
| What fire management choices are being made? *** | 2.61 | 2.31 |
| What should I be doing? | 2.59 | 2.63 |
| Why are the fire management choices being made? *** | 2.50 | 2.21 |
| Why are these fire management options the best ones? *** | 2.46 | 2.15 |
| How is the ecology of the region affected by the fire? | 2.28 | 2.27 |
| Who is responsible for the fire? | 2.28 | 2.16 |
| How much does the fire cost? | 1.73 | 1.69 |

1= Not Very Important, 2= Somewhat Important, 3= Very Important
Asterisks indicate significant difference at .01 (***), .05 (**) and .10 (*) levels.

The fact that evacuees placed greater value on information related to fire management decisions may reflect Taylor's (2007) findings that evacuees are at a different temporal point in information needs and have become interested in fire management choices that could influence how soon they can return to their property. In terms of timeliness and receipt of the information there were few differences between the groups (data not shown), with the only significant difference that evacuees were less likely to indicate they got information about where the fire was going in a timely manner than non-evacuees and to have received information on where the fire was likely to go, but more likely to have received information on how much the fire cost and who was responsible for management of the fire. Finally, although there were no significant differences (data not shown) between the two groups in feeling they had received credible, accurate, or up-to-date information during the fire, evacuees were significantly more likely to indicate that it was important to them to receive credible and up-to-date information.

> I needed more up to date info posted on computers. I needed more info from City, police and fire because I was running a shelter and people there were concerned. – Fourmile Canyon non-evacuee

> Very frustrated by lack of focused real-time, focused info re: exact details of fire (i.e. did my house burn down) I desperately searched many resources - most were useless (local news) or very accurate but too global

> (Inciweb). (2) no info/notice re: evacuation, or when to go back to house, and no advance notice. (3) Road closure info not updated on ADOT (Arizona Department of Transportation). – Schultz Fire evacuee

When asked about what kind of general fire information they wanted before the fire, evacuees were significantly more likely to indicate that they wanted information about likely fire management strategies, evacuation planning, defensible space, and hazardous fuels reduction activities on the local national forest like mechanical thinning or prescribed burning (Table 3). Information about fire hazards and concerns was the information most wanted by both groups prior to the fire, while information about ecological conditions of the local national forest was least wanted. Similar to assessments of during-fire information quality, there were no differences between groups in whether they felt they received credible, accurate, and up-to-date information prior to the fires (data not shown). However, evacuees were more likely to indicate these three qualities were important to them.

**Overall Information Satisfaction**

As indicated in Table 5, we found no significant differences in overall communication satisfaction ratings during the fires. However, for specific topics, evacuees were less satisfied providing lower ratings for information on evacuation and road closures, how they received information, and how easy it was to get information. Surprisingly, more differences were found between the two groups for communication satisfaction before the fire. Evacuees were significantly less satisfied than non-evacuees with overall communication prior to the fire. They were also more likely to be less satisfied with how they were given information and how easy it was to get information prior to the fire, and with information they received prior to the fire about evacuation and forest conditions related to wildfire risk. The one item where no difference was found between the two groups in satisfaction prior to the fire was for information on how to protect their homes, which has been the primary focus of most fire outreach materials in recent years.

Finally, respondents were asked whether they agreed that communication from local government and the Forest Service before and during the fire helped them understand fire management and whether seeing how the fire was managed increased their trust in the relevant entity (data not shown). There was no difference between the two groups in views of communication from and trust in their local governments, both before and during the fires, with both groups holding essentially neutral views. However, while non-evacuees had response levels for the Forest Service similar to those they had for local government, evacuees were less likely to agree that communication from the Forest

Service helped them understand fire management before or during fires, and that seeing how the fire was managed increased their trust in the institution.

> The Forest Service does not communicate with residents about fire prevention strategies and seems impervious to public comment. – Shultz Fire respondent (evacuee)

**Table 5. Information Satisfaction During and Prior to the Fire: Evacuees and Non-Evacuees (Means)**

| **During the fire, how satisfied were you with …** | Evacuees n=136-155 | Non-Evacuees n=203-255 |
|---|---|---|
| Overall communication? | 2.97 | 3.09 |
| Who gave you information?* | 2.95 | 3.14 |
| *How you were given* information? ** | 2.71 | 2.92 |
| *How easy it was to get* information? *** | 2.55 | 2.84 |
| Information you received about *evacuation*? *** | 2.78 | 3.08 |
| Information you received about *road closures*? *** | 2.82 | 3.10 |
| Information you received about *how the fire was fought?* | 3.01 | 3.14 |
| Information you received about why certain fire *management choices* were being made? | 2.77 | 2.91 |
| **Prior to the fire, how satisfied were you with….** | Evacuees n=126-145 | Non-Evacuees n=179-226 |
| Overall communication? ** | 2.67 | 2.90 |
| Who gave you information?* | 2.82 | 3.01 |
| *How you were given* information? *** | 2.57 | 2.85 |
| *How easy it was to get* information? ** | 2.51 | 2.78 |
| Information you received about *evacuation*? ** | 2.51 | 2.82 |
| Information you received about how to *protect your house/ property*? | 3.11 | 3.19 |
| Information you received about *forest conditions* related to wildfire risk? ** | 2.57 | 2.82 |
| Information you received about the *upcoming fire season*? * | 2.57 | 2.79 |

1= Very Dissatisfied, 2= Somewhat Dissatisfied, 3= Somewhat Satisfied, 4= Very Satisfied
Asterisks indicate significant difference at .01 (***), .05 (**) and .10 (*) levels.

### Local Context

Although our primary focus was on assessing differences in information needs between evacuees and non-evacuees, we also assessed whether these differences varied for evacuees by fire. In general we found few differences between evacuees on the two fires. However, the few significant differences that are found highlight the role that local context likely plays in shaping information needs and use.

Table 6 shows that during the fire Schultz evacuees were significantly more likely than Fourmile Canyon evacuees to desire information about ecological conditions and hazardous fuels reduction on the forest and wildfire recovery. Shultz evacuees also were more likely to have provided higher adequacy ratings for information about the fire status, where the fire was, and local ecological conditions.

**Table 6. Evacuee General Fire Information Needs During the Fire: Differences Between Fires. (Means)**

| | How much did you want this type of information? | | Was this information adequate? | |
|---|---|---|---|---|
| | Schultz Evacuees n=102-107 | Fourmile Evacuees n=42-49 | Schultz Evacuees n=83-97 | Fourmile Evacuees n=34-46 |
| Status of the fire | 2.97 | 2.94 | 2.51** | 2.26 |
| Evacuation | 2.91* | 2.80 | 2.44 | 2.57 |
| Where the fire is | 2.81* | 2.94 | 2.60** | 2.33 |
| Fire hazards/ concerns | 2.78 | 2.76 | 2.37 | 2.42 |
| Road closures | 2.76 | 2.76 | 2.43 | 2.63* |
| Protecting home or property | 2.60 | 2.43 | 2.49 | 2.35 |
| Wildfire recovery | 2.58*** | 2.05 | 2.12 | 2.24 |
| Likely fire management strategies | 2.56 | 2.48 | 2.39 | 2.21 |
| Hazardous fuels reduction on the local national forest | 2.28*** | 1.80 | 1.97 | 1.95 |
| Ecological conditions of local national forest | 2.09*** | 1.43 | 2.28*** | 1.68 |

Want scale: 1= Did Not Want, 2= Wanted Somewhat, 3= Wanted Very Much
Adequacy scale: 1= Did Not Receive, 2= Not Adequate, 3= Adequate
Asterisks indicate significant difference at .01 (***), .05 (**) and .10 (*) levels.

.A few differences also were found in what information sources evacuees used in each location during the fire (data not shown). As compared to Fourmile Canyon evacuees, Shultz evacuees were more likely to report use of radio, the call center, USFS public meetings, and conversations with local government representatives during the fire and lower use of television, blogs, Facebook, press conferences, scanners, and websites other than Inciweb. However, except for television and the call center there were no significant differences in assessments of usefulness and trustworthiness of these sources suggesting the different usage reflected local availability issues and not perceived quality of these items. The call center was used more by Shultz evacuees, who were also more likely than Fourmile Canyon evacuees to indicate it was a useful and trustworthy information source. Conversely they were less likely to use television and to judge it as useful and trustworthy information source. This suggests that differences for these two sources do reflect a judgment of information quality. Satisfaction of several types of pre-fire information (data not shown) varied for evacuees between the two sites as well, with Fourmile Canyon respondents reporting higher satisfaction with information regarding likely fire management strategies, fire hazards and concerns, evacuation planning, and defensible space information

These differences are likely attributable to differences in the threats posed by the two fires, as well as the local social context. The Schultz Fire took place mostly on Forest Service land, and endangered the city of Flagstaff's watershed. Therefore, concerns over the forest ecology and watershed (manifested in wanting information about wildfire recovery) make sense in that context. Because of previous natural disasters, residents in the area of the Schultz Fire were aware of the problems with fire and consequent flooding; in fact, some respondents expressed the opinion that the survey should have focused on the flooding after the fire as the main event rather that the fire. In contrast, the Fourmile Canyon Fire took place on mostly private property and the fire posed a less clear environmental impact to the area as it did not endanger a municipal watershed. Differences in use and usefulness of information sources likely reflect differences in local communication structure during the fire and highlight the importance of recognizing that structure when disseminating information. For example, given that the Shultz fire area no longer had a locally based television station and television news was Phoenix based, the lower evacuee assessment of television as an information source during the fire is not surprising and congruent with findings of other studies that found media conglomeration resulted in limited local coverage.

## Discussion

Overall, the findings from this research support the expectation that those who are more directly affected by a disturbance have a greater need for information (Hodgson 2007; Weick et al. 2005). This is reflected in our findings that evacuees used more sources of information and placed greater value on information more directly related to their needs. In our study evacuees accessed more information sources than non-evacuees and had a higher desire for information on evacuation, road closures, protecting homes, and wildfire recovery. The higher value placed on information about protecting homes and property matches the finding from previous wildfire studies (Cohn et al. 2006; Kumagai et al. 2004; Taylor et al. 2007) that evacuees placed more emphasis on receiving information about the status of their property while evacuated. Our study also provides quantitative support for previous qualitative fire studies that have identified that people affected by wildfires desire information that is credible, accurate, timely and place sensitive (Cohn et al. 2006; Taylor et al. 2007). While we found no difference between respondents in their belief that they had received credible and up-to date information, we did find that evacuees were more likely to think these attributes were important. Comments made by evacuated survey respondents highlight these findings:

> You will never understand how extremely hard it was not to know what was going on. People desperately wanted to know if their home made it or not and the agencies involved FAILED to provide this critical information. So many rumors we were told that our house was gone (untrue) with all the satellites available, why didn't you give us pictures? Why were we kept in the dark? People had to sneak up to see if their home made it. Information should have been provided. – Fourmile Canyon Fire evacuee

In addition, the greater use and value evacuees placed on interactive information sources supports the notion (Hodgson 2007; Weick et al. 2005) that reducing uncertainty involves not just seeking information but engaging in discourse. Our results provide a rich quantitative demonstration of the importance of interaction to evacuees who: 1) used a greater number of interactive sources, 2) were more likely to see a number of interactive sources as useful and trustworthy, and 3) were more likely to indicate that characteristics associated with interactive communication (such as information coming from people they trusted and were familiar with) were important to them. As evacuees engage in the information seeking process the ability to access multiple information sources, particularly those that can provide feedback and allow them to discuss the situation, is an important part of the process that helps them make sense of the situation. The findings also indicate that the preference for interactive information sources found in other research on that examined pre- fire information holds for information during wildfires.

Our findings suggest that while mass media sources are appealing because they can reach large segments of the population, their accuracy and usefulness, particularly for those most directly affected during an event, are questionable. Part of the challenge with mass media sources is their ability to provide locally specific information, which will likely vary based on the structure of the local and regional media markets. For instance, our findings regarding the usefulness of radio as an information source differed from findings by Taylor et al. (2007). Although Taylor's study found a radio station that was local to be a highly useful information source for evacuated members of the public, evacuees from our study found radio to be markedly less useful and less trustworthy than non-evacuees. This suggests that views of radio as a useful information source during a disaster may reflect variations in coverage area in different communities and resulting specificity of information provided.

The results also provide support for the findings of other work that suggests that those most affected by a disturbance are more likely to be critical of information, particularly for those information elements that most impact them. Although we found no difference between the two groups on overall during fire communication satisfaction, evacuees expressed lower levels of satisfaction for those information items that were more important to them—ease of information access and evacuation and road closure information. Although not necessarily easy to accomplish, this highlights the value of working to find ways to ensure that evacuees can easily access up-to-date and accurate information about the evacuation and about roadblocks. As the following comment from a Shultz Fire evacuee indicates, poor information can lead to negative outcomes:

> Evacuation info was not delivered in timely manner. No info regarding time allowed, close proximity of fire, or road closures which caused panic. The fire appeared to be closer than it was. My husband was injured during the evacuation due to what we now know was unnecessary haste. We did not know about road closures until they were closed, leaving many including ourselves w/o necessary medical equipment.

Interestingly, there were more differences between the two groups for prior to fire information than during fire information, with evacuees showing lower levels of satisfaction with information prior to the fire including overall communication. Interpreting such differences in responses between evacuees and non-evacuees to before fire information is difficult as there is no clear reason why evacuees should have actually had such different information needs before the fire. Since our surveys were conducted after the fires occurred, it is likely that evacuee experiences during the fire influenced their views of the sources before the fire. The fact that evacuees were more likely to indicate information they received before and during the fire was insufficient for their needs may be a benefit of hindsight and salience. Non-evacuees did not realize that they did not have certain information because they lacked an urgent need for that information. In contrast, evacuees suddenly needed specific information to quell uncertainty about the situation, thereby leading them to realize that they did not have it. As a Schultz Fire evacuee wrote:

> I'm thinking back and informed by what I know now. I am also biased by the post fire flooding which has been MUCH WORSE than the fire itself in terms of on-going impacts on homeowners.

This dynamic shows how experiences during and after an event can color not just opinions of the event itself and afterward but may retroactively influence views of what was done before the fire. It also points to one of the challenges of natural hazard information provision: how to get individuals to pay attention to information before it is immediately relevant to them. However, one of the findings also suggests that the lack of attention may be at least somewhat related to how much information is readily available on the topic: the one area where there was no difference between evacuees and non-evacuees in prior to fire information satisfaction was for information about protecting homes and property, the main focus to date of most pre-fire outreach efforts.

## Conclusion

These findings support previous work (Cohn et al. 2006; Hodgson 2007; Kumagai et al. 2004; Taylor et al. 2007) highlighting the importance that individuals confronted with a wildfire event place on up-to-date, locally-specific information that helps them make sense out of a complex situation and determine what protective actions, if any, they need to undertake. Those more affected by wildfire events have greater information needs, exhibit more active information seeking behavior, and show a greater reliance on interactive information sources than those less affected by fires. The fact that evacuees were also more likely to judge several interactive sources as more useful and trustworthy further reinforces the need for relevant information to be accessible through meetings and conversations. Collectively these findings, coupled with existing fire research and the literature on sensemaking, suggest that while mass media updates may be useful way of reaching a broad audience during a wildfire, those most directly affected prefer targeted interactive communication that takes local context into account. It therefore appears to be particularly important that evacuees have the chance to interact with individuals who can provide them with the current status of desired information, even when there is no new information to disseminate. Differences between evacuee populations at the two fire sites, with respect to their desire for certain types of information and use of certain information sources, highlights the importance of taking local context into consideration when determining the most effective way to disseminate wildfire information during an event. People want and will search for locally specific information; therefore identifying ways to better fulfill those needs is critical.

At a general level our work confirms that the dynamics of information demands found for other hazards also apply for wildfires. Many of the lessons learned here are parallel to those found on other hazards, particularly in relation to those most directly at risk being more active information seekers who place greater emphasis on receiving timely and accurate information (Hodgson 2007; Lindell et al. 2005; Spence et al. 2007). The importance of interactive information is also a common finding in the risk communication literature (Alaszewski 2005; Sellnow et al. 2009; Toman et al. 2005; Weick et al. 2005) and so likely applicable to other hazards. Our research provides clear demonstration that the more directly impacted a group, the higher and more specific its information needs. Together these findings suggest three ways to potentially improve provision of information to evacuees, irrelevant of the hazard:1) identifying better ways to ensure evacuees—a hard to reach group—have access to information in as timely a manner as possible, 2) identifying the specific information needs of that group, given the specific situation, and targeting information content to meet those needs, and 3) designing information dissemination processes so that the more directly impacted a group is by a disaster, the greater the emphasis placed on providing that group with access to as many interactive information sources as possible.

Perhaps the most striking of our findings is the indication that experiences during an event may retroactively shape views of information outreach efforts prior to the event. This provides an additional impetus for efforts to minimize information issues during an event given that any missteps could impact perception of information provided before as well as during the event. It also highlights the need for better baseline data for fire prone communities in order to be able to assess how much of such differences in information assessment are due to differences that existed before an event and how much are a result of retroactive assessments. Whether the more critical view we found that evacuees had of pre-fire information would hold for other hazards is more open to question. One of the relatively unique characteristics of wildfire is the fact that the hazard itself is actively managed during the event. Earthquakes and hurricanes can only be prepared for and responded to--little can be done to decrease their impact during the event itself. The fact that most wildfires are actively managed may contribute to greater critique or blaming behavior by those most affected. Understanding how this dynamic plays out with other, less actively, managed natural hazards merits further investigation. A related topic for further investigation is the idea, suggested by the lack of difference we found between the two groups in pre-fire satisfaction with information about protecting homes, that such retroactive criticism could be mitigated in advance by concerted information outreach efforts prior to an event.

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# Livestock Evacuation Planning for Natural and Man-made Emergencies

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*On March 11, 2011, Japan was struck by the Great East Japan earthquake followed by a 23-foot tsunami, which crippled the Fukushima Daiichi nuclear plant. Because of a lack of plans for livestock evacuation in the case of a nuclear power plant accident, local farmers in the Fukushima exclusion zone had significant losses. Development of a rigorous and mathematical formulation of an evacuation plan for livestock in a case of disasters is essential for producers to lessen the financial and emotional impacts. Thus, we propose two mathematical models for evacuation plan for livestock in the area around a nuclear power plant using integer programming over networks. Since solving an evacuation problem on a time dynamic network is NP-hard, we propose algorithms to estimate an optimal solution for our problem. The methods and models discussed herein apply not only to nuclear plant related disasters, but also to a variety of other emergencies.*

**Keywords**: animal evacuation plan, livestock, nuclear power accidents, natural and man-made disasters

## Introduction

Various papers have proposed the salvageability of livestock after a nuclear crisis to avoid disruption in the economic stability of that sector. For example, a report of the United States Department of Agriculture, Animal and Plant Health Inspection Congressional Research Service (UDSA/APHIS) recommended avoiding “panic slaughter” because livestock that have survived exposure to radiation must be preserved to rebuild healthy and viable populations after a nuclear crisis (Berger et al. 1987). This report also gives detailed steps on how to decontaminate livestock exposed to radioactive material. In the wake of growing concerns by pet owners and livestock producers for animals remaining in the 20 km exclusion zone, the International Fund for Animal Welfare (IFAW) in May 2011 made specific recommendations to the Japanese government that animals should be rescued, decontaminated and provided relief (IFAW 2011). Moreover, a protocol for handling livestock externally contaminated by radioactive material has recently been proposed based on the degree of exposure, the cost of decontamination, the demand for that food product, and the economic impact to the producer (McMillan et al. 2011). Even though the authors of the document have strongly stated the importance of establishing a concrete evacuation plan for livestock in the area around a nuclear power plant, they have not discussed a mathematical and statistical formulation for such a plan. Development of a rigorous and mathematical formulation of an evacuation plan for livestock around a nuclear power plant is essential for producers to lessen the financial and emotional impacts related to losing their animals (Carroll et al. 2006; Wilson et al. 2009).

Modeling an efficient evacuation plan from the disaster zone is essential in order to save livestock before they are externally or internally contaminated by radionuclides such as cesium or iodine. External and internal contamination of livestock by radionuclides is produced in a variety of ways such as radioactive material in air or rain and via internal contamination by ingesting contaminated feed and water (Berger et al. 1987). For example, cesium 137 and iodine are important radionuclides because cesium has a half-life of 30 years and settles into the bone marrow, while iodine because of its relatively large mass and effect on the thyroid. (www.ncrponline.org/Publications/Press_Releases/161press.html)

Apart from the financial damage introduced by the sudden loss of the livestock of a specific area, there are also a number of emotional and social welfare losses associated with losing companion animals or livestock. These factors, weighed in from a sociological point of view, are stressed in Zottarelli (2010). Therein, the author points out the emotional distress caused by the loss of companion animals during Hurricane Katrina.

From the above, it is easy to note that a scheme for fast evacuation of livestock from the disaster zone is vital. Also it is imperative to save as many livestock as possible. Traffic flows for transporting livestock can be seen as flows in a network, a directed graph $G = (N, A)$ where $N$ is the set of nodes and $A$ is the set of arcs. Therefore, in this paper we formulate an evacuation plan for livestock in a case of a nuclear power plant as an optimization, minimizing the evacuation time as well as maximizing the number of transportation of livestock in an evacuation, i.e., flows in a network.

In general, solving a network flow problem is set up as an integer programming (IP) problem, however it belongs to a specially structured set of problems that can be tackled in polynomial time (Papadimitriou and Steiglitz 1998). Integer programming, on the other hand, belongs in general in the set of NP-hard problems (Schrijver 1986). In the case of a time expanded network, as is the case in our work, where we are not only interested in a static network, but in a time dependent one, the problem becomes NP-hard. This means solving the integer program might be intractable in the large scale and, thus, employing an exact solver is impractical. For this reason, people usually try to estimate the IP solution using linear programming (LP) techniques, which can be solved in polynomial time, by relaxing the integral condition of the solution. In this paper, we will discuss the exact IP solutions and compare them with the solution obtained using an augmented Lagrange multiplier heuristic approach.

In this paper, we focus on the lessons learned from the Fukushima Daichii nuclear plant meltdown and subsequent evacuation process. However, our models and methods can be universally applied to evacuation frameworks that include a known disaster source. It is not always the case that the source of a disaster can be well defined in the setting of the underlying transportation network; in many disasters, though, that is the case. When a hurricane is about to hit an area, the site of landfall can be predicted with substantial accuracy, giving us a clearly defined evacuation area. Of course, the same can be stated in the case of a volcanic eruption. For active volcanoes, the danger source is the volcano itself, while the affected area to be evacuated can be computed through various simulations. In the case of a bioterrorist attack, or a chemical spill, once more the danger source is known, albeit not well in advance. In all the above cases, where the source is known, or can be found after the incident has started, our methodologies can be applied with no alterations in their considerations.

## Formulation and Algorithmic Implementations

In this section, we will formulate our evacuation plan for livestock in a case of a nuclear power plant accident. Let $G = (N, A)$, where $N$ *is* the set of nodes and $A$ is the set of arcs, be a network given. Let $S \subset N$ be the set of nodes that are considered safe. Let $f_{ij}^t$ be a variable denoting the number of animals at arc $(i, j)$ at the time $t$ and $d_i^t$ be a variable denoting the number of animals waiting for rescue at node $i$ at time $t$. Let $p_{ij}^t$ be the known probability that arc $(i, j) \in A$ will be available at time $t$ and let E be the lower bound of the success probability we aim to achieve.

First we consider a maximum flow in a network in order to evacuate as many livestock as possible from the disaster zone.

$$(1) \quad \max \sum_{t \in T} \sum_{i \in N/S} \sum_{j \in S} f_{ij}^t$$

$$(2) \quad s.t. \sum_{t \in T} \sum_{j \in R.S.(i)} f_{ji}^t - \sum_{t \in T} \sum_{j \in F.S.(i)} f_{ji}^t = d_i^{t+1}, \qquad \forall i \in N/S, \quad \forall t \in T$$

$$(3) \quad f_{ij}^t \leq u_{ij}^t, \qquad \forall (i,j) \in A, \ \forall t \in T$$

$$(4) \quad \sum_{t \in T} \sum_{(i,j) \in A} f_{ij}^t \mathrm{p}_{ij}^t \geq \epsilon \sum_{t \in T} \sum_{(i,j) \in A} f_{ij}^t$$

$$(5) \quad d_i^t \geq 0, \qquad \forall i \in I, \quad \forall t \in T$$

$$(6) \quad f_{ij}^t \geq 0, \qquad \forall (i,j) \in A, \quad \forall t \in T,$$

Where *R.S.* (*i*) is the reverse star of node *i* and *F.S.* (*i*) the forward star. The formal definitions are

$$R.S.\ (i) = \{j : (j, i) \in A\}$$

and

$$F.S.\ (i) = \{j : (i, j) \in A\}.$$

In the formulation, equation (1) is the objective function that is maximized. It corresponds to maximizing the number of animals that are being evacuated from the endangered area (*N/S*) toward one of the safe zones (*S*). The constraint presented in equation (2) guarantees that the number of animals waiting to be rescued at a given node and time must be equal to the number of animals that originally were there, plus the ones that visited that node on their way to safety, and minus the ones that have already been evacuated. This is clearly the time expanded version of the flow preservation constraints that are seen in network flow problems.

Thus, equation (3) is a simple link capacity constraint that can drop to zero if the link is permanently destroyed or closed. Since this is a vehicular evacuation, it is fair to assume that there exists an upper bound on the number of animals that can be evacuated using a specific arc at each given time. Also, the constraints in equations (5) and (6) are simply there to enforce the non-negativity of demands and flows.

A closer look at equation (5) reveals that it is highly unrealistic to assume that all links will be fully functional throughout the evacuation. Especially when it comes to catastrophic events, several roads of the underlying transportation network could either be closed by officials or destroyed by the hazard agent while people and animals are still being evacuated. However, with modern simulation techniques, we can obtain reasonable expectations about these events. After these simulations, we have at our disposal a series of probabilities that a certain link will be functional at a certain time $t$ in the future. In this constraint, we require that the selection of routes satisfies a certain probability. With that constraint, we ensure a high probability of the evacuee animals reaching the safe zones within the time horizon given.

The solution vector obtained by the first formulation will be in the form of a vector $x_{ij}^t$. This vector would represent the number of animals using arc $(i, j) \in A$ at time/period $t \in T$. At this point, it is important to note that the solution vector is not easily applicable to a realistic representation of the livestock evacuation problem. However, it is used a starting point for more applicable mathematical formulations, such as the one that follows. A second formulation based on the vehicle routing problem can be adopted to render the underlying model more realistic. The problem can then be formulated as:

$$\text{(7)} \qquad \min \sum_{(i,j)\in A} \sum_{k\in K} c_{ij} x_{ij}^k$$

$$\text{(8)} \qquad s.t. y_i^k \leq \sum_{j:(j,i)\in A} x_{ji}^k, \qquad \forall i \in N, \ \forall k \in K$$

$$\text{(9)} \qquad \sum_{k\in K} y_i^k = 1, \qquad \forall i \in N$$

$$\text{(10)} \qquad \sum_{i\in N} y_i^k d_i \leq C^k, \qquad \forall k \in K$$

$$\text{(11)} \qquad 0 \leq y_i^k \leq 1, \qquad \forall i \in N, \ \forall k \in K$$

$$\text{(12)} \qquad x_{ij}^k \in \{0, 1\}, \qquad \forall (i,j) \in A, \ \forall k \in K.$$

In this problem we have a fleet of vehicles ($K$) and a set of destinations (“clients”) with a given demand $d_i$. Each of the vehicles of the fleet has a capacity $C^k$. In this formulation we have two sets of variables:

$$x_{ij}^k = \begin{cases} 1, & \text{if arc } (i,j) \text{ is being employed for vehicle } k \\ 0, & \text{otherwise} \end{cases}$$

and $y_i^k$ which is equal to the “percentage” of the demand that vehicle $k$ can serve. Hence, in equation (9) the summation of the percentages that each vehicle contributes is equal to 1. Also, as indicated in equation (8), a vehicle can serve a node only if it has been assigned to an arc that terminates in that node. In equation (10) the capacity constraint requires that each vehicle cannot surpass its capacity limitation $C^k$. Last, equations (11) and (12) ensure that $y_i^k$ will remain between zero and one along with the binary nature of variable $x_{ij}^k$.

Also, as indicated in equation (8), The solution vectors obtained by the second formulation can be easily utilized. The vector $x_{ij}^k$ represents whether arc $(i, j) \in A$ is to be used by vehicle $k \in K$. That will help design the routes that all serving vehicles need to use in order to safely evacuate the maximum number of animals. The second vector, $y_i^k$ represents the percentage of its capacity (storage capacity for livestock) that it can contribute at each of the nodes $i \in N$.

## Algorithmic Design

The algorithmic design appears to be simple, yet it is highly efficient. In situations where a large-scale evacuation is necessary, it is acceptable that the results be obtained as fast as possible, even if that implies sub-optimality, rather than wasting resources and computational time to reach optimality. This is also the main driver of our implementations. Taking into consideration the recent catastrophic events of Fukushima after the earthquake, it becomes increasingly obvious that a fast and well-organized, yet not perfect, plan is much preferred to a late, optimal evacuation routing model.

The algorithm we are following in this project can be summed in Algorithm (1) below. Notice that in this algorithm, we solve the Lagrange relaxation using a commercial solver (in our case Gurobi 4.6). Then, after we achieve an increase in the number of animals we can successfully evacuate, we stop the optimization phase and turn to the rounding phase. As mentioned before, since we are dealing with a large scale optimization problem, we are primarily interested in retrieving a good quality, feasible solution. Hence, we are applying a simple, yet efficient in the worst case scenario, rounding method. Every one of our fractional flows will be rounded up, implying that at some point we might obtain less node demand than we actually need to satisfy, which does not affect the results.

For the same reasons as before, we applied a similar algorithmic idea to the second formulation. Once more, the latter formulation is a more realistic representation and hence a much more difficult integer program to deal with. The underlying idea for the algorithm is that, if we somehow relax the coupling constraint in equation (8), then we are left with a much easier program that only deals with the $y$-space of the problem. The basic idea is presented in Algorithm (2).

**Algorithm 1. The Algorithm Designed for the First Problem Formulation.**

$z* \leftarrow \infty$, $z \leftarrow 0$, $\epsilon \leftarrow 10^{-2}$

**while** $|z^* - z| > \epsilon$ **do**

  $z^* \leftarrow z$

  Solve the Lagrange Relaxation of Problem (1)-(6) and obtain $z = \sum_{t \in T} \sum_{i \in N/S} \sum_{j \in S} f_{ij}^t$

  Update dual Lagrange multipliers

**end while**

Round all flows $f_{ij}^t$ up.

**return** $f_{ij}^t \quad \forall (i,j) \in A, \ \forall t \in T$

**Algorithm 2. The Algorithm Designed for the Second Problem Formulation.**

$z* \leftarrow \infty$, $z \leftarrow 0$, $\epsilon \leftarrow 10^{-2}$

**while** $n$ **do**

  $z^* \leftarrow z$

  Solve the Lagrange Relaxation of Problem (21)-(26) and obtain $z = \sum_{(i,j) \in A} \sum_{k \in K} c_{ij} x_{ij}^k$ and $y$

  Update dual Lagrange multipliers

**end while**

Round all binary selection variables $x_{ij}^k$ up.

**return** $x_{ij}^k \quad \forall (i,j) \in A, \ \forall k \in K$

## Computational Results

In order to obtain these results, we created a series of networks (ranging from 30-100 nodes and from 10-30 time steps) and applied our algorithm. We compared the results to the ones obtained by Gurobi 4.6 on an Intel Core 2 Duo at 2.0 GHz. For each of the experiments shown in Table 1 and 2, 30 different instances were created and solved. The results appear in the tables.

**Table 1. Computational Results Obtained for the First Formulation.**

| Horizon | Nodes | Time (sec) | IP Time (sec) | Average Optimality Gap (%) | Maximum Optimality Gap (%) | Minimum Optimality Gap (%) |
|---|---|---|---|---|---|---|
| 10 | 30 | 3.6 | 9.0 | 1.3 | 2.7 | 0.0 |
| 10 | 50 | 8.2 | 15.0 | 1.5 | 1.9 | 0.0 |
| 10 | 100 | 22.1 | 37.0 | 1.5 | 2.9 | 0.0 |
| 10 | 30 | 8.0 | 14.2 | 1.2 | 1.4 | 0.1 |
| 10 | 50 | 21.3 | 39.0 | 1.2 | 1.7 | 0.0 |
| 10 | 100 | 63.0 | 109.0 | 1.9 | 2.4 | 0.0 |

**Table 2. Computational Results Obtained for the Second Formulation.**

| Nodes | Time (sec) | IP Time (sec) | Average Optimality Gap (%) | Maximum Optimality Gap (%) | Minimum Optimality Gap (%) |
|---|---|---|---|---|---|
| 20 | 4.5 | 19.0 | 3.3 | 10.7 | 0.0 |
| 30 | 9.9 | 34.0 | 3.5 | 13.9 | 0.0 |
| 50 | 22.1 | 69.0 | 5.5 | 22.8 | 0.2 |
| 80 | 41.2 | 182.0 | 4.2 | 9.4 | 0.3 |
| 100 | 75.6 | 331.4 | 6.2 | 16.5 | 0.0 |
| 200 | 223.0 | 1309.0 | 10.9 | 22.4 | 0.1 |

As we can see, our algorithm obtains results that are near optimal at all cases. It is important to note that in almost every one of our cases, there was at least one instance that was solved to optimality using our relaxation approach. It is also very interesting to see that our algorithm is producing results efficiently and rapidly, outperforming the commercial solver in all instances.

In addition to the computations that were performed to empirically demonstrate the success of our modeling and algorithmic efforts, a graph/network based on the Fukushima site was created and put to test. Both formulations produced solutions that were near optimal at all cases (within 5% difference). For the numbers of the animals, we used the official data for the livestock from the Japan Department of Agriculture and the officially recognized farms close to the nuclear plant site. Safety was considered to be reached after reaching a 20 km distance from the plant. Last, a horizon was set to be equal to a 30-minute time step. In our approach, discrete time steps are assumed so as to easily model it as a mathematical program. We assumed that there is a time limit after which no further people, livestock, or vehicles leave the affected area. This time limit was selected to be equal to 12 hours (24 horizons).

As for the second formulation, we assumed that a fleet of 34 vehicles is employed all with a capacity of 10 animals per vehicle. The value of 34 was selected after preliminary examination of the set [25, 40] to identify a set of initial conditions for the problem that are realistic enough, yet provide us with a feasible solution. With these site conditions, all demands could be met and every farm animal from the area could reach safety within the given time limits. For future research and further implementations, we could discuss a non-homogeneous fleet of vehicles with different animal categories. At the moment, all animals are considered homogeneous in order to facilitate the rounding algorithms presented.

The network created consists of 57 nodes and 99 arcs (roads) all of which have distinct, realistic capacities. The capacities are only employed in the first formulation, while in the second one they are replaced by a Steiner forest (vehicle assignment) constraint. The results given by the algorithms are presented in Table 3, where the first solution is given by our algorithmic scheme and the second one is the optimal result produced by the solver itself. The result is characterized optimal from the mathematical programming point of view, while in practice it is a boundary solution (extreme point). Hence, it might prove infeasible due to the road closures and further restrictions that were not disclosed when the evacuation begins. This is the focus of a number of research studies, called robust optimization. For more information, the interested reader is referred to Ben-Tal and Nemirovski (2002) and Beyer and Sendhoff (2007).

**Table 3. Computational Results Obtained for the Practical Application.**

| | Implementation Evacuation Scheme | “Optimal” Evacuation Scheme |
|---|---|---|
| First Formulation | 23 horizons | 21 horizons |
| Second Formulation | 34 vehicles | 29 vehicles |

## Application of the Algorithms

The premise of our work has been greatly affected by the disaster that occurred in Japan in 2011. A similar disastrous scenario could occur in the United States because 20 percent of its energy is generated by 104 nuclear power reactors—of which 52 are about 40 years old and many of which are within states having a considerable livestock industry. For example, a 2007 USDA Agricultural Census shows that there are 33 million beef cattle and 9.2 million dairy cattle in the United States, with Florida, Tennessee and Arkansas having a heavy beef cattle industry and other states in the southeast U.S. having a considerable dairy industry.

In addition to that, applications of the proposed mathematical models include not only a nuclear plant crisis but also emergencies such as natural disasters, exotic animal diseases, pests, bioterrorism attacks, and chemical spills. To clarify, the premise of our work might have its roots in the tsunami and the nuclear power plant meltdown in Japan, but it can be generalized to include other situations where an area needs to be permanently or temporarily evacuated. In all cases where a natural or man-made disaster spreads towards an area that humans or animals inhabit, our models can be easily applied to develop an evacuation plan that is guaranteed to be both of high quality (i.e., resources are well-utilized, most animals are evacuated safely, humans are not endangered) and very fast compared to the same solutions provided by a commercial solver.

To apply our models to realistic emergencies, we have been working on two projects:

(1) Collaborating with veterinarians in the state of Kentucky for Public Health in order to implement our models in the cases of a natural disaster occurring in the state and

(2) Collaborating with local farmers in the Fukushima exclusion zone and collecting the data from the zone in order to learn from the unfortunate experience of the Fukushima Daiichi nuclear power plant accident

In Kentucky, the state Public Health department is highly concerned about developing evacuation plans for natural disasters such as earthquakes and floods. Consequently, they contacted the authors to participate in a meeting where state emergency preparedness was discussed. During the meeting, veterinarians expressed their interest in devising a plan for the state of Kentucky that would guarantee a safe evacuation to the majority of dairy cows, beef cattle, and horses (Linnabary 1993), which are a major economic factor for the state. The second author has been participating in their meetings and communicating with them since April 2012.

Furthermore, Dr. Shigeki Imamoto has been in the Fukushima exclusion zone to conduct research on the status of livestock as an official veterinarian from the Japanese government since April 2011. He has been working with local farmers in the affected area to help support the management of their farms and livestock since then. In working with the local farmers in the Fukushima exclusion zone, we are analyzing what went wrong during the Great East Japan Earthquake and are developing strategies to reduce damage in future disasters. Similar opportunities have arisen for collaborating with researchers who have offered us an opportunity to include them in our work such as the case of a volcanic eruption (Bird et al. 2011; Wilson et al. 2012).

Last, it is very important for human and animal evacuation plans to be integrated. However, it is easy to see that evacuation management for the human population in the risk area should have higher priority than the animal population. Both of the models presented herein treat the livestock evacuation problem in isolation. In the future, livestock evacuation must be examined concurrently with human evacuation, but ensuring that human evacuation takes precedence at all times. Recently, we have been working on a generalization of the evacuation problem as a whole, including both evacuation of humans and livestock. This problem will have to be formulated as a two-stage mathematical problem in which the optimal solution guarantees that the two evacuation processes do not interfere. That is, human evacuation is always prioritized to ensure the well-being and safety of human population before tackling the livestock evacuation problem.

## Discussion

In this paper, we proposed two mathematical models that aim to help solve the evacuation problem of livestock in the case of an emergency. The first model aspires to solve a time-dependent maximum flow problem that maximizes the number of animals that can be evacuated while minimizing the time it takes to do so. The second one assumes that a fleet of vehicles that can transport animals out of the danger zone is available and tries to minimize the number of vehicles that need to be used in order to maximize the number of animals that reach safety. Both models assume that a time limit exists, after which all operations in the risk area cease.

This is not the first attempt to develop a full-scale evacuation plan for livestock during an emergency. However, it is an attempt to mathematically model a problem by employing operations research methods. It has been stressed in the past that evacuation management needs to include livestock, as proposed by Casper et al. (1995) and Mansmann et al. (1992). More recently, jurisdictions such as Brantley GA have adopted animal evacuation practices since 2006.

One important aspect of the livestock evacuation problem that needs to be addressed in the future is the one of obtaining the necessary data. At the moment, there have been efforts to collect all information on cattle numbers and exact locations of the farms where they are kept. However, collecting this information and combining it with data on the local transportation network is still a challenging task. Google Earth can be of assistance, as described by Xin and Hu (2008). In addition, other interesting approaches in data collection can be found in De Silva and Eglese (2000) and Vatsavai et al. (2006).

In order to be able to apply our models to real data sets, we must be able to solve a large IP problem. However, in general, this might prove to be very computationally expensive with a large system. Thus, in this paper, we proposed heuristic methods to estimate an optimal solution of our IP problem. We also used a LP relaxation to approximate an optimal solution but the gap between the IP optimal value of each formulation presented herein and its LP relaxation might be large. Thus, it might be interesting to investigate the size of the gap between the IP optimal value of each formulation and its LP relaxation. When the feasible region (which is called a polytope) is totally unimodular, an optimal solution of the IP problem over the feasible region equals an optimal solution of its LP relaxation (Schrijver 1986).

This study provides owners of livestock a solution to preserve their animals from an area affected by a nuclear accident. McMillan et al. (2011) initiated this effort by proposing a plan to assess and handle livestock that have been externally contaminated. Our study presents two distinct mathematical models that allow livestock to be successfully evacuated from an area as soon as a nuclear crisis or other life threatening disaster occurs. Future research, a collaboration among scientists from the University of Colorado, University of Kentucky, and the University of Florida, will include studying the effects of radiation on the progeny of animals from an affected zone as well as understanding the public perception, acceptance of livestock, and animal products used for human consumption originating from areas affected by the Fukushima Daiichi nuclear plant. The research team plans to do this by surveying the public and launching an aggressive public relations campaign based on results from physical measurements and data analysis.

The meltdown at the Fukushima Daiichi nuclear power plant as a result of the earthquake and tsunami on March 11, 2011 was indeed one of the worst nuclear disasters in history. While people had several options for evacuating from the affected areas, a systematic and coordinated evacuation plan was not available for owners of livestock, causing many cattle, pigs, horses, and chickens to starve to death while locked in their pens. This is our attempt herein: to provide a scientific solution to minimize the economic impact to the livestock industry in the unfortunate case of a natural or man-made disaster, and to recommend considering farm animals as evacuees in the event of a future crisis.

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# Simulation Evacuation Modeling of A Commercial Shopping District to Safe Zones

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*Commercial shopping districts offer challenges for emergency planners to plan for the evacuation of short-notice emergency events. This paper illustrates a simulation analysis of the evacuation a large commercial shopping district, which focuses on street and parking lot vehicle traffic. Microscopic simulation is used to track the behaviors of vehicles evacuating from parking lots to safe zones. Evacuation scenarios investigate evacuation strategies by varying factors involving the occupancy rate of parking lots, inbound traffic control, and destination assignment policy. The performance of the evacuating vehicles is measured by an evacuation risk profile including the most problematic parking lots in terms of evacuation time. A trade-off analysis illustrates the effectiveness of the evacuation strategies in terms of costs, time, and risk. The simulation results indicate that an optimized destination assignment policy can alleviate traffic congestion and reduce total evacuation time.*

**Keywords**: Evacuation; microscopic simulation; evacuation risk.

## Introduction

Emergency planning has been an emphasis of homeland security, where the planning of evacuation is a significant issue. Evacuation generally represents the mass mobility of vehicles and pedestrians escaping from affected areas to safe regions, often in response to an emergency agency's evacuation orders during an emergency. The loss of property and potential casualties can be significant if the evacuation plan is not well developed. For instance, an unprecedented devastating tsunami hit Indonesia in 2004, causing more than 130,000 confirmed deaths and thousands of homeless people, due to lack of tsunami warning systems and well-prepared evacuation plans (Asian Development Bank 2006). Thus, evacuation plans that consider how people exit an affected area are critical to improving safety and response efforts.

Our interest in this research involves the short-notice evacuation of people within a commercial shopping district due to an emergency. For example, commercial shopping districts offer prime targets for terror attacks. In addition, the large concentrations of people increase the risks associated with short-notice natural events such as tornadoes and flash floods. In some sense, the work presented here extends the ideas used in special events planning to short-notice evacuation situations. Special event planning involves the pre-planned movement of a large number of people into and out of an area. A classic example of special events planning is the handling of football stadium traffic on game days. In special events, planners know from historical experience what conditions to expect (e.g., the number of people) and what management strategies (e.g., traffic routing) to use to optimize the safe movement of people but this is only for situations that are known in advance to occur at a particular time/date. Commercial shopping districts can offer similar concentrations of people, but not necessarily under planned conditions. In our situation, we do not know with certainty (or we have very short notice) that an emergency will occur within an area; however, we can anticipate the possibility and still develop strategies that can be deployed to reduce the risks associated with these situations. This involves models that can assist planners in understanding the risks associated with an area, which is a focus of this paper.

The methods for modeling evacuation can be categorized into two types: static methods and dynamic techniques. Static methods such as Bulk Lane Demand (Cova and Church 1997) are usually used for a preliminary analysis, where evacuation planning is simply measured based on static factors such as current network capacity and evacuation traffic volume. In real situations, evacuation is a dynamic process involving the movements of people and vehicles. The behavior of people is usually full of uncertainty in making decisions such as destination choice, route choice, and driving speed. In addition, the traffic operation or pedestrian movements usually change over time causing dynamic traffic congestion and traffic bottleneck locations. Therefore, the modeling of traffic operations and pedestrian movements is very important for local planners. Such models enable them to predict traffic congestion on evacuation routes and guide evacuation planning to avoid such impediments. The traditional static method may not be adequate when considering these situations. The development of computational resources has given rise to simulation techniques that are able to mimic complicated systems in more detail level via micro-simulation.

Large regional evacuation simulation modeling has been an important research area for the emergency planning of regions suffering from nature disasters and man-made attacks such as tsunami, earthquake, radioactive release, wild fire and terrorist attacks (Chen, Meaker, and Zhan 2006; Satinnam et al. 2005; Wolshon, Catarella, and Lambert 2006). The evacuation modeling of mid- to large-scale local areas has not received significant attention. Such areas include neighborhoods, large parking areas, commercial districts, and the urban-wildland interface. One of the reasons is the unique topography of these areas, which usually requires more detailed modeling of the environment and movements of vehicles and pedestrians. Because of increases in population and building structures within such areas, the need for developing evacuation plans is necessary and important, especially when the existing transportation system has not been improved to meet increasing traffic demand over a period of time.

To evaluate different evacuation strategies, most researchers focus on the benefits of evacuation plans such as the reduction of total clearance time as well as travel times for individual vehicles. However, there is a lack of research associating the effectiveness of evacuation strategies with evacuation risks and evacuation costs. Evacuation risks involve many aspects such as evacuee fatalities and disturbance to local traffic flows. Evacuation costs include, but are not limited to, implementation costs of evacuation plans and the costs of evacuation resources (e.g. emergency vehicles and responders).

The goals of this paper are to illustrate micro-simulation techniques on the evacuation of a mid to large-scale commercial shopping district and to examine a number of response strategies that could be considered in such situations. The paper first reviews background studies in evacuation modeling, and then addresses key modeling issues. These issues include such topics as parking lot modeling, trip generation, and destination choice. Model experimentation and results are presented to evaluate different evacuation strategies. Finally, conclusions concerning the effectiveness of the modeling are discussed and future research areas are presented.

## Background and Literature Review

Because of its ability to represent detailed dynamics, simulation has been an important analysis technique within evacuation modeling. There are three scales of simulation approaches: micro-simulation, meso-simulation, and macro-simulation. Meso-simulation and macro-simulation basically model the behaviors of aggregated traffic flows, whereas micro-simulation, often called agent-based simulation, models individual resources (vehicles and pedestrians) as independent agents who can make decisions by interacting with both other agents and the surrounding environment. Microscopic simulation can track the detailed movements of resources, and therefore emergent behaviors can be obtained through simulating the individual agents. (Pidd, de Silva, and Eglese 1996; Southworth 1991; Sheffi, Mahmassani, and Powell 1982; Teodorovic 2003).

Southworth (1991) described an evacuation study as consisting of five separate processes: trip demand generation, evacuation departure timing, destination choice, routing assignment, and building-up of evacuation plans and analysis. Trip generation involves estimating how many evacuees participate in the evacuation. Southworth (1991) indicated that network coding, spatial and temporal distribution of population, and vehicle utilization are the emphasis of trip generation. Since it is very challenging to collect data about population distributions, most researchers assume that the trip demand can be estimated by using the evacuation participation rate in the traffic analysis zones. Chen et al. (2006) used a formula developed by Nelson et al. (1989), where the number of evacuating vehicles for hurricane categories are approximated by multiplying the factors involving vehicle ownership, households' quantity, household occupancy rate, household participation rate, and vehicle usage level. Fu and Wilmot (2004) developed a binary logic model to formulate a dynamic evacuation demand assignment. This model included factors such as household type, hurricane characteristics, evacuation orders by authorities, and time periods in a day during a hurricane evacuation. Without considering compound factors like Fu and Wilmot (2004) while capturing the randomness of the number of vehicles in each household during evacuation, Cova and Johnson (2002) introduced a Poisson distribution to simulate the number of vehicles in each house at different times of the day.

Evacuation departure timing represents the time from detecting the emergency to starting evacuation. It is usually different for different locations and it may be affected by factors such as warning mechanism, relative distance to emergency site, structure inhabited, and personalization of the emergency warning (Sorensen, 1991). The departure time may be obtained from historic evacuation data or modeled with a logistics distribution (Sorensen and Mileti 1989; Rogers and Sorensen 1991; National Center for Transportation and Industrial Productivity 2007). Cova and Johnson (2002) presented a reverse Poisson distribution to model the temporal pattern of departing vehicles from each household.

For the routing assignment, Southworth (1991) summarized three approaches used to model the route selection process: myopic route assignment, an optimization model based route assignment, and pre-specified route assignment. Sinuany-Stern and Stern (1993) introduced shortest path and "myopic" view routing methods in the modeling. Under evacuation conditions, the destinations may be shelters or safe zones outside of the affected areas. Cova and Johnson (2002) summarized four methods for destination choice: closest exit assignment, traffic data-based approach, manually established method, and probabilistic approach. Since evacuees probably prefer to go home during an evacuation, Jha, Moore and Pashaie (2004) proposed that the destination should be assigned based on the population proportion living outside the affected area.

There has been significant research in modeling evacuations; however micro-simulation in evacuation modeling has not been widely applied until the 1990s. Sinuany-Stern and Stern (1993) presented a sensitivity analysis for total evacuation time in a case study of a small city using the simulation language SLAM II. To support the development of contingency plans for evacuation, Pidd et al. (1996) developed a spatial decision support system (SDSS), linking a GIS (ARC/INFO) with a special micro-simulator written in C++. More recently, Chen and Zhan (2008) used an agent-based simulator, Paramics, to explore the effectiveness of evacuation strategies including simultaneous and staged evacuation.

For developing an emergency plan at the neighborhood scale, Cova and Johnson (2002) presented a framework for using a micro-simulation to develop and test evacuation strategies within the urban-wildland interface, where a custom scenario generator and geographic information system (GIS) were employed to simulate the traffic and visualize simulation results. At the same time, Church and Sexton (2002) applied microscopic simulation to the evacuation of a neighborhood with high risks of wildfires. Another noticeable neighborhood-scale evacuation is the case study of a hurricane evacuation in Cape May County, where the contra-flow plan was taken into consideration within the simulation modeling to mitigate traffic congestion in evacuation (National Center for Transportation and Industrial Productivity 2007).

Different from previous evacuation studies, Wojtowicz and Wallace (2010) presented a traffic simulation coupled with tabletop exercises for a mid-size capital district with parking lots. The authors assumed that the evacuation demand was generated from the centroid of a parking lot without considering the interactions of vehicles within parking lots. A cost/benefit analysis was presented to adjust the use of traffic simulation combined with table exercise to improve local traffic incident management. Two types of costs were considered in association with building the traffic simulation model and performing tabletop exercises: however, the research does not consider costs such as emergency personnel/vehicle usage, signage and gas consumption.

There are many off-the-shelf micro-simulators such as VISSIM, CORSIM, and TransModeler. This paper utilized Paramics to model the traffic flow. Paramics focuses on simulating the movements of people and individual vehicles, including the interaction between vehicles, and vehicles and pedestrians. It has been successfully applied to modeling the traffic operation of local arterials and regional freeway networks (Chen et al. 2006; Chen and Zhan 2008; Chu, Liu, and Recker 2003; Ozbay, Mudigonda, and Bartin 2005; Satinnam et al. 2005).

This review of the literature indicates that there is a lack of research on modeling the evacuation of mid- to large-scale local areas such as the parking lots of large shopping districts. Especially, most evacuation studies assume the vehicles are directly released to traffic flows, without considering the movements within parking structures (e.g., vehicles backing out of parking spots or driveways, and the interaction with pedestrians). However, the time consumed in escaping the parking lots is likely to take nontrivial amounts of time, which may have a negative effect on the evaluation of evacuation strategies using current evacuation methods. Also, there has been little work on developing a systematic method to estimate the related evacuation costs of different evacuation strategies.

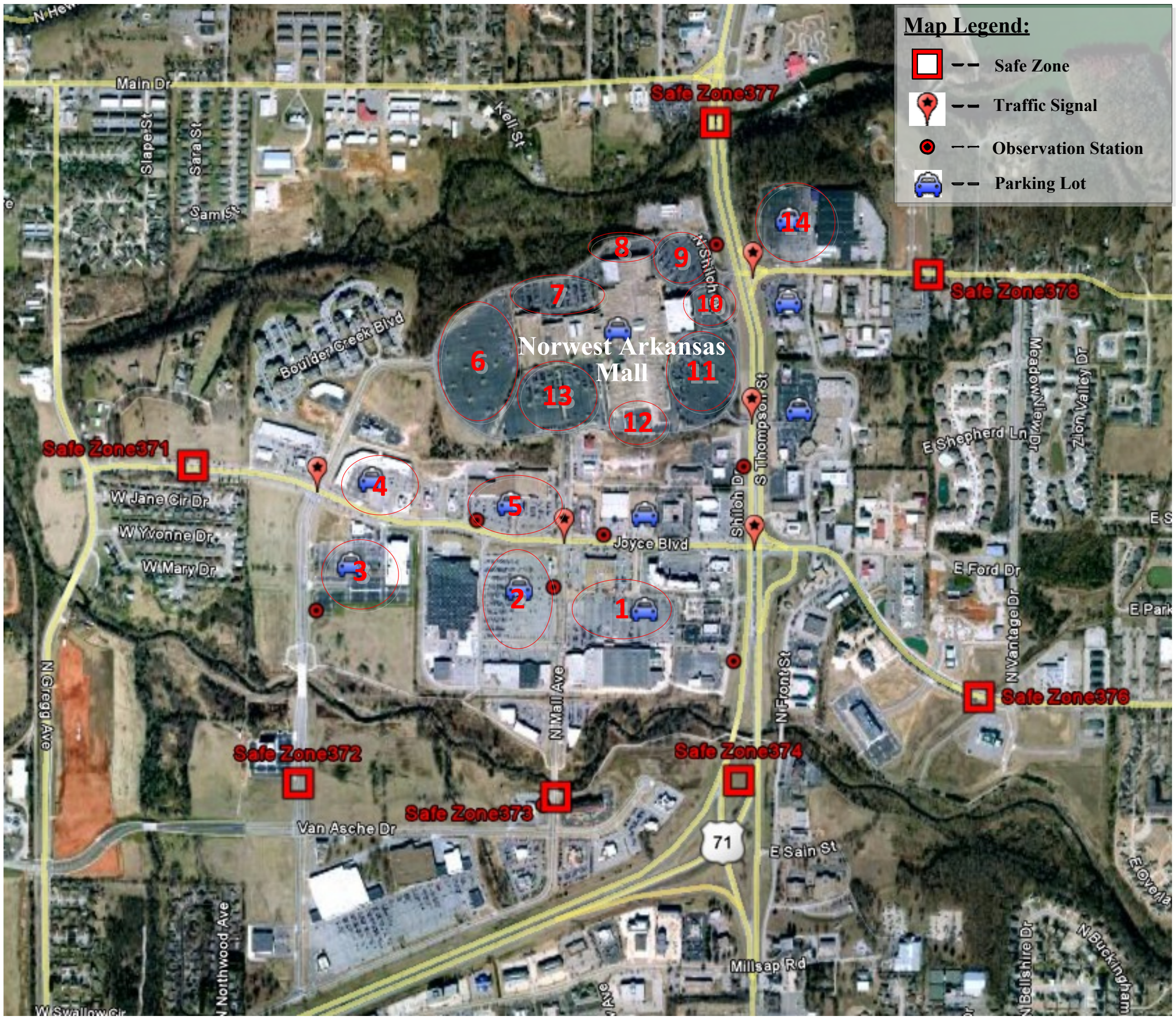
The work presented in this paper most closely relates to the work in Cova and Johnson (2002) on wildfire evacuation. We will utilize a number of their modeling assumptions for evacuation initiation by applying them to parking lots rather than households. In addition, we evaluate evacuation management strategies involving the allocation of resources to reduce or stop inbound traffic as well as methods to best direct evacuees out of parking lots towards surrounding safe zones.

## Microscopic Simulation Modeling

This section describes how to develop a simulation model to examine the evacuation of a mid- to large-scale local area. The purpose of this section is to set the stage for the interpretation of simulation results that examine the effectiveness of alternative evacuation management strategies for such situations. To provide a specific example for the evacuation modeling issues, we use data from a large shopping area around Northwest Arkansas Mall and Spring Creek Centre in Fayetteville AR, which is shown in Figure 1. This area is a highly visited commercial district covering about 3.1 square miles with hundreds of stores and more than eight thousands parking spaces. Therefore, this area is an excellent example of an area that could be a prime target for a terrorist attack. To model a worse case scenario, we assume that an evacuation is ordered during afternoon peak shopping hours from 4:30 to 8:00 when traffic is much higher than usual. We model the processes involved in evacuating people (e.g., shoppers) from the area to safe zones and how evacuation traffic affects the local traffic network under emergency conditions. To analyze this situation, we followed the methodology outlined in Figure 2.

Figure 2 illustrates that the modeling process requires data collection, modeling key issues such as trip generation and vehicle traffic, as well as simulation validation/calibration, and analysis. The first step of this process requires collecting data on such elements as road geometry, parking lots, calibration conditions, traffic control, resources participating in evacuation, etc. We utilized Paramics for the basic traffic simulation modeling. Paramics has the ability to extract network data from several data sources (e.g., emme/2, ESRI Shape Files, MapInfo, Corsim, CSV, etc.) and convert the imported information into a basic network. Existing ESRI GIS shape files were used as the data sources to build the road network. Other data such as traffic volume, traffic signal operation, and parking lot data (e.g., occupancy rate of parking lots and vehicle parking distributions) were collected manually. The second element of this methodology is modeling special issues related to evacuation for which standard traffic simulation programs such as Paramics are not designed. These issues are discussed in the following section.

**Figure 1. The Commercial Shopping District under Study**

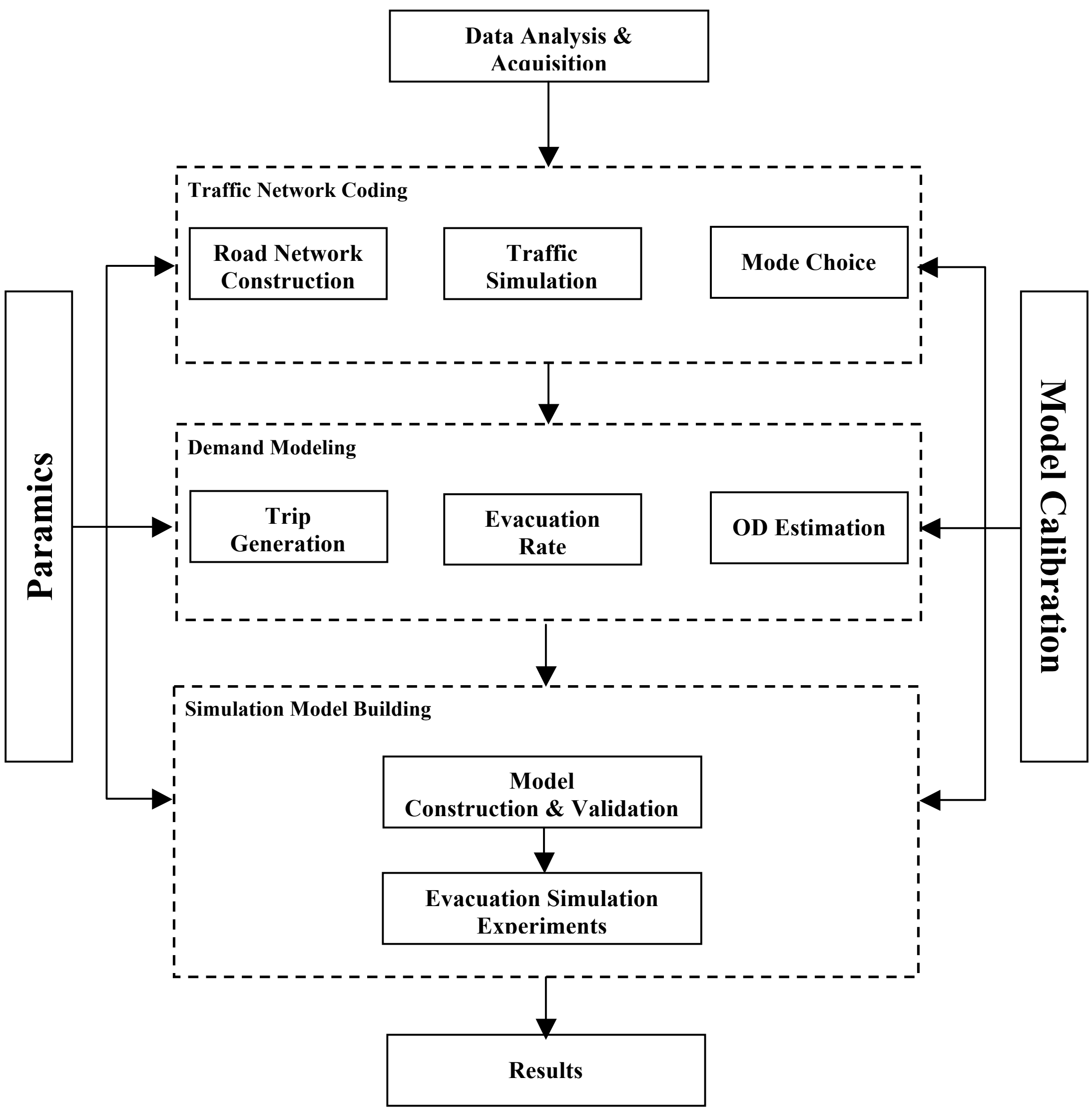



## Special Evacuation Modeling Issues

If an emergency occurs and evacuation is necessary, evacuees may need to exit buildings, walk to parking lots, and drive to safe areas. This process involves evacuation demand generation, parking lot modeling with movements of vehicles and pedestrians as well as their interactions, evacuation departure time modeling, route choice, and safe zone assignment. To focus on developing good evacuation strategies, this paper used parking lots as the origin point of evacuation traffic. The key modeling issues include: 1) parking lot modeling, 2) trip generation, 3) departure time modeling, 4) destination choice modeling, and 5) model calibration.

Parking lot modeling concerns how to represent parking lots in simulation software in order to model traffic origination. A parking space is generally less than 6 m in length and 3m in width. In Paramics, the Area Zone can be built on a link to represent a parking row but the length of the link must be greater than 20 m. Paramics therefore cannot model such detailed structures as individual parking spaces. In fact, most traffic simulators cannot model at this level of detail. In order to overcome this software limitation, we aggregated parking spaces within a parking row into several small parking zones and generate vehicles from the aggregated parking zones. Although this method cannot capture the detailed movements of vehicles and their interactions within each parking zone, it can track the collective behaviors of vehicles exiting from parking zones and, to some extent, it can simulate the disruption caused by vehicles in the traffic lanes within parking lots.

**Figure 2. Schematic of Evacuation Simulation Methodology**




Trip generation focuses on estimating how many evacuees participate in evacuation. Because the number of vehicles in each parking lot is stochastic and varies with the time of day, it is difficult to collect this information. In our analysis, we observed that drivers usually want to park within the parking spaces closest to store entrances, a parking pattern that can be modeled with a distribution curve. Given that the occupancy rate of a parking lot is the ratio of the number of vehicles parking at a parking lot to the capacity of the parking lot, we can use the vehicle distribution curves and occupancy rates for parking lots at different times of a day to estimate the average number of vehicles $\lambda_{ij}$ generated from parking zone *i* within parking lot *j*. In this study, we varied $\lambda_{ij}$ across the parking zones to represent the vehicle parking patterns within each parking lot.

Suppose that the number of vehicles $x_{ij}$ originating in parking zone $i$ of parking lot *j* is Poisson distributed, $x_{ij} \sim$ Poisson ($\lambda_{ij}$) (Cova and Johnson 2002). Since evacuation usually occurs in a short time period, it is reasonable to assume these Poisson processes are stationary. Thus, the number of vehicles from each parking zone can be randomly generated based on the given $\lambda_{ij}$. Paramics requires that a demand profile be provided at the beginning of a simulation run, so we used the Java programming language to randomly generate the number of vehicles for each origination-destination pair based on the Poisson parking zone models and imported the data into demand profile files for Paramics.

A departure timing model is used to simulate how evacuees respond during evacuation in loading evacuation traffic into the local traffic network. Evacuation departure time includes evacuation notification time and preparation time, and which vary for different evacuees. Based on the observation of evacuation processes, the evacuation rate is usually low at the beginning, peaks gradually and later reaches a trough. Therefore it is reasonable to assume that the probability density of evacuation departure events by time can be modeled by a Poisson distribution (Cova and Johnson 2002).

Suppose the total evacuation time is divided into *N* intervals each having T minutes (e.g. 5 minute intervals), and each evacuee could start evacuating at interval *n*. Assume that *N* is a random variable that has a Poisson distribution. Therefore the percentage of vehicles evacuated in time interval *n*, $P_n$ can be calculated as follows:

$$P_n = P\{N = n\} = \frac{\gamma^{n} e^{-\gamma}}{n!}, n = 0,1,2 \ldots\ldots$$

where $\gamma$ is the mean number of departure intervals, and $\gamma$*T is the mean departure time for all vehicles.

Suppose X is the total number of vehicles generated for a parking zone as calculated in trip generation, the number of vehicles that evacuate in time interval *n* can be obtained as $X * P_n$. In software such as Paramics, the generated number of vehicles will be released in each time interval. This allows the number of vehicles released to vary according to a departure timing model. Once the vehicles are released into the network at the appropriate time, the vehicles move towards their destination via a destination choice model.

A destination choice model mainly addresses the issue of how to select destinations in order to assign traffic demand for each origination-destination pair (OD). We assume that parking lots are demand origin points and that safe zones (destinations) are areas outside of the study region. Evacuees (i.e. vehicles) are able to select any direction for escape. We modeled seven safe zones to absorb evacuation traffic as shown in Figure 1. We examined two destination models: 1) a random assignment model where a vehicle can choose any one of the seven safe zones with the same probability. 2) an optimized safe zone assignment model where evacuees can only go to designated safe zones based on their origin parking zone. These will be discussed further in the next section.

The last modeling issue to address is that of model calibration. Calibration is part of the model validation process. Validation ensures that the model sufficiently represents reality so that good decisions can be made. Calibration involves adjusting the model or its inputs in order to match the key performance characteristics needed for decision making. To calibrate our model, a base model was developed to represent background traffic conditions under non-emergency conditions. Actual traffic volumes of main roads during afternoon peak hours were collected during 15 minutes intervals. For validating the simulation model, the mean absolute percentage error (MAPE) between observed traffic counts and simulated traffic counts was used as a measure for goodness of fit at different observation stations. We observed that the mean absolute percentage error (MAPE) over all was 7.35% and the maximum MAPE is 9.43%. These results are within Department of Transportation guidelines for calibration accuracy. Thus, we can conclude that an evacuation analysis using the model will be acceptable, especially in the case of a relative comparison between evacuation scenarios.

## Evacuation Scenario Analysis via Simulation Experiments

For emergency planners faced with how to safely evacuate areas such as that modeled in the previous section, a number of important alternatives must be considered. In our discussions with emergency planners, two basic strategies are available for responding to such events: 1) inbound traffic control and 2) out-bound traffic control. Because this is an unplanned event, there will be traffic within the area prior to the event and there will be inbound traffic that will want to move through (or into) the area during evacuation. To handle inbound traffic, emergency responders can be deployed at key locations on the boundary of the affected area to stop entering vehicles. Thus, the control of inbound traffic is a factor that can be explored in the experiments. We examined three levels for this factor: 1) no reduction of inbound traffic, 2) gradual reduction of inbound traffic over a period of time (e.g. 15 minutes), and 3) totally shutting off inbound traffic after a period of time. Gradual reduction represents the possibility that the effectiveness of traffic control will depend on the time that it takes responders to be deployed. The total shut off of traffic after a delay, represents either a coordinated stopping of traffic after a fixed time period or the delay to implement automated traffic control.

The control of out-bound traffic may be more difficult. Emergency responders may need to enter the affected area in order to direct out-bound traffic. Alternatively, there may be signage or automated traffic control methods for routing the vehicles.

**Table 1. Simulation Experiment Scenarios**

| | Occupancy | Inbound Control | Destination Choice |
|---|---|---|---|
| Scenario 1 | Normal | None | Random |
| Scenario 2 | 85% | None | Random |
| Scenario 3 | Normal | Delayed | Random |
| Scenario 4 | 85% | Delayed | Random |
| Scenario 5 | Normal | Gradual | Random |
| Scenario 6 | 85% | Gradual | Random |
| Scenario 7 | 85% | Normal | Assigned |
| Scenario 8 | 85% | Delayed | Assigned |

We examined two alternatives for this situation: 1) no out-bound routing and 2) directed routing to safe zones. In the first case, we simply assume that the driver destination choice is randomly distributed over the safe zones. In the second case, we use a destination choice model that is based on an optimal assignment of parking lots to safe zones. We also examined the effect of increasing the occupancy of the parking lots. Based on these factors, we decided to examine the eight scenarios presented in Table 1.

**Initial Scenarios Results and Analysis.**

This section considers the first six evacuation scenarios, where only the random destination choice policy is included in the evacuation model. We decided to look at these scenarios because they allow for an analysis of the effectiveness of controlling inbound traffic. The simulation results reported here are based on running multiple simulation replications (at least 30) with different random seeds. The results are reported by averaging across 30 replications. In the results, we examine the mean evacuation time (Mean ET), the maximum evacuation time (Max ET), and the minimum evacuation time (Min ET).

Table 2 presents the evacuation time analysis results for the entire area. According to the results, overall evacuation time will increase if the inbound traffic level stays the same but the occupancy rate of parking lots increase from the current occupancy rate to an 85 percent occupancy rate. This is as to be expected and illustrates that the model is responding as intended. The results indicate that the mean evacuation time could be reduced about 37-51 percent if the inbound traffic is decreased gradually or eliminated after a delay. For example, the mean evacuation time for Scenario 3 is 7.75 min comparing to 16.0 min of Scenario 1. These results indicate that controlling inbound traffic can have a significant effect on clearance time.

**Table 2. Evacuation Time Analysis with 95% Confidence Limits Across Scenarios**

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|
| Mean ET | 16.00±0.13 | 55.35±0.19 | 7.75±0.05 | 28.66±0.09 | 10.02±0.06 | 31.88±0.10 |
| Max ET | 99.72±5.55 | 180.37±7.23 | 39.56±1.99 | 87.06±2.25 | 45.54±1.59 | 88.81±1.99 |
| Min ET | 0.31±0.01 | 0.31±0.02 | 0.30±0.01 | 0.29±0.02 | 0.32±0.01 | 0.29±0.02 |

Because the model includes parking lots, emergency planners can determine which parking lots may have issues during an evacuation. There are about 30 parking lots within the study region, but the evacuation time for the most critical parking lots—identified as parking lots 1-14 are shown in Table 3. The maximum evacuation times generally occur in scenario 2, due to its high occupancy rate and lack of traffic management strategies.

**Table 3. Average Evacuation Time with 95% Confidence Limits for Different Parking Lot across Scenarios**

| Parking Lot | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|
| 1 | 15.91±0.67 | **76.17±0.70** | 8.82±0.32 | 39.59±0.34 | 10.70±0.38 | 42.97±0.35 |
| 2 | 17.73±0.31 | 46.03±0.41 | 10.72±0.15 | 31.00±0.24 | 12.63±0.18 | 33.22±0.28 |
| 3 | **33.97±0.54** | 72.48±1.00 | 12.91±0.18 | 23.88±0.28 | **18.02±0.22** | 29.62±0.32 |
| 4 | 30.65±0.79 | 50.97±1.14 | **14.20±0.29** | 22.27±0.42 | 17.81±0.35 | 28.18±0.50 |
| 5 | 15.84±0.39 | 34.60±0.48 | 6.00±0.13 | 18.37±0.23 | 7.82±0.18 | 22.15±0.27 |
| 6 | 9.97±0.34 | 68.89±0.42 | 5.30±0.15 | 33.92±0.20 | 7.11±0.22 | 37.92±0.21 |
| 7 | 9.96±0.18 | 54.03±0.70 | 5.32±0.07 | 27.81±0.31 | 7.23±0.11 | 30.50±0.35 |
| 8 | 9.51±0.50 | 60.29±2.20 | 5.93±0.26 | 38.08±1.25 | 6.85±0.30 | 39.55±1.31 |
| 9 | 10.55±0.24 | 75.70±0.88 | 6.74±0.14 | **46.70±0.49** | 7.61±0.16 | **49.20±0.50** |
| 10 | 12.04±0.57 | 65.88±1.67 | 7.85±0.36 | 40.14±0.96 | 9.02±0.41 | 43.48±0.99 |
| 11 | 9.59±0.20 | 47.04±0.44 | 6.32±0.12 | 33.39±0.32 | 7.64±0.15 | 35.00±0.32 |
| 12 | 10.13±0.78 | 24.51±1.00 | 4.57±0.27 | 15.49±0.54 | 6.19±0.39 | 17.72±0.72 |
| 13 | 11.52±0.24 | 71.72±0.56 | 5.11±0.18 | 30.49±0.23 | 7.40±0.13 | 33.81±0.25 |
| 14 | 4.49±0.20 | 19.19±0.37 | 2.61±0.07 | 6.64±0.10 | 3.78±0.13 | 9.83±0.15 |

We can see in the table that the largest evacuation times generally occur for parking lots 1, 3, 4 and 9. Further analysis of these parking lots highlighted some special traffic interactions that arise from their design. For example, evacuating vehicles from one of the parking lots are unable to turn left out of one of the exits because a road divider significantly reduces traffic flow. These are the types of insights that are useful to develop evacuation traffic management strategies.

To further explore the results for specific parking lots, we examined evacuation time patterns for each parking zone. Only the parking zones within parking lot 2 are considered here. As discussed in the previous sections, parking zones within a parking lot can be grouped into three sections based on their distance to the entrance of the building: close, middle, and far. The simulation results (not shown here) indicated that there was no significant difference in the evacuation time for different aggregated parking rows. It is likely that this is due to the fact that we did not model the time required for shoppers to find their cars and because the simulation software does not permit modeling at the parking space level. Because of this we believe that further investigation into this effect is warranted.

Given a limited evacuation time, it is important for local emergency planners to know which safe zone gives evacuees the shortest evacuation travel time. The mean evacuation time for different destinations is tabulated in Table 4. The results indicate that evacuating vehicles would experience less travel time if they choose to go to safe zones 371 or 372 (see Figure 3). However, it takes about 50 percent more time to escape from the affected region if evacuees choose safe zones 374, 376, 377, or 378. One of the reasons for these results is that safe zones 371 and 372 are much closer to the shopping areas than others. Also, evacuation simulation animation indicated that serious traffic congestion occurs on the main arteries within the area, which in turn causes many traffic bottlenecks on downstream locations and greatly impedes the evacuation traffic heading to safe zones 374, 376, 377, and 378. Again, we see from the evacuation time to individual destination that controlling inbound traffic has a significant effect.

**Table 4. Average Evacuation Time with 95% Confidence Limits for Destinations across Scenarios**

| Destination | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|
| 371 | 9.00±0.24 | 48.39±0.47 | 3.90±0.07 | 24.80±0.24 | 5.70±0.11 | 27.80±0.25 |
| 372 | 8.18±0.20 | 47.65±0.47 | 3.95±0.07 | 25.13±0.24 | 5.64±0.10 | 28.08±0.25 |
| 373 | 15.41±0.32 | 54.12±0.47 | 7.31±0.11 | 27.84±0.22 | 9.48±0.14 | 31.18±0.24 |
| 374 | 19.94±0.35 | 59.28±0.49 | 9.09±0.14 | 30.25±0.24 | 11.89±0.17 | 33.57±0.25 |
| 376 | 20.49±0.36 | 62.06±0.50 | 9.85±0.15 | 31.08±0.24 | 12.82±0.18 | 34.59±0.25 |
| 377 | 19.58±0.38 | 56.92±0.51 | 10.20±0.15 | 30.70±0.25 | 12.47±0.19 | 33.87±0.26 |
| 378 | 19.32±0.37 | 59.09±0.50 | 9.92±0.14 | 30.75±0.24 | 12.25±0.18 | 34.15±0.26 |

**Figure 3. Origination Zones Distribution**


**Extended Scenario Results and Analysis.**

In this section, two more simulation scenarios are analyzed by considering safe zone assignment strategies. One of the objectives for an evacuation plan is to minimize the total evacuation time. One feasible method for achieving this objective is to assign each parking lot to one or more safe zones and direct traffic to those assigned safe zones. In order to obtain an approximately optimal zone assignment plan without considering all factors, the evacuation route is assumed to be the only factor that affects the total evacuation time. We also assume that each parking zone can only be assigned to one safe zone. This study used a general mathematical programming model to develop an optimal safe assignment plan as shown as follows.

Objective function:

$$\text{Minimize } \sum_{i \in I} \sum_{j \in J} t_{ij} * x_{ij} \qquad (1)$$

Subject to

$$\sum_{j \in J} x_{ij} = 1, \ \ \forall i \in I \qquad (2)$$

$$x_{ij} = \begin{cases} 1 & \text{if parking zone i select to go to safe zone j} \\ 0 & \text{otherwise} \end{cases} \qquad (3)$$

$$t_{ij} \geq 0, \quad \forall i \in I, \quad \forall j \in J, \qquad (4)$$

where I and J are the index sets for parking zones and safe zones respectively, $t$ represents the evacuation time, and $x$ is the binary decision variable that assigns a parking zone to a safe zone. Constraints (2) and (3) ensure that each parking zone is only assigned to one safe zone. To validate and finally determine the safe zone assignments, this study uses both average evacuation time and median evacuation time (from the simulations) for each parking zone and safe zone pair in the objective function and compared model results.

Scenarios 7 and 8 are designed to consider factors of inbound traffic control, 85% occupancy rate of parking lots, and optimized safe zone assignment plans. For simplicity, the analysis for this extended model covers the experiments related to scenarios 2, 4, 7, and 8. The selection of these scenarios also allows the effect of the inbound traffic control policy to be examined. Because of changes made in data analysis, all the evacuation scenarios were rerun with different random seeds. Thus, the results presented in the following may have small differences from results in the previous section.

The evacuation time results for each scenario are tabulated in Table 5. For each safe zone assignment plan, the evacuation time for a scenario is reduced if inbound traffic is eliminated. For example, the mean evacuation time for scenario 8 is 7.27 minutes, which is much less than the average evacuation time (12.12 minutes) for scenario 7. For each background traffic level, the average evacuation time is reduced more than 70 percent in the model that uses safe zone assignments. Therefore, the safe zone assignment policy has a significant effect on the clearance times.

**Table 5. Evacuation Time Analysis with 95% Confidence Limits across Scenarios**

| | Scenario 2 | Scenario 4 | Scenario 7 | Scenario 8 |
|---|---|---|---|---|
| Mean ET | 53.79 ± 0.19 | 27.68 ± 0.09 | 12.12 ±0.06 | 7.27 ± 0.04 |
| Max ET | 174.78 ± 7.40 | 83.76 ± 2.28 | 66.70 ± 1.07 | 48.22 ± 0.97 |
| Min ET | 0.30 ± 0.02 | 0.30 ± 0.02 | 0.24 ± 0.01 | 0.24 ± 0.01 |

## Evacuation Trade-Off Analysis

As we saw from the previous results controlling incoming traffic and assigning safe zones can have a significant effect on evacuation time performance. However, both of these strategies involve emergency response resources that involve additional costs. To explore the trade-offs involving evacuation times and resource requirements, this section focuses on evaluating the effectiveness of the evacuation scenarios by presenting a trade-off analysis involving evacuation time, risk, and cost.

Evacuation involves the mobility of vehicles and people, as well as the involvement of other resources (e.g. the police department, emergency planning department). Therefore, cost can be an important factor when evaluating the effectiveness of an evacuation plan. We focus on the costs of implementing the evacuation strategies and do not consider other ancillary costs such as the loss of property, rebuilding costs, and traffic fatality during evacuation. We group evacuation costs into two categories: variable costs and fixed costs.

Variable evacuation costs occur during an incident and are a major part of total evacuation costs. These costs include, but are not limited to, emergency responder costs, background traffic trip costs, and evacuation traffic trip costs. For example, there are many emergency responders such as police officers and traffic workers who are responsible for guiding evacuation traffic and setting up traffic barriers. As a result, their wage and fuel costs must be accounted for within the analysis. Also, there are thousands of evacuation vehicles and background vehicles involved in the evacuation. The need for evacuation increases the normal travel delay time for people within the area. According to the Texas Transportation Institute's (TTI) annual Urban Mobility Study (Schrank and Lomax 2009), the value of travel delay (e.g. traffic congestion) for 2007 was found to be \$15.47 per hour per person for a big city such as NY. In this study, we use \$15.00 per vehicle per hour.

Fixed evacuation costs occur before an incident and include pre-built evacuation traffic signage cost and relevant field employment cost. The study area in Figure 1 has almost four hundred parking zones and many road intersections. As discussed in previous sections, emergency responders are assumed to begin controlling evacuation traffic 15 minutes after the beginning of the evacuation. Because of this delay, it would be difficult for emergency responders to set traffic signage (e.g. barriers, stop signs, direction signs) within such a short time. As a result, this study assumes that evacuation signage is built before the evacuation. The total cost of these traffic management devices includes construction labor cost, signage purchasing cost, and other maintenance cost, which is taken into account as a part of the evacuation cost for a scenario.

Using scenario 8 as an example, the evacuation cost analysis is illustrated in Table 6. The initial values for variables such as gas price, emergency responder wage rate, and emergency sign cost were obtained from evacuation simulation results and local internet resources at AccessFayetteville (2010). Also, cost for the base model without evacuation traffic is set as the base line and the corresponding evacuation cost for any other scenarios is calculated as the difference in between that scenario and the base model.

For different evacuation management strategies, the corresponding evacuation times are not the same. Without considering other factors, the lower the evacuation time, the better the evacuation scenario should be. As a result, evacuation time serves as a major measure of performance to evaluate the effectiveness of the evacuation plans.

Emergency evacuation is generally time-sensitive. As a result, we should evaluate the evacuation risk that evacuees are able to evacuate from the affected region within a certain time limit. Evacuation risk can be estimated by the probability that all evacuees cannot evacuate from the emergency region within a time limit $\theta$, that is, $P\{T>\theta\}$, where θ represents a time threshold. We assume that θ is 50 minutes. Based on the simulation results of evacuation traffic trip information, P{T>50} can be estimated.

**Table 6. Evacuation Cost Analysis for Evacuation Scenario 8**
**85% OR+Safe Zone Assignment + Inbound Traffic Control**

| | | Num (Unit) | Time (hr)/Value | Sub-Total |
|---|---|---|---|---|
| Variable Cost | Emergency Responders Cost For Traffic Control | | | 710.32 |
| | Emergency Responders Wage Cost | 20 | 1.54 | 555.90 |
| | Emergency Responders Gas Cost | 20 | 1.54 | 154.42 |
| | Background Traffic Trip Cost | | | 53316.93 |
| | Background Traffic Gas Cost Within Area | 1555 | 0.0036 | 27.90 |
| | Background Traffic Time Value Cost Within Area | 1555 | 0.0036 | 83.70 |
| | Background Traffic Gas Cost Around Area | 5321 | 0.5000 | 13301.33 |
| | Background Traffic Time Value Cost Around Area | 5321 | 0.5000 | 39904.00 |
| | Evacuation Traffic Trip Cost | | | 16888.25 |
| | Evacuation Traffic Gas Cost | 6967 | 0.12 | 4222.06 |
| | Evacuation Traffic Time Value Cost | 6967 | 0.12 | 12666.19 |
| Fixed Cost | Traffic Signs Related Cost | 136 | 80.00 | 10880.00 |
| | Extra Emergency Responders Cost | | | 2408.90 |
| | Temporary Emergency Responder Cost | 30 | 1.54 | 2084.63 |
| | Temporary Emergency Vehicle Cost | 7 | 1.54 | 324.28 |
| | | | Total Cost: | 84204.40 |

An overall comparison is presented in Table 7 for scenarios 2, 4, 7, and 8. These results indicate that the evacuation management strategies (e.g. diverting background traffic and assigning parking lost to safe zones) clearly dominate the base scenario. For example, the evacuation time for scenario 4 is almost 50 percent less and evacuation risk will be reduced about 23 percent when compared to scenario 2.

**Table 7. Evacuation Factor Analysis Across Scenarios**

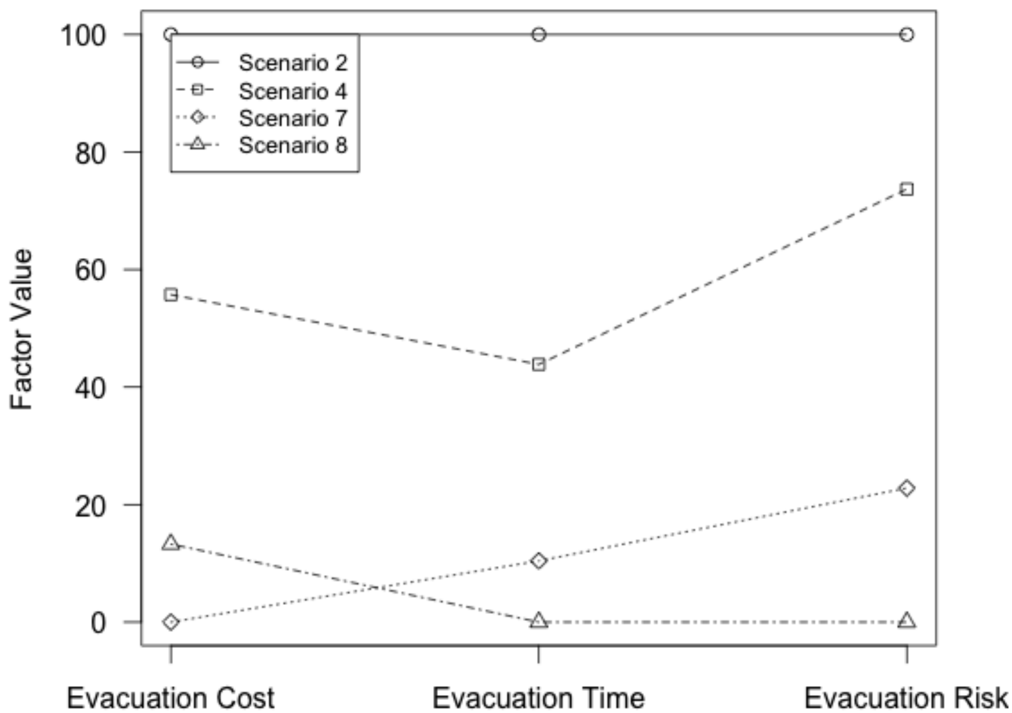
| | Evacuation Cost ($) | Evacuation Time (min) | Evacuation Risk |
|---|---|---|---|
| Scenario2 | 212695.64 | 53.79 | 0.65 |
| Scenario4 | 147084.63 | 27.68 | 0.50 |
| Scenario7 | 64522.21 | 12.12 | 0.21 |
| Scenario8 | 84204.40 | 7.27 | 0.08 |

A trade-off analysis among different scenarios can be performed based on these performance measures. Because the units of the evacuation factors are not the same, an aggregate value function approach was used to normalize the values to the same baseline. In this study, the maximum value is set at 100, the minimum is set at 0, the rest of the values are rescaled linearly between 0 and 100, and the adjusted values are shown in the Table 8. Without considering the importance of different evacuation factors, the effectiveness of four scenarios is shown in Figure 4. The graph indicates that scenarios 7 and 8 dominate the other evacuation scenarios.

**Table 8. Rescaled Values of Evacuation Factors**

| | Evacuation Cost ($) | Evacuation Time (min) | Evacuation Risk |
|---|---|---|---|
| Scenario2 | 100.00 | 100.00 | 100.00 |
| Scenario4 | 55.72 | 43.86 | 73.68 |
| Scenario7 | 0.00 | 10.42 | 22.81 |
| Scenario8 | 13.28 | 0.00 | 0.00 |

**Figure 4. Trade-off Analysis without Considering Factor Weights**




## Summary and Conclusion

Even though the evacuation cost, evacuation time, and evacuation risk for each scenario are specific to the shopping district examined in this study, it should be clear that evacuation management strategies that reduce inbound traffic and direct outbound traffic to safe zones can achieve a significant reduction in the time needed to evacuate a large parking area. In addition, a trade-off analysis of the costs and benefits of the strategies indicates that, despite the additional costs that may be associated with evacuation management strategies studied here, there is evidence to suggest that these costs can be outweighed by the reduction in evacuation time. According to the trade-off analysis, we also found that evacuation strategies involving optimized destination planning dominated the other strategies.

Such an analysis becomes possible with a well-designed and calibrated microscopic simulation model. One of the advantages of microscopic simulation is its ability to model detailed traffic responses. However, this detail comes at the cost of significant data collection requirements. We also found that current traffic simulation packages have inadequate capabilities for modeling detailed parking lot dynamics, which may be important to capture. For example, Paramics cannot model such detailed elements as individual parking spaces. Therefore, aggregated parking zones were assumed to be evacuation demand origins, which precludes detailed modeling of pedestrian and vehicle movements within parking lots.

Moreover, model validation and calibration is a concern. This is especially relevant when using microscopic simulation models. Model calibration is required throughout the model building process. There can be numerous errors in the network traffic generated by micro-simulators and the default values for controlling driving behavior cannot always adequately represent evacuation conditions. Also, currently the major method for calibrating simulation models is trial and error. Therefore, model calibration can be a very time consuming process.

The models developed in this paper are only the beginning of the research in these areas, and there are several interesting areas that need study further. This study developed evacuation scenarios by considering only three factors: occupancy rate of parking lots, inbound traffic control, and destination assignment; however, there are a number of other factors that can affect evacuation processes such as evacuation sequence (e.g. simultaneous and staged evacuation), response rate (e.g. slow or fast rate), and traffic operations (e.g. contra-flow lanes), driver aggressiveness, detail parking lot modeling.

Within the context of the evacuation of large areas (e.g. commercial shopping districts, cities, industrial complexes, etc.), parking lots serve many important functions. First of all, parking lots serve as assembly areas for building evacuations. They also serve as origins for vehicles exiting the evacuation area and in some cases the destination. As discussed in previous sections, the modeling of parking lots involves two parts: modeling the individual parking spaces and modeling the interaction between pedestrians and vehicles in parking lots; however, we found no commercial off-the-shelf traffic simulation packages that can adequately model this situation under evacuation conditions.

National estimates of the urban area dedicated to parking lots ranges from 2 to 5% according to Jin and Zhang (2002) and Imhoff et al. (2000). Davis et al. (2010) analyzed the number of parking spaces relative to the total area available within Tippecanoe County, Indiana, which includes Purdue University and the cities of Lafayette and West Lafayette, Indiana. They found that there were approximately 202, 714 parking spaces or about 1.7 parking spaces per person (6.3 spaces per family). Within a targeted analysis of a mall area, they found that 55% of the land is occupied by parking lots, which had an approximate 28% occupancy rate overall and a 55% occupancy rate for industrial parking lots. They concluded that about 6.5% of the urban footprint was dedicated to parking lots. Thus, we can conclude that parking lots are an important, large, and integral part of our transportation system and will remain so for the foreseeable future.

Future work will be needed to develop more realistic simulation models that incorporate evacuation dynamics within parking lots. This should also include pedestrian modeling because, at the beginning of an evacuation, pedestrians (e.g. shoppers and workers) will have interaction with evacuating vehicles both within parking lots and on evacuation routes, which could have significant effects on total evacuation time. Therefore, it is important to model pedestrian movements by analyzing pedestrian demand generation, pedestrian route choice, and pedestrian movement and the interaction with vehicles.

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# Beyond Vertical Evacuation: Research Considerations for a Comprehensive "Vertical Protection Strategy"

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*Vertical protective strategy (VPS) refers to activities intended to move people to a level of elevation above a (perceived) threat within the area at risk. VPS is an important but understudied approach to providing safety, particularly in the case of short warning events, such as tsunamis and coastal floods. While extensive engineering analyses have looked at the feasibility of VPS, the social, scientific and policy analyses associated with it have only been given cursory attention. This paper attempts to fill this gap by first briefly introducing VPS and then discussing the strategy in relation to shelter in-place and traditional horizontal evacuation. We then go on to highlight issues related to the adoption and implementation of VPS as a government sponsored activity. Last, we propose a research agenda that identifies areas to be further investigated.*

**Keywords**: vertical evacuation, evacuation, tsunami, hurricane, protective actions

## Introduction

The word "evacuation" typically elicits a vision of people driving away from a threatened area or fleeing from a building in response to a hazard. It has also been used to refer to the movement of people above a threat within the geographic area at risk. The latter form is most often called "vertical evacuation". The term vertical evacuation is problematic since it is used indiscriminately to refer to a wide range of actions and activities that people might take to protect themselves. This inconsistency creates conceptual confusion. In this paper, we provide a series of more precise terms to refer to this type of protection. The central concept we have adopted tis *Vertical Protective Strategy* (VPS). For us, VPS is an umbrella term that captures a host of protective actions whose primary protective nature comes from *increasing one's elevation within a threatened area*, i.e. vertical elevation.

There are many actions that could be classified as part of one's VPS. Further, we already know a considerable amount about such activities given that they have been used in many instances worldwide. In particular, vertical Protective actions are an appropriate response to hazards with short warnings. They have been used in floods (Aguirre 2004), tsunamis (Applied Technology Council 2008; 2009; Atwater et al. 2005; Murata et al. 2010; Takahashi et al. 2008; Takeuchi and Shaw 2008) and hurricanes (Nigg, Barnshaw and Torres 2006). As a result of anecdotal success stories, governments around the world are now considering how these actions fit together in a comprehensive VPS. Further, they are working extensively to incorporate the same into their formal emergency response and mitigation planning. To achieve this objective, they have carried out extensive engineering analyses. However, with a few exceptions, parallel social science and policy analyses have been given only cursory attention (Berke 1991; 1987; 1989; Ruch et al.1991).

This paper seeks to address this shortcoming by illustrating how a social science and policy analysis perspective can enhance conceptual clarity and can improve actual operations. In addition, it provides insights into considerations that should form the foundation of any VPS and highlights issues to be considered when looking at designing and implementing the same. We conclude this article by providing concrete conclusions and research recommendations.

## "Vertical Evacuation" and the Need for Conceptual Clarity

As mentioned above, in our conceptualization, the aspect of vertical evacuation that differentiates it from other protective behaviors, such as horizontal evacuation and sheltering in place, is the use elevation to get people above a threatened area. Achieving this elevation requires the use of some type of structure and/or natural feature. Examples include natural (hills, trees) or manmade structures (soil berm, vertical shelters, and multi-story buildings). The extant literature has discussed a number of approaches or actions that would qualify as part of a comprehensive vertical protection strategy. In particular, much has been written about the use of buildings to achieve vertical protection from a hazard. These are sometimes seen as vertical evacuation sites, but in other instances they are referred to as vertical protective shelters instead (Sorensen and Sorensen 2007; Wolshon et al. 2005a and b). The use of two terms, to refer to essentially the same protective action, is largely driven by the dimension of that activity different authors choose to focus on. Vertical shelter focuses a person's attention on the increased elevation and building features whereas vertical evacuation focuses on increased elevation and the movement away from a threat. We contend that both are flawed in that they have not gone far enough to distinguish what is truly unique about these approaches, namely the role of elevation in providing for safety. We believe that researchers and practitioners alike should take note of this reality and should distinguish among three distinct strategic dimensions of protective action planning. The first dimension is the *vertical protective dimension*. For our purposes, any activity aimed at moving people to a higher elevation *within* a threatened area would fall under this category and the pre-planned activities aimed at increasing this type of protection should be considered part of one's VPS[1]. Actions directed at moving people away from the threatened area—such as pedestrian evacuation, or evacuation by boats, cars or trains—would be part of one's *evacuation protective strategy* (EPS). Finally, any combination of actions aimed at achieving safety through the cover of man-made objects (retrofitted building or newly created hazard proof buildings would be consider part of their *structural protective strategy* (SPS). Recognizing these three distinct strategic elements will force us to consider the degree to which different real life actions promote safety. Further, it will help us to consider how a range of threats that an area is likely to face might generate different demands for each dimension of protection. Finally, it challenges us to reconsider how current planning and analytical activities address or neglect these different dimensions. The latter is particularly important, given that in practice many of the activities in which we engage touch on all three dimensions to some degree or another. Moreover, although a dominant intended strategy can be detected, approaches that provide for safety in multiple strategic dimensions simultaneously are preferable. This conceptual background provides the foundation for our more extended discussion of the analytic dimensions of a VPS.

## Adopting a VPS

A VPS can be implemented both by governments and citizens in order to reach an acceptable level of safety. In considering this element of protection, we first need to recognize that the actions related to it can be both *spontaneous* and/or *preplanned*. Spontaneity refers to all the novel actions undertaken in response to a sudden threat. In the literature these are most often referred to as emergent or improvised behaviors. Preplanned protective behaviors, on the other hand, are those that have been to some degree considered and accounted for prior to an event. An example of a preplanned VPS can be seen in the City of Nishiki, located in the *Mie* Prefecture in Japan, where the local government built 16 shelters between 1994 and 2005. These shelters are no more than a five minute walk from every village and are located close to high ground with Nishiki tower being used by all those in its proximity. The city also dismantled privately owned abandoned buildings to prevent their collapse during an earthquake (Nakaseko et al. 2008). It should be noted that while we think of planning as an isolated activity it is often the case that plans reflect the structuring of results from similar prior emergent activities in advance of some future event. We believe more attention should be placed on ensuring that good outcomes from prior uses of vertical protective actions be integrated into one's VPS.

As a preplanned strategy, VPS can be an *optional/last resort* or part of *comprehensive* strategy. The determining factors for deciding the most appropriate use of a protective strategy are 1) the type of hazard and its forecasting possibilities and 2) specifics of the context involved. For instance, lead time is determined by the characteristics of the hazard, such as wind speed, water depth, and hazard predictability that, in combination with characteristics of the impacted area (density of population, urban or rural area, and location of the individual), are determinants for the selection of the most appropriate protective strategy or action. Since lead time is determined by the hazard, it is not the same for all hazards.

In the case of a tsunami, the affected population and the government have anywhere from a few minutes to 21 hours, depending on whether it is near or far source generated, to undertake any protective behavior. For near source generated tsunamis, a VPS can be an adequate strategy, but in the case of a far source generated event it might not be suitable. Other situations, such as hurricanes, have much longer lead times, forecasted at least three days in advance. In situations like these, the decision to adopt a vertical rather than a horizontal protective strategy are made when the predictability of the hazard is still imperfect.

As an *optional strategy*, a VPS is viewed as a remedy for situations in which people have not been able to evacuate horizontally and it is too late for them to reach a safe place (Wolshon et al. 2005a, 2005 b) VPS and structural protection strategies (vertical shelters and refuges) have proven optimal for flood related threats such as tsunamis.

For hurricanes a VPS might be an optional strategy since "going upstairs in hurricane-proof buildings" (Salmon 1984) is considered a "last resort strategy". Here, vertical evacuation is not meant to replace the horizontal strategy but to complement it. Adding to this complexity are contextual constraints, such as high population density that may cause road network congestion. This is the scenario faced by the Indonesian city of Padang (Stanford University 2009) and dike ring 14, in the Netherlands, which includes major cities like Amsterdam, Rotterdam, and Den Haag in which most of the Dutch GDP is produced (Jonkman, Vrijling and Kok 2008). When used as a *comprehensive* strategy, VPS incorporates horizontal evacuation features such as pedestrian horizontal evacuation. Pedestrian horizontal evacuation takes into account crowd movement, density, speed and flow. In order to easily reach elevation supports, a walkable distance for the evacuees has to consider differences in speed between those with and without disabilities.

Underestimations of evacuation times can result from simple factors such as "waiting to make use of the heavily queued stairs" (Pauls 1994, p.7).

Once a VPS is considered, its adoption and design should be aimed at drawing upon and enhancing existing patterns of action within communities. In fact, for a strategy to be effective it must be a combination of pre-planned foresight, people daily's activities and local patterns of hazards response activity (disaster subcultures). For instance, people born and raised along the Chilean coastline, are aware of the possibility of tsunamis and know that in the event of a strong earthquake they should run up to the hills as quickly as possible. This local pattern of activity is an important adjustment that saved many from the tsunami that hit Chile on February 27, 2010, despite the central government retracting the formal tsunami warning. The former should learn and take cues from the latter within a community setting by including elements that can best be analyzed through social science and public policy analyses rather than exclusively looking at engineering characteristics.

## VPS and Structural Prerequisites

The implementation of a VPS requires the use of existing or newly created vertical supports. These vertical supports can be part of an emergent or preplanned VPS. Distinguishing between emergent and preplanned strategies and vertical supports tells us whether or not a VPS is implemented as a form of preparedness or response.

In the United States elevation supports have mainly been used as part of emergent vertical protective strategies. Their use as part of a preplanned VPS has been considered in Florida (The Southwest Florida Regional Planning Council 1994) and Louisiana (Urban Transportation and Planning Associates 1976) since the 1970s and in Texas since the 1980s (Stubbs and Sikorski 1987) to deal with hurricanes and more recently in Oregon and Washington to deal with tsunamis. The combination of components that make up a VPS depends on the kind of threat a community faces.

Two forms of VPS that can also be characterized as part of a structural protective strategy are vertical shelters and vertical refuge. Vertical shelters for hurricanes are defined as buildings that are more than two stories high and "located landward of the velocity or V-Zones defined by the National Flood Insurance Program, and fully engineered" (Ruch 1991, p.22). Vertical evacuation refuges for tsunamis are defined as "a building or earthen mound that has sufficient height to elevate evacuees above the level of tsunami inundation, and is designed and constructed with the strength and resiliency needed to resist the effects of tsunami waves" (Applied Technology Council 2009, p. 1). In the event of a tsunami, the most important factor is elevation and this is why both buildings and earthen mounds can be used as vertical refuges. These examples show how structural components are valuable since these can protect against wind and, elevation is required to protect against storm surge.

In 2008 and 2009 the Applied Technology Council published guidelines on vertical shelters at FEMA's request to discuss the design of structures for vertical evacuation from tsunamis and to provide guidance to community officials facing a tsunami threat (Applied Technology Council 2008; 2009). These guidelines were based on the Japanese experience with escape buildings or vertical shelter/refuge. It is important to note that FEMA's guidelines distinguish between vertical shelters and refuge on the basis of the duration of stay of the occupants. In addition, vertical refuge/shelter can be distinguished on the basis of ownership (private or public), purpose, location and sizing. Structures can be built new or be the result of retrofitting. Usually new buildings are public property, while retrofits are either public or privately owned. For instance, parking garages, hotels, schools, and existing buildings can be designed as vertical shelters (Applied Technology Council 2008).

In Japan, escape buildings/vertical shelters and elevated platforms are central. Figure 1 is an elevated platform, known as a Tasukaru (life-saving) tower, that is located in Tanabe, Wakayama Prefecture. The figure shows details about the tower's height, sealed door, and available resources such as boxes containing canned food, blankets and other emergency supplies. Several such structures have been built in Japan. This platform can host about 100 people. However, since these types of structures stand alone, they are more susceptible to be used for improper/unrelated activities.

**Figure 1. Vertical shelter in Tanabe town, Wakayama Prefecture**

Source: http://www.city.tanabe.lg.jp/bousai/hinan-tower.html

Figure 2 shows the Shirahama elevated shelter in Toyo town, Kochi Prefecture that is used both as a shelter and as a panoramic viewpoint. This elevated platform can accommodate 700 people and measures 11.5 m (37.7 ft) in height. Another form of elevated shelter is the Tsunami Evacuation Raised Earth Park (TEREP) designed by GeoHazards International (GHI) and funded by Swissre in the city of Padang in

Indonesia. The idea is to provide safety in flat zones by embedding a multipurpose engineered structure in the urban context (Swissre 2010).

**Figure 2. Shirahama elevated shelter, Toyo town, Kochi Prefecture**

Source*:* http://dokodemo.cocolog-nifty.com/blog/2007/04/index.html

Figure 3 shows the Nishiki tower, Mie Prefecture, in Japan. The tower is a multipurpose building used as the mayor office and as a Tsunami museum. It has a capacity of about 500 people and a shelter is located at the top. According to Nakaseko et al. (2008), the height of this building is 23 m (71.5 ft) and the sheltering area starts at an elevation of 20 m (66.2 ft). A spiral staircase on the outside of the building is equipped with storage space and fitted with floodlights to facilitate easy access to the building when it is dark. During non-emergency times, the first floor is used as a warehouse, the second floor as a meeting place for district residents, and the third floor as an exhibition center for promoting tsunami awareness.

**Figure 3. - Nishiki Tower, Mie prefecture**


Source*:* Institute for Fire Safety and Disaster Preparedness. Retrieved on August 1, 2011 from: http://www.bousaihaku.com/cgibin/hp/index2.cgi?ac1=B742&ac2=&ac3=673&Page=hpd2_view.

**Standards, Legal Compliance/ Requirements and Ethical Considerations**

VPSs include emergent use of structures, which has the potential to generate two significant issues. The first of these concerns liability and responsibility for populations seeking refuge—especially liability for vertical structure failures that could result in a 100 percent fatality rate (Salmon 1984). The second issue concerns the ethics surrounding this strategy, both of which need to be explored by public officials. Two issues are most pressing; and difficulties in rescuing and providing assistance to vertical evacuees.

Due to its novelty, there is no consolidated risk assessment tradition for VPS. Generally safety is equated with the probability that a building might collapse; the lower the probability, the safer the structure. Agreement on the standards for structural characteristics of vertical structures and on typologies of buildings which can be adapted to fit these requirements is desirable. In Japan, after the Tohoku earthquake, some local governments hesitated to build specific vertical protection structures because of the lack of structural integrity standards. On the 25th of July, 2012, the municipality of Yoshida-cho, Shizuoka prefecture, was the first Japanese local government to create a committee comprising researchers, and prefectural and national governmental officers to establish standards for the durability of vertical evacuation structures.

The key obstacle US public officials identified for the adoption of VPSs for hurricanes and tsunamis is concern for liability in cases of vertical shelter failure (Berke 1991), which can result from floating and/or flying debris and from the inability to build structures capable of resisting all future events. For instance, the Nishiki tower is designed to withstand an earthquake intensity of VII on the Japanese Meteorological Agency seismic intensity scale (up to Modified Mercalli Intensity—MMI = XII) and the impact of a ship propelled into it by tsunami waves.

In referring to unforeseeable events, the March 11, 2011, Tōhoku earthquake and tsunami demonstrated the failure of probabilistic forecasting in relation to the possibility of exceptional events. In that case some vertical shelters or escape buildings were overtopped by tsunami waves due to building heights that were inadequate for the level of flooding that occurred. Ignoring all these issues might render a government negligent.

Another challenge related to the use of vertical shelter is uncertainty about the length of stay. Vertical shelters must be stocked with basic supplies (food, water and beds) sufficient to meet the needs of evacuees for the duration of their stay. This issue, also known as evacuee welfare, was recently addressed in Japan in the aftermath of the Tōhoku earthquake in which evacuees spent two or three days even though the buildings were designed to be occupied for only six hours (Fraser et al. 2012). Furthermore, the supplies available in the vertical shelter need to be checked periodically to ensure that they will be usable when needed.

Liability is an important aspect when discussing any kind of evacuation as it also involves ethical questions. For instance, in Japan, since the tsunami, some governmental officials argue that vertical structures are a possible evacuation option and that those in the risk area, not the government, should decide how to evacuate depending on their specific situations. On the other hand, there is concern that giving people the option to choose between vertical and horizontal protective strategies could impact their decision to leave the area. Ruch (1984, 1991) examined the impact of allowing evacuees to choose an evacuation strategy but the results of that study were inconclusive. Thus, the main question becomes whether it would be less risky for governments to avoid using vertical shelters and place the onus of horizontally evacuating on the affected population. However, when people do not have enough time to evacuate to locations outside the threatened area, governments should try to increase the number of evacuation options. A responsible government should promote and support different evacuation strategies and ensure that those most suitable to the specifics of their communities are available. Engaging communities in dialogue concerning the need for shared responsibility could be a way to ensure that liability concerns do not inhibit people from choosing the most effective strategy for their specific situation.

### Stakeholders Support and Involvement in the Planning Process

Involving communities and other key stakeholders in planning for VPS is crucial to resolving ethical questions and making the strategy effective. Taking into account the different and often conflicting interests of stakeholders makes planning more complex. Berke (1987) analyzed the attitudes of hurricane hazard specialists, real estate workers, building residents, environmental groups, and elected officials towards the building of vertical shelters. Each group voiced their concerns on economic, legal, safety and environmental issues and on the location of vertical refuge in inland or hazardous areas (Table 1).

Table 1 shows that hazard specialists are mainly concerned with legal and safety matters. Owners of buildings, building developers and building residents do not want to incur the additional costs needed to make building safer. These stakeholders claim that buyers should decide for themselves on risk-taking matters. Leading these stakeholders toward a consensus is difficult, but necessary for any implementation effort to succeed. The extreme fragmentation of stakeholders' interests can have a negative impact on the adoption of a VPS (Berke 1991).

In contrast, Project Safe Haven used a more participatory approach in planning the sighting and design of vertical structures in the coastal areas of Pacific County and Gray Harbor County in the state of Washington. The project, funded by the National Tsunami Hazard Mitigation Program, and carried out by scientists from the University of

Washington, is unique as it attempts to bring together scientists, public officials, emergency managers and communities to develop a feasible VPS. Officials, emergency managers and scientists clustered to form a steering committee that works to identify opportunities and barriers to VE.

**Table 1. Stakeholder/Concern Matrix**

| | Stakeholders | | | | |
|---|---|---|---|---|---|
| Concerns | Hurricane Hazard Specialists | Real estate Interests | Building Residents | Environmental Groups | Elected Officials |
| **Economic** | | | | | |
| Building design and construction costs | | X | | | |
| Housing costs | | | X | | |
| Program implementation cost to government | | | | | X |
| **Legal** | | | | | |
| Liability of government | X | | | | |
| Liability of private interests | X | X | X | | |
| Protection of private property | | X | X | | |
| **Safety** | | | | | |
| Delivery of emergency services | X | | | | |
| Structural failure | X | | | | |
| High evacuation time due to intensive development | X | | | | |
| **Environment** | | | | | |
| Impact on natural environment | | | | X | |
| Impact on community amenities/quality of life | | | X | | |

Source: Berke, Phillip (1987). "Vertical Shelter from Hurricanes: Risk Perceptions and Politics." *Coastal Zone '87: Proceedings of the Fifth Symposium on Coastal and Ocean Management, Seattle, Washington, May 26-29, 1987, p.3822.*

To support this process, a SWOT (strengths, weaknesses, opportunities, and threats) analysis was implemented together with open houses in which project achievements were reviewed. Site visits were conducted in each community, which helped "identify opportunities for, and barriers to, potential VE projects" (Project Safe Haven: Pacific County 2010, p. 1). In particular, the project estimated that it will take residents' evacuating on foot approximately 15 minutes to get to the vertical structures. This allowed the steering committee to better understand the geography of these areas, and the risks they face when encountering a tsunami. Project Safe Haven considered the use of structures such as berms, towers and elevated platforms that would have provided safety to 6,300 residents in Pacific County and 18,450 residents in Gray Harbor County. In total, the project recommended the construction of 20 structures in Pacific County and 32 structures in Gray Harbor County for total estimated costs of 13 and 64 million dollars, respectively. Cost is an important consideration for both emergency managers and citizens in the decision making process. Planning for VPS requires expenditure for the construction and maintenance of new vertical structures. The project also considers the functionality of the structures during non emergency times. Examples of non-emergency use are elevated platforms that can be used as a covered market area and a fire station, which would be able to host 300 people in a safe zone measuring a minimum of 2,560 square feet located on the roof of the building. Because the proposed vertical structures are defined as refuges and therefore only meant for short-term use, the project did not take into consideration the duration of stay. Since the proposed vertical structures are classified as refuges, these facilities do not need to meet the requirements of the Americans with Disabilities Act. The project, in recognizing this shortcoming attempts to account for people with reduced mobility by providing wheelchair access to the structures (Project Safe Haven: Pacific County 2010; Project Safe Haven Gray Harbor County 2010).

There remains uncertainty as to how these projects will be funded. Grants from State and local governments, public-private partnerships, self-funding and local revenue are all possible sources of funding. Due to a lack of market incentives for private companies to build ex novo or retrofit buildings that can be used as vertical shelter, it is arguable that governmental intervention is required to provide the necessary funding.

### Social Perspective: Resilience and Disaster Subcultures

Rather than expect a linear relationship between warnings and people's behavior, it is important to consider differential vulnerability among local population segments. Examples of vulnerable population segments include those with limited mobility, social status, special needs, and those with limited knowledge of the environment and possible protective behavior such as tourists. Tourists are a particularly vulnerable segment of the population because they are dependent on local inhabitants to adopt suitable self-protective behavior (Burby and Wagner 1996). In Hawaii and Thailand, tourists are usually vertically protected in hotels, while the rest of the population escapes to high ground.

For instance, during Hurricane Katrina, many people did not evacuate horizontally because they were not allowed to bring their pets with them, did not have a car, or because their social network was not large enough for them to be able to find alternative means of transportation (Rodriguez, Trainor and Quarantelli 2006). The following is an excerpt from the narrative of one of the vertical evacuees during Hurricane Katrina:

> I felt deeply marked by my single status and profoundly alone. Evacuation was clearly a family affair (…) I could not imagine what I would do, where I would go, if I could not get out. Then, my friend K, a renowned African American jazz musician, phoned. He, his family, and some fellow musicians were able to book rooms in one of the old large brick hotels—this was known as a 'Vertical Evacuation'" (Batlan 2008, p.166).

Furthermore, disaster subcultures need to be considered as they represent the means by which communities cope with recurrent hazards. Coincidentally, a few days before the Tōhoku earthquake and tsunami hit Japan, evacuation drills were carried out to mark the anniversary of the March 3, 1933 Showa-Sanriku earthquake and tsunami. This evacuation drill gave the Japanese the opportunity to refresh a life saving lesson learned from the past: "Tendenko". Tendenko literally means "in case of a Tsunami think of your individual safety first and not of your family" in order to avoid being killed together (Yamori et al. 2011). This way of thinking recognizes the limited time within which action needs to be taken. In fact, the 1933 earthquake and tsunami showed that people were more likely to be overtaken by the tsunami if they delayed their evacuation to look for family members (Shaw et al. 2011; EERI, 2011a and 2011b).

## Conclusions and Recommendations

The aim of this paper was to enhance conceptual clarity with respect to actions aimed at elevating people above a threat. To achieve this, we distinguish between types of protective strategies and characterize some protective actions commonly associated with these strategies. Three types of protective strategies were identified, namely VPS, horizontal protective strategy, and structural protective strategy. In discussing the relationships among these strategies and their protective actions we have highlighted how, in some specific cases, protective strategies do not exist independently. For example, due to specific weather conditions it might be necessary to combine vertical protective actions with structural protective actions. This acknowledges that response to a hazard may encompass multiple evacuation strategies, thus revealing the dynamic nature of protective actions and subsequently the complexities in planning for the safety of populations that require movement up from a threat.

We have clarified the conceptual components of VPS to offer a solid basis for a social science and public policy understanding of what is a fast growing response strategy. In summation, VPS can be spontaneous (associated with emergent behavior) or preplanned. Strategies can be either comprehensive or optional. When VPS is used as an optional or last-resort strategy, the dominant strategy might be a HPS. As an optional strategy VPS is often viewed as providing people who could not get out in time or viewed staying in the threatened area as important, a last resort alternative.

Even though many governments are opting for the use of VPS, some governments remain reluctant, particularly due to structural maintenance and liability issues. The potential for structural failure is a major obstacle toward more widespread adoption of VPS by governments that are reluctant to deal with liability issues. However, in light of certain hazards and contextual realities, choosing another strategy over VPS could lead to suboptimal outcomes. In addition, we highlight the importance of considering differential vulnerability among local population segments such as those with special needs or reduced mobility, tourist populations, and disaster subcultures that can either facilitate or hinder preplanned strategies.

We believe that VPS should be considered a valuable strategy, particularly in areas where hazards and contextual realities do not allow for alternative strategies or require VPS as an optional strategy. VPS has already played an important role in both preplanned and emergent responses to catastrophic events, in particular the 2011 Tōhoku tsunami and the 2004 Indian Ocean tsunami. Adopting a VPS strategy requires governmental commitment and attention to both engineering and social science aspects. Even though important advances have been made in recent years, VPS needs to be further investigated, especially from a social perspective. A social perspective should not be viewed as a "complication" (Stubbs and Sikorski 1987, p. 2) but rather as critical to determining if an approach will succeed or fail.

This paper is a first attempt at discussing VPS from a social science perspective. As such we propose a number of important issues that should be included in the research agenda surrounding this approach to safety. First, we recommend that researchers examine the concerns that some governments have with respect to VPS and identify ways to overcome these concerns and ensure that VPS, if the most optimal strategy, can in fact be implemented.

Another research topic arises from Salmon's (1984) argument that VPS will enhance coastal residents' feeling of safety and thus encourage construction in, and inhabitation of, risky areas. However, one can question whether this is specific to VPS or if it is the case for any protective strategy. Will people continue to inhabit tsunami risk areas because of economic opportunities and consequently develop protective strategies? We also need to know how emergent strategies can be integrated with preplanning. It would-be valuable to see if a pre-planned VPS strategy can accommodate an emergent VPS strategy. How can one ensure that a combination of pre-planned and emergent responses is designed so both components complement each other instead of counteracting each other?

The examples of the survivors from Hurricane Katrina and the Tendenko disaster subculture demonstrate that disaster subculture (Anderson 1965; Engel et al. 2012; Wegner 1978; Wegner and Wellner 1972; 1973) also plays an important role in the success of an evacuation. While emergency managers should "work within and with cultural frameworks" (Engel et al. 2012, p.2), researchers should devote more time to understanding the interplay of disaster subculture and disaster management. For instance, is VPS part of disaster subcultures and if so, why and how? What motivates people to develop VPS over other strategies? It would be useful to investigate to what extent disaster subcultures are translatable to other contexts? Would it be possible to promote a Tendenko culture within the USA context?

Furthermore, research is needed into planning for "special needs" has to be developed since it may be quite different during horizontal and vertical evacuations. Last, another important aspect that needs to be taken into account and further investigated in planning for vertical evacuation is the estimation of evacuation time. Most of the studies only address evacuation time based on individual speed pace. As a matter of fact we all know that evacuation most of the time is not an individual, but rather a group, protective action. For instance, what would be the time needed by a mother of three children or the owner of a pet to evacuate to a safer location. Would it still be between 5-15 minutes? Thus, it is critical that both individual and group evacuation times are estimated.

## Note

[1] We do note that some may find it conceptually troubling that we have excluded the possibility of obtaining protection by decreasing one's elevation, but we have done so purposively. We made this choice after significant thought given that reducing elevation very rarely if ever makes one safe in and of itself. In truth, going into basements and storm cellars, as is often the case for tornadoes, does provide a person greater safety, but not because of the reduced height. Instead the degree of protection comes from surrounding one's self with a strong building or with earth. In essence, these are structural protections as described below.

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# Assumptions and Processes for the Development of No-Notice Evacuation Scenarios for Transportation Simulations

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*Emergency management agencies and departments of transportation benefit from transportation simulation support when developing their emergency response or evacuation plans. No-notice events are increasingly becoming part of these plans. Few, if any, studies have shown how to operationalize general no-notice evacuation considerations. To fill this gap, this article describes essential features and reasonable assumptions that should be considered in the development of no-notice evacuation scenarios for use in conjunction with transportation simulation models. Although the information presented here centers on a specific location and disaster, the concepts may be generalized and adapted for use in other locations and hazards and are of value to both practitioners as well as researchers seeking to develop similar models.*

**Keywords**: No-notice; Evacuation; Scenario.

## Introduction

Events requiring mass evacuations for a given area have low probabilities. The limited history of such events also means that there are few past experiences from which to learn and to improve the methods and systems for moving people during emergencies. This lack of experience also makes it difficult to make confident forecasts of travel conditions during emergencies.

Planning evacuations for no-notice events is even more challenging than planning for more frequent, more predictably located natural events. Hazardous materials events and terrorist attacks, for example can occur nearly anywhere and at any time without any warning. This lack of a controlled set of scenarios creates challenges for agencies developing evacuation plans for all hazards or no-notice events, in particular. Yet, these plans will be critical should an event actually transpire. This article describes essential features and reasonable assumptions that should be considered in the development of no-notice evacuation scenarios for use in conjunction with transportation simulation models in order to develop evacuation plans applicable to no-notice events, evaluate transportation system performance, develop evacuation management strategies, identify bottlenecks, and identify critical links. Some of the transportation strategies employed for hurricane evacuations can be transferred to the no-notice context, but no-notice events typically affect smaller areas and do not allow as much time to implement manpower- and equipment-intensive strategies. Evacuation plans that can handle large surges of traffic in the no-notice context will also benefit evacuations for events with more notice where demand can be spread over a day or more.

This article outlines the no-notice evacuation scenario development considerations encountered in a recent study which will be useful to other researchers as the desire to incorporate no-notice events and all hazards into emergency plans. The remainder of this paper is organized into four sections. The next section provides an overview of the background pertaining to no-notice evacuation modeling, primarily from the transportation modeling perspective. Then, an outline of the types of information needed for transportation simulation is provided. The following section details the items to consider when developing scenarios for simulation, including examples from a recent study pertaining to a hypothetical terrorist attack and justification for assumptions. The final section offers some concluding comments.

## Background

The literature available for no-notice evacuations is considerably sparser than it is for hurricane evacuations, likely due to the typically smaller evacuation area, lower frequency, and/or security sensitivity. Even as recently as 2006, little work focusing on the practice for no-notice evacuations was available (Wilson-Goure, Houston, and Easton 2006). Since then, a few studies (e.g., Auld et al. 2012; Carnegie and Deka 2010; Liu, Murray-Tuite, and Schweitzer 2012) have involved surveys or interviews of residents in the context of hypothetical no-notice events; however, the level of detail provided to the respondents is much sparser than that needed for transportation simulation. Other interviews and surveys were conducted after real events occurred (e.g., Aguirre, Wenger, and Vigo 1998; Cutter and Barnes 1982; Houts et al. 1984; Perry 1981, 1983) but these studies often focused on testing specific theories, hypotheses, or models and did not collect all of the data required for simulation. However, the results of the surveys and interviews for both real and hypothetical events are useful in developing models of citizens' responses to events and help inform the demand side of future simulation efforts.

Other studies focus on optimization based approaches (e.g., Jabari, He, and Liu 2009; Liu, Murray-Tuite, and Schweitzer 2011; Zhang, Niu, and He 2010; Zheng et al. 2010) and transportation simulation tools, either real-time (e.g., Chiu and Zheng 2007) or off-line. Generally, these optimization based studies are from the perspective of the emergency managers or transportation network operators and assume that citizens follow protective action recommendations, at least at an assumed compliance level. Optimization model results do not necessarily correlate with individuals' or households' anticipated behavior (Murray-Tuite, Schweitzer, and Morrison 2012a). Murray-Tuite et al. (2012b) found that hurricane evacuees selected routes based on familiarity and/or because they thought the routes would be the fastest/shortest rather than because a management agency recommended the route. Hsu and Peeta (2011) allowed variation in response in their models, but did not have behavior data to verify their models.

Real-time decision making tools are useful and important during an emergency, but not to the exclusion of pre-event planning and what-if analyses. The two should operate synergistically. The planning phase helps identify the resources that may be required during an actual event, infrastructure locations that should be protected, and locations where particular strategies are consistently beneficial. Furthermore, the potential for power or communication system damage/failures could severely limit real-time tools' use in an actual event. Thus, their use should not be to the exclusion of, but rather in conjunction with, pre-event planning and scenario testing. Pretorius et al. (2006) cite emergency evacuation plans as one of the key resources during evacuation operations. To make the planned and actual conditions as close as possible, the pre-event planning scenarios should be as realistic as possible.

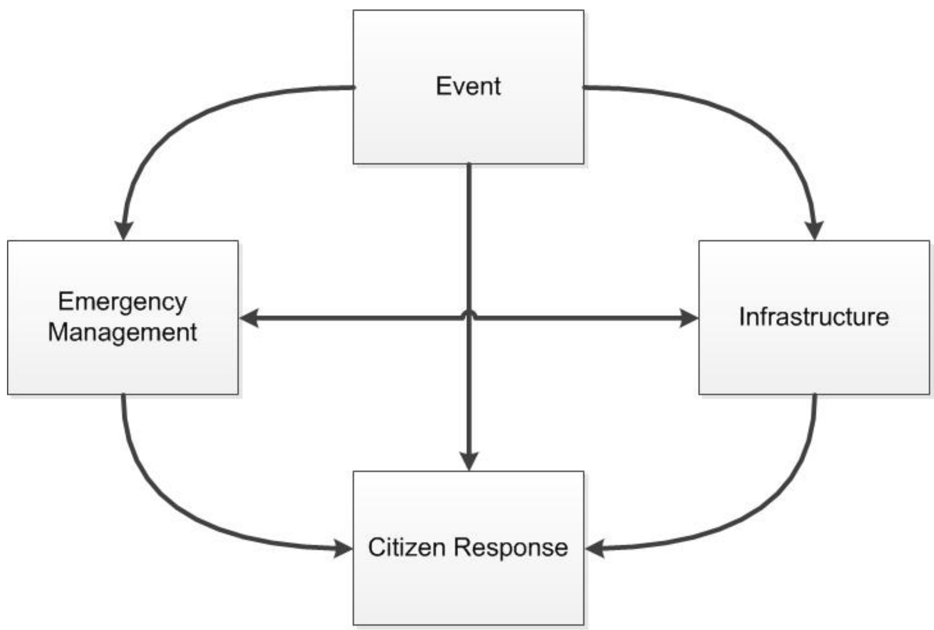
## Transportation Simulation Needs

To simulate scenarios, transportation simulation models require a set of supply and demand based inputs. The supply side incorporates the features of the road network, including link characteristics—such as direction, number of lanes, speed limits, and capacities—and node characteristics, such as control operations. At the most basic level, the demand side inputs include the number of vehicles departing at a given time and traveling from a given zone to another given zone. The model operates on a set of embedded rules to move vehicles from their origins to their destinations. Various parameters for the rules and internal models should be calibrated prior to use, as well as demand, which are non-trivial tasks. Simulation scenarios involve variations of the supply, demand, parameters affecting the rules, and/or the rules themselves. Once the simulation is complete, the desired performance measures can either be directly obtained from the tool's outputs or derived by post-processing the available results.

## Developing Scenarios

Both the demand and supply inputs for no-notice evacuations are different from typical travel days and depend on the specified scenarios. Ideally, the scenarios account for the interacting forces of the event, emergency management, infrastructure condition, and citizen response. Figure 1 illustrates how these forces interact to produce the scenario inputs for the simulation model. The interaction of the citizen response (demand) and infrastructure state is simulated within the transportation model.

**Figure 1. Interacting Forces for Scenario Development**




### Event

The event precipitating the evacuation needs to be considered in detail and at a minimum specify the type, severity, location, and timeline. The type of event helps guide what response would be appropriate – evacuate or shelter-in-place; will decontamination activities be required; will law enforcement investigate the event; will infrastructure be damaged or need to be inspected for safety; will injuries be present; etc. Sheltering in-place, although sometimes the appropriate protective action, is not especially interesting from a transportation simulation perspective and scenarios where sheltering in-place is desired (with full compliance) need not be simulated, unless desired for comparison purposes. The type also indicates whether environmental cues will be present—such as sights, sounds, or smells that alert people to danger and increase the likelihood of evacuation (Perry 1983). Finally, the event type helps inform whether transit service will be available; transit agencies will not operate if doing so puts their employees or customers at risk.

Event type, severity, and location determine the amount of infrastructure damage that should be modeled and the size of the area that will require a mandatory evacuation. The size of the evacuation area and its location indicate whether multiple jurisdictions will have to coordinate and how many and where public shelters should be opened. Dunning and Oswalt (2007) add that topography is an important consideration as well. Certain chemicals are heavier than air and evacuating citizens into or through valleys would place them at greater risk than sheltering in-place.

Terrorist attacks are often modeled with a specific target (e.g., Peeta and Hsu 2009). Historical events or other information may help identify impact locations. For example, in a recent study by the authors, the funding agency selected a location based on historical terrorist attacks. Other studies (e.g., Liu 2011) selected locations based on the likelihood of an event according to the locations of hazmat sites and critical transportation infrastructure.

Finally, event timing and the progression of the threat are important considerations for the emergency response plan and evacuation demand estimation. The time-of-year and day-of-the-week determine the estimates of different types of evacuees – residents, workers, tourists, and students. Time-of-day influences how the evacuation notices can be issued, the types of evacuees, and dispersion of the resident population. For instance, citizens cannot be notified of the evacuation order by television if it is the middle of the night. Nighttime evacuation scenarios can assume that most people will be at home whereas daytime evacuations involve greater dispersion of the household. Noh et al. (2009) suggest that the worst-case time-of-day scenario for a downtown area is between 11 AM and noon. Time-of-day also influences the amount of background traffic (non-evacuees) that will be present in the network and their origins and destinations.

In the authors' project, scenarios were based on an attack involving unspecified hazardous materials at a specific location with no danger of incident escalation or transportation infrastructure damage. Two radii around the target were examined; radii could also be informed by recommended evacuation distance for chemicals (see, for example, USDOT 2012 for hazmat transport incidents). Both scenarios occurred during the evening peak travel period of a weekday to generate the maximum background traffic. Health risks were assumed to be minimal to ensure continuity of transit modes and ease the complexity of trying to model switching transportation modes, which could be especially difficult for those who did not drive to work. These scenarios could be more complex by varying some of these conditions, but at the same time, one needs to limit the number of simulations so that one is not simulating and analyzing indefinitely.

## Emergency Management

Zimmerman et al. (2007) point out that for no-notice incidents, emergency managers will not have full situational awareness and will operate on incomplete information and pre-event plans. Quick decision making is critical for saving lives in no-notice events. Without advance information, the emergency response plan will be implemented post-impact. Elements of the plan may pertain specifically to infrastructure damage caused by the event or involve modifications to the network (discussed in the next section) to facilitate evacuation. Safety precautions may call for isolating the directly impacted area from non-emergency traffic and should be reflected in the infrastructure modeling.

Communicating the appropriate protective action to the public is one of the key elements for the scenario modeling. Citizens who receive a clear evacuation notice have higher likelihoods of evacuating (Baker 1979; 1991; Gladwin and Peacock 1997; Hasan et al. 2011; Lindell et al. 2005). If desired, the spread of information over space and time can be part of the scenario modeling. This could be accomplished using diffusion models such as the one by Rogers and Sorensen (1991). In the authors' study, to manage the overall scenario complexity, the assumption that the evacuation order would be issued 15 minutes after the event and that warning dissemination could be part of the response curve for traffic loading (discussed below) simplified the information dissemination considerations.

## Infrastructure Capacity and Configuration

Infrastructure damage or closure by emergency managers is event-dependent (Wilson-Goure et al. 2006). Similarly, transit operations also depend on the event and special transit operations may depend on the evacuation plan. On the other hand, certain capacity enhancements can be implemented, whether by policy or based on the assumption that drivers would use all available capacity. For instance, high occupancy vehicle (HOV) restrictions can be suspended or hard shoulders can be used. In the authors' study, hard shoulders were already in use due to peak period operations but HOV restrictions were assumed to be eliminated 10 minutes after evacuation starts.

Other traffic management strategies can be resource and time intensive. Zimmerman et al. (2007) indicate that contraflow operations require three to five hours to implement, and thus are not likely to be implemented for no-notice events. However, other possible strategies include modified signal timing, ramp closures, and crossing elimination. The last two strategies require resources and careful planning with respect to demand in order to be effective; however, their operations are more localized than contraflow operations and can be implemented faster.

Information, as available, can be provided to drivers about road closures, incident locations, and congestion conditions. When information provision is included in the scenarios, the methods should be considered (e.g., 511, radio, Internet, and fixed and portable variable message signs—VMS), as well as updating frequency. As an example, the authors assumed that evacuees would receive new information every 10 minutes through in-vehicle devices. Start and end times of congestion warnings on variable message signs may need to vary by location and can be determined after analyzing initial simulations.

Basic scenarios may be examined in conjunction with traffic incidents. Associated locations, severities (number of lanes closed), and durations can be determined from historical incident records or in conjunction with random incident models. If incident locations are close together and individually would not produce significantly different simulation results, only one of these should be chosen.

**Citizen Response**

Ideally, behavioral models, such as those that predict evacuation departure times, origins, destinations, and routes should be specific to a particular area, event, and network. However, the data collection efforts for many detailed scenarios can be cost prohibitive and the nuances of the scenario definitions may be lost on the respondents or survey administrators. There is also a question about how well anticipated behavior will match actual behavior. Fortunately, Kang et al. (2007) found that the two are in line with each other over many dimensions.

Estimating the number of different types of travelers is complex. One must consider evacuees who are in the mandatory evacuation area, evacuees who elect to travel but are not required to or ignore advice, and travelers that are not addressed by the evacuation order. Further complicating the issue are special facilities (e.g., hospitals, prisons) and people with special needs who need assistance to evacuate. All travelers need to be defined in terms of their origins, destinations, departure times, modes of transportation, and routes.

Additional considerations may be needed for the traffic mix. For example, trucks do not have the same features as personal vehicles, especially in hilly areas. The simulation model may be able to handle all of these types of demands, but if not, and truck volumes are comparatively small, trucks may be converted to passenger car equivalents using factors from the Highway Capacity Manual. Truck evacuation traffic should also be considered if volumes are substantial, the evacuation area is sufficiently large, and/or a major trucking source is affected.

*Evacuee Estimates.* Compliance with an evacuation notice has been a concern for hurricanes, among other disasters. This is similarly an issue for no-notice events. If detailed behavior models are available for the event/area, they should be used. In their absence, assumptions regarding the percent compliance may be required. When making conservative estimates for emergency planning purposes a response rate of 100 percent, which assumes that everyone within the threat area will evacuate, is commonly used. Such an assumption would generate the maximum amount of travel into the system and would also likely result in the most lengthy clearance time.

Identifying the evacuees naturally depends on the event, its timing, and the emergency plan. Evacuees may be categorized in different ways, such as residents and transients (e.g., tourists and business travelers, see Drabek 1996). It may be reasonable to assume that most of the evacuees can transport themselves, but any special populations and their evacuation plans should be incorporated as appropriate. For some cases, special populations may be safer sheltering in-place rather than evacuating due to the time-intensive nature of obtaining transport, preparing the dependents for travel, and then evacuating.

During a nighttime evacuation, most of the resident are likely to be at home and transients will be in hotels. However, during the day, people will be more dispersed, making the estimation of evacuees more challenging. At these times, evacuees may be further segmented into workers, students, at-home residents, shoppers, and tourists, estimates of which will depend on the particular time of day. Calculations for the first four groups may be informed by a transportation planning model. Information for predicting the number of tourists may be obtained from state or local tourism entities.

In the authors' recent study, estimates of the total number of workers requiring evacuation were based on the evening peak period origin-destination matrix from a local metropolitan planning organization's (MPO) transportation planning model. MPO travel models, such as the one used from the Metropolitan Washington Council of Governments, are helpful to show normal daily traffic patterns, including origins, destinations, and routes as well as the times during which these trips are taken. In turn, this information can be used for estimating both evacuation trips and the background traffic that would exist in the network at the time of an emergency. From the normal day travel demand calibration effort, an adjusted demand matrix was obtained that included some pre-peak demand, the entire evening peak, and some post-peak demand. This matrix consisted of trips of all types. To separate the work-home trips, the calibrated matrix was multiplied by the planning model's ratio of work trips to all trips and these ratios varied across time periods. Student trips could be similarly estimated if required by the time-of-day scenario. Shopper evacuees can also be calculated in a similar fashion, but using the planning model's home-based shopping trips rather than work trips.

To predict the number of at-home residents who would evacuate, information from the U.S. Census can be used. For a worst case demand scenario, the number of retirees and unemployed persons may be assumed to be at home at the time of the event. As an estimate of retirees, the authors used the number of individuals aged 65 and older. These statistics were used in conjunction with the proportion of the Census area within the mandatory and shadow evacuation radii. Other factors in the at-home resident calculation include employed residents who live in the evacuation area but work elsewhere. The authors assumed that their percentage was proportional to the ratio of the elapsed peak period to the entire peak period. To generate the number of vehicles, the authors assumed a vehicle usage rate (80%) in the range identified by Ewing (2010). Employed residents who were outside the evacuation area at the time of the event were assumed to not return home but follow the destination assumptions discussed below.

Tourist volumes may be estimated from information provided by the state tourism organization, including the total number of annual tourists, the highest percentage for the month of travel, the average number of nights spent in the state, the percentage associated with the cities in the study area, and the percent traveling by personal vehicle/rental car. Depending on the evacuation area, evacuees using aircraft as their mode of evacuation may need to be considered. An airport authority can provide estimates of the numbers of passengers and greeters (e.g., family or friends meeting the passengers at the airport) during a specified timeframe (employees should be addressed in the estimates of the number of workers). Analysts may also assume that, due to the event, some flights would be diverted to other airports and that an estimate of the number of vehicle trips could be based on the airport's parking spaces. Although not all vehicles in the parking lot would be used, taxis and greeters would provide service.

In addition to all of these considerations for the mandatory evacuation area, researchers should also anticipate shadow evacuees. In the authors' study, shadow evacuation was assumed to occur in the area with a radius at least double the mandatory evacuation radius. A behavioral study for the area suggested that estimates of 40 percent of workers and 20 percent of residents in the shadow area would be reasonable (Guterbock et al. 2009).

*Intermediate Trips.* A long history of observations of family gathering during evacuations (e.g., Johnson 1988; Johnson, Feinberg, and Johnston 1994; Killian 1952; Perry 1985; Perry, Lindell, and Greene 1981; Perry and Mushkatel 1984) suggests that this behavior should be incorporated into the demand considerations if the timing of the event warrants. Liu et al. (2012) confirm that parents anticipate gathering their children during no-notice evacuations. Failure to include such behavior leads to overly optimistic evacuation time estimates and traffic patterns that would otherwise not be captured, potentially conflicting with traffic management strategies (Liu 2011; Murray-Tuite 2007; Murray-Tuite and Mahmassani 2004). However, child pick-ups would be negligible at times other than those hours unless there participation in extracurricular activities is high.

*Background Traffic.* This type of traffic can have a significant impact, especially when the evacuation area does not encompass the entire simulated network. Few empirical studies are available to inform estimates of the travelers not participating in the evacuation. At a minimum for transportation simulation, some pre-event traffic is required to generate realistic network conditions.

The authors created three background traffic scenarios for their study. The first allowed background traffic to follow typical day volumes and departure timing. The second kept the volumes the same but condensed the departure time span to half of the peak period in order to represent the case in which these travelers would be aware of the event and try to reach home sooner. Finally, for the same volumes, the departure time span was expanded to 1.5 times the peak period to represent the condition in which people might stay at work longer to avoid evacuation related traffic.

*Destination Assignment.* Based on numerous hurricane related studies (e.g., Drabek and Boggs 1968; Moore et al. 1963; Murray-Tuite et al. 2012b; Wu, Lindell and Prater 2012), the homes of relatives and friends and then hotels/motels are preferred accommodation types for evacuees, compared to public shelters. Public shelters, however, may be used temporarily, depending on the duration for which evacuees anticipate being away from home and the nature and timing of the evacuation (Mileti, Sorensen and O'Brien, 1992).

Although many hazards have readily identifiable source locations, directions of movement, and speed of progression, not all do. When the location and movement characteristics of a hazard are unknown or cannot be forecast, one may consider two scenarios for evacuee destinations. One destination assignment scenario may focus on homes and hotels/motels. The authors assumed that evacuees would travel to dispersed locations in proportion with the normal travel, according to a regional planning model. Noh et al. (2009) based the dispersion on social/recreational trips from a planning model. In the other scenario, evacuees can be assigned to public shelters identified by the emergency management agency. For smaller evacuation areas, the local shelters may be able to accommodate all evacuees but larger evacuation areas require travel beyond the regional transportation simulation model. In that case, the evacuees can be assigned to external zones in the direction of those shelters. Reality will likely fall somewhere between these two scenarios, probably closer to the first, but the number of simulations needs to be reasonable.

Other types of travelers should be assigned reasonable destinations. In particular, barring isolation of network components due to the event, background traffic should be assigned to their original destinations. Similarly, workers and shoppers who are evacuees that live outside of the evacuation radius should be assumed to go home. Any intermediate trips considered should have appropriate intermediate destinations (e.g., schools).

*Mode Split.* The modes available for evacuation depend on the event, its timing, and evacuation plans. Transit may not be available in the middle of the night, regardless of the event's effects. At a more individual level, if an event occurs during the workday, commuters who used transit will not have access to personal vehicles except by carpooling with co-workers; thus, the number of personal vehicles cannot be increased despite slight mode changes.

Personal vehicle use during evacuations has shown both similarities and differences when compared to regular travel. Generally, vehicle occupancy is higher during evacuations since families tend to travel together. However, certain types of events—such as floods, fires, and hurricanes—that threaten any vehicles that are left behind may offset the higher vehicle occupancy as drivers seek to avoid their loss.

When personal vehicles are appropriate for the event, they are the preferred mode of transportation for residents and tourists. Hurricane related studies revealed vehicle usage ranging from 72-91 percent of all registered vehicles (Ewing 2010).

In the authors' study, they made four more assumptions related to modes. First, transit services would operate normally. Second, travelers, particularly background traffic, would use their normal modes of transportation. Third, airport evacuee mode split is 17% transit and 83% personal vehicle; these values are based on normal mode splits provided by the airport authority. Finally, pedestrians would not interfere with vehicle traffic; should this last assumption be relaxed, capacity reductions should be modeled.

*Traffic Loading/Departure Times.* The loading of evacuation traffic onto transportation road networks is a reflection of people's decision to evacuate. The speed at which this occurs depends on a range of variables that relate to the dissemination of evacuation information, preparation time, experience, community behavior, and the characteristics of the threat. Although the cumulative time scales differ for different hazards, it is typical to see an S-shaped response curve in which the evacuation begins slowly. Zimmerman et al. (2007) and others indicate that some people may evacuate even before an official evacuation order is issued. Wolshon et al. (2010) found that as many as 10 percent of evacuees depart spontaneously. This pattern of behavior is common especially for with-notice hazards like hurricanes as some evacuees seek to depart the hazard zone as early as possible because they may feel particularly threatened, seek to avoid later traffic congestion, and so on. Then, soon after the order is given, the evacuation response rapidly gains momentum with about 80 percent of the total number of evacuees departing over about a third of the total clearance time. Finally, over the final third of the cumulative clearance time window, the final 10-20 percent clears the risk area. This last part of the evacuation, which is also labeled the "evacuation tail", can significantly lengthen total evacuation time (Wolshon, Jones, and Walton 2010).

The widely-used logistic curves (Yazici and Ozbay 2008) are characterized by two parameters, one is the half loading time and the other, $\alpha$, indicates the response rate. Short loading time and high $\alpha$ values generate concentrated departure times. The authors adopted an $\alpha$ value of 0.5, which represents rapid response and considered two scenarios for half loading time—30 minutes and 60 minutes. These parameters were selected to be conservative.

*Route Selection/Traffic Assignment.* The traffic simulation tool will include at least one traffic assignment technique. Often, the method is based on some version of equilibrium. However, a user-based equilibrium requires travelers to have knowledge of the conditions over all possible paths. For normal travel, the knowledge is gained through experience, which is not practical during evacuations (Lindell and Prater 2007). More realistic assumptions involve evacuees selecting a good, but not necessarily optimal path, especially those going to a non-home location.

Background traffic, on the other hand, especially those far from the impact area, should be assumed to follow their habitual paths, at least initially (Zheng et al. 2010). Their paths may be affected by real time traffic information and delays. Assumptions about the percentage of travelers that will hear the traffic information will have to be made and parameters reflecting delay tolerance will need to be specified.

The authors' study used the software DynusT, which allowed at least two types of traffic assignment. Background traffic was assigned to their normal paths with a single delay threshold. In the initial scenarios, en-route information was not provided to the background traffic but was provided to all of the evacuees; this was done to facilitate post-processing activities, but should be varied in additional scenarios. Evacuees were simulated with "one-shot" assignment, which provides evacuees with good but not necessarily optimal paths.

A summary of the key scenario elements, considerations, and potential sources of information that may be considered for evacuation simulations is provided in Table 1.

## Modeling Experience

Based on the examples indicated throughout the above discussion, the authors developed 24 base scenarios (two evacuation radii, three background traffic cases, two destinations, and two departure time/loading curves). Each of these was subjected to four incident locations (temporary capacity reductions) and four traffic management strategies implemented at least 25 minutes after the event occurs. Without interacting the incident and management strategies, this led to 192 scenarios. The simulation input and selected output files required nearly 13 GB for each scenario (2.5 TB total) and approximately 1.5-3.5 hours to run each, depending on a variety of factors, such as the number of simultaneous runs, the processor, information strategies, and number of vehicles simultaneously in the network. The total number of vehicles involved in the scenarios was on the order of 5,500,000 with a network of 5,648 nodes and 12,890 links.

The large number of scenarios is not suitable for presentation to decision makers as the comparisons are difficult to make. Outputs of interest include, but are not limited to, travel time for evacuees overall, travel times for evacuees to reach safety, travel times for all vehicles, and speeds and densities for each link in the network. The last two performance measures vary with time and can be displayed with GIS tools or animations. Instead of presenting all of the results, researchers should select ones that generate significant differences. Naturally, this will require significant effort on the part of the analyst. Detailed results from the authors' study are not publicly distributable.

**Table 1. Scenario Elements and Information Sources**

| Scenario Element | Potential Models | Assumptions | Sources of Information and Dependencies |
|---|---|---|---|
| Event type | Damage models; structural models | Impact on infrastructure | Historical records; geography; government agencies |
| Event severity | Event type models | Impact radius | Emergency Response Guidebook (Cloutier and Cushmac 2004); historical records; professional judgment |
| Event location | Event type models | Affected infrastructure, population | Historical records; professional judgment; government agencies; maps |
| Event timing & progression | Event type models | Time-of-year; time-of-day; day-of-the-week | Appropriate models; historical records; government agencies; professional judgment; maps |
| Infrastructure Condition and Capacity | | Capacity reductions and timing | Event damage models; structural models |
| Infrastructure Condition and Capacity | | Capacity increases/ reductions & timing; information provision strategies | Response plans from emergency management agencies and departments of transportation |
| Emergency management | | Speed of decision making; speed of information spread; degree of information receipt | Emergency management agencies; professional judgment; surveys |
| Citizen response – special facilities | Routing models | Whether to evacuate or not; number of vehicles; destinations; departure times | Special facilities' emergency response plans; local response plans; interviews |
| Citizen response – special needs | Routing models; departure models | Whether to evacuate or not; number of vehicles; origins; destinations; departure times | Local response plans; interviews/surveys |
| Truck traffic | Routing models | Personal car equivalents (if desired); origins; destinations; departure times | Highway Capacity Manual; transportation planning models |
| Mandatory evacuee estimates | Behavior models | Compliance; number of people in the mandatory evacuation area | Surveys; Census data; transportation planning models; state or local tourism entities; airport authorities; event characteristics |

**Table 1. Scenario Elements and Information Sources (Continued)**

| Scenario Element | Potential Models | Assumptions | Sources of Information and Dependencies |
|---|---|---|---|
| Shadow evacuee estimates | Behavior models | Area of shadow evacuation; number of people in the mandatory evacuation area; shadow evacuation rate (or more detailed if available) | Surveys; Census data; transportation planning models; state or local tourism entities; event characteristics |
| Vehicle usage rate | | | Surveys; previous studies (e.g., Ewing 2010); transportation planning models; Census data; event characteristics |
| Intermediate trips | Behavior models | Existence; quantities; origins; destinations | Event characteristics; previous studies (e.g., Lin et al. 2009; Liu 2011; Liu et al. 2012; Ma, Krometis, and Sen 2009); transportation planning models; school and facility response plans; local response plans |
| Background traffic | Routing models; information response models; behavior models | Quantities; origins; destinations; departure times; routes | Event characteristics; transportation planning models; surveys |
| Evacuee destinations | Behavior models | Accommodation types and locations | Surveys; transportation planning models; shelter locations from emergency management agencies; event characteristics |
| Mode split | Discrete choice models | Use of normal modes; availability of public transportation models | Event characteristics; interviews with transit providers; local response plans; transportation planning models; surveys; vehicle usage rate |
| Traffic loading / departure times | S-curves; Rayleigh distribution (e.g., Tweedie's approach) | Parameter values | Previous studies (e.g., Noh et al. 2009; Wolshon et al. 2010; Yazici and Ozbay 2008) |
| Route selection | Routing models; information response models; behavior models | Behavior assumptions; information updates; response thresholds | Simulation capabilities; historical traffic conditions; behavioral studies |

## Summary and Conclusions

Emergency management agencies and departments of transportation benefit from transportation simulation support when developing their emergency response or evacuation plans. No-notice events are increasingly becoming a part of these plans. Although a general outline of considerations is available from the Federal Highway Administration (Zimmerman, Brodesky, and Karp 2007), few, if any, studies have illustrated how these considerations can be operationalized.

This study provides details of scenario development based on the general considerations and the authors' research experience. The scenarios should consider the four interacting components of the event, infrastructure, emergency management, and citizen response. The event should be specified in terms of type, severity, location, and timeline in order to identify infrastructure effects, the need to evacuate, the method of delivering evacuation warnings, whether transit will operate in the affected area, and to some degree how citizens will respond. Infrastructure operability and safety, combined with emergency plans, will determine whether evacuees and background traffic can use the full network. Authorities may also increase capacity by suspending HOV restrictions and allowing the use of hard shoulders. They may also modify the network through traffic management strategies, such as modified signal timings, ramp closures, and turning movement restrictions at intersections. Furthermore, information can be provided to travelers through variable message signs and in-vehicle devices to help them avoid congestion and effectively use the network. The citizen response will be influenced by the event, official warnings, and infrastructure conditions. Estimating travel demand requires consideration of spontaneous evacuation, mandatory evacuation compliance, special populations, and background traffic. This article provides assumptions and methods to compute at-home resident, worker, shopper, tourist, and airport evacuees whose destinations are scenario-based. Modes of transportation, departure times, and routes should also be considered. This paper suggests justified assumptions for these factors.

Although no single hypothetical scenario is likely to perfectly replicate a real event that occurs in the future, the simulations of a variety of scenarios can be useful and informative for emergency management. The scenarios allow for the identification of factors to which the results are sensitive. Little sensitivity allows agencies to be fairly confident with assumptions about those factors but high sensitivity may indicate areas for future detailed study. Such analyses also indicate where traffic management strategies should be consistently implemented, and where a strategy is only effective in certain situations. In some scenarios, implementing a strategy designed for a completely different case, may deteriorate evacuation performance and place evacuees at increased risk.

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## BOOK REVIEWS

*The Routledge Handbook of Hazards and Disaster Risk Reduction*, 2012, edited by Ben Wisner, JC Gaillard, and Ilan Kelman. London: Routledge.

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Can social sciences provide analyses that could transform disasters by altering methods of Disaster Risk Reduction (DRR)? The *Routledge Handbook of Hazards and Disaster Risk Reduction* brings forth propositions reflecting continuing research in this field for over six decades. These include:

> '[A]ctions have consequences and that no development investment or policy is risk neutral' (p.5)…. [P]eople move about and occupy territory for reasons – a variety of historical and contemporary reasons – combining choice and lack of choice. ...The relations that govern daily life and the routine use of resources and space are the same relations that determine who in society will suffer death, injury, disruption and livelihood loss in hazards manifestations and who will have resources to recovery quickly and achieve even better circumstances than before' (p. 5).

As increasingly frequent disasters provide evidence for such conviction, the challenge is how to apply these and other propositions in the current scenario of varied socio-cultural and political contexts.

The handbook is successful in inviting critical thinking that makes it different from a technical guide. In contrast to a 'handbook', the editors call it a 'left foot book' inspired by a character of Christy Brown from the 1989 film *My Left Foot*. They have opted for freshness, innovation, courage and hard work that is apparent in the use of an 'upside down' world map that shows the nearly global coverage of the book and their desire to turn conventional thinking 'on its head'. The editors and authors explore both the theory and story sides of DRR in accessible language. A large effort must have gone into coordinating authors from five continents. Amidst details, a reader also finds a good sense of humor. A variety of information presented in boxes, figures and tables seize attention.

The handbook aims to end the isolation of work on disasters and DRR, and to overcome the perception that dealing with disasters is solely about humanitarian response (p. 17). Eighty-two authors have analyzed ongoing research, policies and practices for hazards and DRR across the world in sixty-five chapters. The editors use the *Pressure*

*And Release* [PAR] framework to guide the conversation (Blaikie et al. 1994, Wisner et al. 2004). The handbook is divided into five parts and thirteen sections that address different aspects of DRR.

The book starts with an engaging introduction offering a framework for integrated DRR and explaining the structure of the handbook. However, this is not all. The reader is guided at every step through a section of introductions that cover the issues addressed in each part. The second chapter thus sets the background for next twelve chapters in part one by providing the 'Big Picture' view of hazards, vulnerability and DRR. Before moving into details, the third chapter presents models of vulnerability, capacities and recovery along with a story of how the PAR framework developed.

The chapters that seek to explain root causes and dynamic pressures of vulnerability have been grouped into three sections - 'Politics, history and power', 'Culture, knowledge and religion', and 'Environment, development and sustainability'. Explicit chapters on history, politics, human rights and violence in the first section bring out the specific roles of these factors in the construction of both risks and DRR. Chapters in the second section draw attention to multiple perspectives, their interconnectedness and decisive socio-cultural context. The story of a landslide from the central Karakoram Range in the Himalayas indicates that a wealth of knowledge can be preserved in local tales. In addition to chapters on the significance of hybrid knowledge (i.e., an integration of indigenous and scientific knowledge) and faith-based institutions, there is a chapter discussing promising opportunities for using disaster films and songs for DRR. The third and final section of part one addresses urban risks attributed to contrasting urban visions and explores the nitty-gritty of linkages between DRR and sustainable development in policy and practices.

In contrast to the earlier 'Big Picture' views of hazards, vulnerability and capacities, part two of the handbook provides a fine-grained examination. Its first section catalogues data sources for all hazards and lists a variety of tools for the short-, medium-, and long-term hazards identification, forecasting, monitoring and visualization that make this handbook a very useful resource for DRR. The next four sections address a variety of hazards categorized into hydro-meteorological, geophysical, biological and astronomical hazards. Each chapter examines physical and social aspects of specific hazards along with their respective DRR strategies.

The handbook also draws attention to some secondary hazards that are less frequently discussed from the DRR point of view, such as waste slides in urban dumpsites or erosion of plant genetic resources. Its last section addresses the twin concepts of vulnerability and capacity, where individual chapters look into disability, gender, children, the elderly, and caste, ethnicity and religious affiliation. The selected parameters are not only seen as factors responsible for discrimination, marginalization and socio-economic vulnerability, but have also been studied for their positive role when particularly high vulnerable groups are mobilized and enlisted in DRR activities.

The third part of the handbook focuses on preparedness and response, wherein the editors set the context with models of capacities and recovery. This part addresses varied but interconnected issues of warning, preparedness, evacuation, emergency management principles, information requirements for damage or need assessments and economic valuation, health impacts, food security as well as shelter and reconstruction. It also brings to notice some controversial issues such as emergency feeding, post disaster resettlement, and corruption. One section is specifically devoted to recovery that looks into psychosocial and socio-economic impacts, resulting needs and support for satisfying such needs.

Planning, prevention and mitigation of disasters is the focus of part four. The editors again use the model of capacities and integrated DRR elaborated from the PAR framework to introduce this topic and complete the loop. This section emphasizes that DRR must focus on reducing vulnerability and enhancing capacities. Its initial section discusses governance, advocacy and self-help in eleven chapters by looking into details of planning at different scales, financial mechanisms, economic policy, protection of infrastructure, and social and livelihood protection—along with actions from the community and civil society. The next section attends to communication and community participation, with one chapter suggesting a role for university research in DRR along with others that address children's education, media and participatory action research. The final part of the book rolls out thirteen 'lucky left foot themes' that summarize the findings and indicate future research areas.

The handbook is the result of a gigantic effort. The reader is made aware of the equally enormous challenge of DRR, which can be addressed only if everyone takes it seriously. It is evident from the handbook that leadership for DRR is present across the world, but it also becomes clear that many local voices are still unheard and many more places are still invisible from the commonly agreed platform for DRR—the UN's *Hyogo Framework of Action* (http://www.unisdr.org/we/coordinate/hfa).

The book has some weaknesses. Its organization leaves a reader confused at times. The handbook classifies and labels only the biological hazards as ecological, which puzzles the reviewer, as it is unclear why other hazards are not 'ecological'? Planning for recovery is one of the less attended issues of DRR in many nations. A detailed account of recovery in the handbook makes it noteworthy; however, one wonders why the title of part three limits itself to preparedness and response. With the objective to make each chapter self sufficient, the editors repeated a few figures in multiple chapters. At first sight, this seems unnecessary but it ultimately helps the reader to understand links between the handbook's different parts. The fifth chapter, on political power, introduces an interesting figure called 'the power cube'. As it comes just after a chapter on history, the missing time dimension in this figure is striking and grabs the reader's attention.

In brief, this handbook is a welcome addition to the literature on hazards and DRR that shows disasters are rooted in 'normal' life and, therefore, can be reduced. Although the editors courteously state that their ‘vision guides the handbook but the handbook guides nobody, at least not directly’, it certainly widens the horizon of wisdom for students, practitioners and policy makers interested in DRR.

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*Reporting Disaster On Deadline: A Handbook for Students and Professionals, 2012, by* Marty Steffens, Lee Wilkins, Fred Vultee, Esther Thorson, Greeley Kyle and Kent Collins. New York, Routledge.

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This slim volume aims to educate journalists about disasters as social phenomena, and help them understand how better to fulfill their responsibilities for informing and educating the public. The first chapter, "Covering disasters without becoming one" is the weakest, and put me off from reviewing the book for some time. Happily I picked it up recently and finished it, and now I can recommend it to disaster researchers as a valuable repository of insights from the other side of the microphone, and to journalists for its useful advice on how to deal with covering disasters through all the policy and administrative phases.

Steffens' first chapter offers a brief historical overview of disaster reporting, and the importance of accurate and timely coverage. It is the least well written of the chapters, and contains one bit of misinformation, stating that the flooding of New Orleans in 2005 was "caused by dams that broke" under the strain (p. 8). I was left wondering what the purpose of this chapter was.

The second chapter, by Fred Vultee and Lee Wilkins, and the third, by Vultee, focus on educating journalists about the current theoretical understanding of disasters. They do a good job in Chapter Two, "What's probable and what's possible," covering the basics of what scholars know about disasters and offering suggestions to help news organizations cover disasters. They follow an idiosyncratic but logical set of disaster phases (Warning, Impact, Immediate post-impact, Recovery and Mitigation), used to organize their review of social science findings, as well as lists of planning and story recommendations. They pay a welcome amount of attention to mitigation, explaining that although it is the least "newsy" period, it is actually critical to building social capacity and reducing disaster impacts. They also demonstrate a solid understanding of issues around warnings and the other phases. They know that panic is actually rare and, although their citations are to old Killian and Quarantelli pieces, they are solid references. Chapter three focuses on terrorism, using Brian Jenkins' (1975) definition of terrorism as "violence that communicates" (p. 37). It is refreshing to read a journalists' critique of the "everything changed after 9/11" meme. Since terrorism is a communications act, Vultee reminds journalists that they must seek to understand the social and economic contexts out of which the attacks arise. He also cautions them to avoid uncritical repetition of the premise that terrorism is a Muslim phenomenon, even though doing so can elicit "angry letters to the editor, scornful blog and Twitter comments, and general accusations that journalists are politically correct liberal cowards selling out American culture" (p. 48). The section on "Securitization" was less helpful and felt a bit rushed, but the chapter ends with practical advice for news professionals.

Chapter Four explains how to develop a "Crash Book," a manual that every newsroom, no matter what the platform, should have, including sections on newsroom operations, community, state and national emergency services, disaster scene information, and sources for analysis and with special expertise. Each chapter of the Crash Book should include a checklist followed by a "topical section" with more in-depth information that can make things run more smoothly when a situation develops. Collins and Kyle recommend a "shakedown cruise" to test the crash book, and the constant maintenance and updating of the Crash Book, perhaps by interns. They conclude with checklists for tasks to be performed both before a disaster and immediately upon activation of the newsroom for disaster/terrorism coverage. Their sample call list is fairly complete, which makes the absence of the Local Emergency Management Agency more surprising. A media outlet will do its audience no favors by neglecting to find out what the LEMA has to say before jumping to the state level agency.

Chapter Five, "The quality of disaster news", focuses on framing, noting seven common and (sometimes) useful frames: Economics, Blame, Conflict, Prediction, Devastation, Helplessness, and Solidarity. Thorson notes the scholarly critiques of media coverage, including the tendency to perpetuate disaster myths noted by Drabek in 1986 and others since. He offers "Public Health-Based Disaster Reporting" as a useful model that can help journalists focus on prevention of harm to the population and segments thereof. The final section provides positive examples of good stories about each of the phases outlined in Chapter One.

In Chapter Six, Kyle provides advice for journalists on how to maintain their own safety and health, both physical and mental, while covering disasters. He notes the prevalence of PTSD among war correspondents, and cites anecdotal evidence from large-scale disasters such as Hurricane Katrina and the Indian Ocean Tsunami of PTSD among journalists. He notes "unseasoned rookies work nights and weekends and so the least experienced and most vulnerable are most likely to be asked to cover spot news, murder and mayhem" (p. 87), leaving them especially likely to be negatively affected. He has good ideas of how to set up systems that can minimize the incidence of psychological problems for journalists and steps to address problems that do arise.

Despite a title that does not do it justice (Covering Consumer Issues), Chapter Seven by Steffens provides a good introduction into the analysis of disasters' socioeconomic impacts. He notes that there are some myths about the cost of disasters as well as about general human response to them, including the idea that nobody gains economically from disasters and that their effects are distributed across the population. Steffens also wrote Chapter Eight, "More Than Just a Victim," which discusses the rising importance of citizen journalists in this day of exploding technological and social communications systems. He says that professional journalists bring training and professional standards to their disaster reporting, but amateur content "often brings immediacy that journalists cannot deliver" (p. 110).

Lee Wilkins wrote the last two chapters. Chapter Nine focuses on ethical journalistic practice. It is not as well written as the middle section of the book, but once you get past this distraction, there is some good material here. He believes that journalists must not focus only on getting the story first and right, but also on transparency, by which he means that journalists should be open about uncertainties in their reporting. Following up on stories is an excellent time to demand accountability by public officials and provide in-depth coverage of policy issues, while linking them to an issue that may increase the attention the public is willing to pay to such normally boring material. The concluding chapter is a brief explanation of the purposes of the book, which would have been more useful as the introductory chapter.

This book is appropriate for journalism students, but also for students and scholars of disaster, whatever their discipline. The authors showed some familiarity with the state of research on disasters and hazards, and highlighted the availability of resources such as the Natural Hazards Center in Boulder CO, that can help journalists increase their knowledge, and thus the quality of their reporting.


## Interested in what others are doing in the hazards and disasters community? Join the crowd.

The Natural Hazards Center at the University of Colorado at Boulder plays a vital role in reducing the risks posed by natural, technological, and human-induced hazards. For almost thirty years the Hazards Center has served as a national and international clearinghouse of knowledge concerning the social science and policy aspects of hazards and we continue to advocate sustainability, interdisciplinary partnerships, and an all-hazards approach to the management of extreme events. Our basic goal is to strengthen communication among researchers, practitioners, policy makers, and other concerned individuals, and we focus on the collection and sharing of research and experience related to disaster mitigation, preparedness, response, and recovery. The Center publishes a wide variety of publications, often freely available on our Web site, ranging from works-in-progress to peer-reviewed studies, with the intent of reaching as wide an audience as possible. These publications include the ***Natural Hazards Observer***, ***Disaster Research*** (e-newsletter), the ***Natural Hazards Review*** (in cooperation with the American Society of Civil Engineers), full-length research studies (monographs), working papers, and special publications such as ***Beyond September 11: An Account of Post-Disaster Research***. Information about these publications as well as other Hazards Center projects, such as the Disaster Grads listserv for students interested in hazards and disasters, our extensive library and its online searchable database ***HazLit***, and the Quick Response Research Program, is available on the Web at:

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