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Identification and Analysis of Factors Affecting Emergency Evacuations

Main Report

Sandia National Laboratories

U.S. Nuclear Regulatory Commission
Office of Nuclear Security and Incident Response
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ABSTRACT

This study examines the efficiency and effectiveness of public evacuations of 1,000 or more people, in response to natural disasters, technological hazards, and malevolent acts, occurring in the United States between January 1, 1990, and June 30, 2003. A universe of 230 evacuation incidents was identified and a subset of 50 incidents was selected for case study analysis. Case study selection was based on a profiling and ranking scheme designed to identify evacuation incidents of sufficient complexity to challenge the local and regional emergency response capabilities. Case study analysis included completion of a detailed question survey for each incident. Advanced statistical methods, including regression analyses and correlation analyses, were used to identify factors contributing to evacuation efficiency. The regression analyses identified that community familiarity with alerting methods and door-to-door notification were statistically significant for a more efficient evacuation. The following factors were statistically significant for a less efficient evacuation: traffic accidents, number of deaths from the hazard, number of injuries caused by the evacuation, people spontaneously evacuating before being told to do so, people refusing to evacuate, and looting or vandalism. In addition, interviewees stated that the following contributed to the efficiency and effectiveness of their evacuation: a high level of cooperation among agencies, use of multiple forms of emergency communications, community familiarity with alerting methods, community cooperation, and well-trained emergency responders. All 50 evacuation cases studied safely evacuated people from the area, saved lives, and reduced the potential number of injuries from the hazard.

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EXECUTIVE SUMMARY

This study revealed that large-scale evacuations in the United States, whether preplanned or ad hoc, are very effective and successfully save lives and reduce the potential number of injuries associated with the hazard. The local responders typically initiate the evacuations and expand them to include regional or federal agencies as the size of the evacuation dictates. An overwhelming factor cited as contributing to evacuation success was a high level of coordination and cooperation among agencies and an effective command structure (e.g, the command structure was well understood, agencies worked well together, and emergency responders were empowered to make decisions). Those interviewed during this investigation stated that they thought training and exercises had contributed to the effectiveness of their evacuations. All 50 of the communities questioned for this study had provided training to emergency response personnel, and 40% had tested their plan in a full-scale field exercise.

Shadow evacuations (people evacuating outside of the designated evacuation area), had no significant impact on traffic or congregate care center capacity or on the efficiency of the evacuation, in general. Public awareness of the hazard, of evacuation procedures, and especially of alerting methods was often cited as contributing to the efficiency and effectiveness of an evacuation. Cooperation from evacuees was repeatedly cited as contributing to safe, efficient, and effective evacuations.

This study identified a universe of 230 evacuation incidents in the United States between January 1, 1990, and June 30, 2003, where at least 1,000 people were evacuated. No radiological-related evacuations occurred during this time frame. A subset of 50 incidents was selected for case study analysis using a detailed questionnaire. Advanced statistical methods, including regression analyses and correlation analyses, were used to analyze the questionnaire responses in order to identify key factors contributing to evacuation efficiency.

The regression analyses identified that community familiarity with alerting methods and door-to-door notification were statistically significant for a more efficient evacuation. In addition, the following factors were statistically significant for a less efficient evacuation: traffic accidents, number of deaths from the hazard, number of injuries caused by the evacuation, people spontaneously evacuating before being told to do so, people refusing to evacuate, and looting or vandalism. Although it should be noted that only six cases involved deaths from the hazard, and of these six, only one case involved deaths during the evacuation itself. In addition, only two cases involved injuries during the evacuation.

Emergency communications, traffic, and citizen action were the most common issues reported by interviewees. Emergency communication issues were reported in 28% of the cases studied. This usually involved radios that were not on the same frequency. Radios were used in 92% of the cases studied. However, multiple forms of emergency communication were used in 40% of the cases, which often compensated for these failures. Traffic issues, such as traffic congestion, were reported in 28% of the evacuation cases studied. However, traffic accidents occurred in only 8% of the cases. Finally, some type of citizen misbehavior was reported in 24% of the cases;

however, this was generally limited to a small portion of the population. In addition, looting and vandalism was reported in only 10% of the evacuation cases.

All 50 evacuation cases studied safely evacuated people from the area, saved lives, and reduced the potential number of injuries from the hazard. Nearly a third of the 50 evacuations studied had no issues associated with them, such as communication failures or traffic issues, and nearly three-quarters of the cases encountered one or none of these types of issues. Only one case, the East Bay Hills Fire near Berkeley, California in 1991, involved deaths during the evacuation. In this particular instance, special circumstances, including steep hills and narrow roads, combined with poor visibility due to the wildfire, were directly responsible for the deaths and injuries that occurred during the evacuation. However, the East Bay Hills Fire evacuation overwhelmingly saved lives that would have otherwise been lost.

The evacuation research also identified that many communities are actively engaged in activities to improve their emergency response capabilities, including modernizing communication systems, developing transportation analyses and assessments to improve traffic flow, improving local education awareness, and developing interagency and cross-boundary coordination plans.

ACKNOWLEDGMENTS

In the aftermath of the terrorist attacks of September 11, 2001, the NRC Emergency Preparedness staff began a review of the planning basis for nuclear power plant emergency preparedness programs. Each licensee must demonstrate with reasonable assurance that it can effectively implement the emergency plan to adequately protect public health and safety in the event of a radiological emergency. An important facet of protecting the public health and safety is the use of protective measures including public evacuation. However, when the staff attempted to verify that indeed public evacuations are effective, there was not a systematic government study to confirm the anecdotal assumptions of effectiveness. This study was commissioned to provide an impartial examination of the public evacuations.

There were many NRC contributors that helped bring this study to fruition. Kathy Gibson provided the vision and the needed management support to initiate this project. Randy Sullivan provided the technical leadership to ensure this project met the needs of the emergency preparedness community. Debra Schneck was the project manager responsible for contractual matters, Daniel Barss provided technical review, and Joe Anderson assisted with completion and publishing. Lori Dotson and Joe Jones of Sandia National Laboratories preformed the detailed technical investigations that led to this insightful study. Sandia staff including Joe Schelling, Susan Carson, Marty McRoberts, and Marilyn Gruebel, provided technical support and review for the document. Statistical support was provided by Laura Ring Kapitula as an independent consultant.

ACRONYMS

AP	Associated Press
ARIP	Accidental Release Information Program
ATSDR	Agency for Toxic Substances and Disease Registry
BFD	Baltimore Fire Department
BNSF	Burlington Northern Santa Fe
CANS	Community Alert Network System
CEMP	Comprehensive Emergency Management Plan
CIRC	Chemical Incidents Reports Center
CNN	Cable News Network
CSB	Chemical Safety and Hazard Investigation Board
CWSERP	Church World Service Emergency Response Program
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DRC	Disaster Research Center
ECC	Emergency Command Center
EOC	Emergency Operations Center
EP	Emergency Preparedness
EPA	Environmental Protection Agency
EPZ	Emergency Planning Zone
ETE	Evacuation Time Estimate
FDNY	New York City Fire Department
FEMA	Federal Emergency Management Agency
FRA	Federal Railroad Administration
HMIRS	Hazardous Materials Information Resource System
HSEES	Hazardous Substances Emergency Events Surveillance
ICP	Incident Command Post
ICS	Incident Command System
LANL	Los Alamos National Laboratory
LEPC	Local Emergency Planning Committee
MSDS	Material Safety Data Sheet
MUA	Multi-Attribute Utility Analysis
NOAA	National Oceanographic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NTIS	National Technical Information Service
NTSB	National Transportation Safety Board
NUMARC	Nuclear Management and Resources Council
NYPD	New York City Police Department
PA	Public Address
RAIRS	Railroad Accident/Incident Reporting System

SARA	Superfund Amendments and Reauthorization Act
SCBA	Self-Contained Breathing Apparatus
SNL	Sandia National Laboratories
TMI	Three Mile Island Nuclear Power Plant
WTC	World Trade Center

1.0 INTRODUCTION

Radiological-related evacuations are a rare occurrence and none were identified during the 12.5-year time-frame encompassing this study. However, public emergency evacuations in response to natural disasters and hazardous materials accidents occur rather frequently in the United States. Emergency evacuations of at least 100 people occur more than once a week, and major evacuations of more than 1,000 people occur more than three times per month in the United States (Weston, 1989). These evacuations have generally proceeded safely and effectively, even when managed by local emergency response officials with little or no practical evacuation experience or planning.

1.1 Objective

The objective of this study is to assess the emergency evacuation process in the United States, including evaluating evacuation experience (e.g., time to complete evacuation, traffic issues, deaths or injuries, etc.) and identifying critical factors affecting emergency evacuations (e.g., training, drills, preparedness, ad hoc versus preplanned, etc.). The study examines public evacuations of 1,000 or more persons in response to natural disasters, technological hazards, and malevolent acts occurring in the United States between January 1, 1990, and June 30, 2003, and examines 50 evacuation incidents in greater detail.

1.2 Purpose

The purpose of this study is to gain an objective understanding of the emergency evacuation process in the United States and to identify the critical factors that influence the efficiency of emergency evacuations.

1.3 Scope

The scope of this investigation includes the following tasks:

1. Conduct a comprehensive literature search on the general topic of emergency evacuation and on specific evacuation cases.

2. Identify the universe of evacuations meeting the following criteria:

   - U.S. mainland public evacuations;
   - Evacuations occurring between January 1,1990, and June 30, 2003;
   - Evacuations involving more than 1,000 people; and
   - Evacuations of people from more than a single building or industrial facility.

3. Profile each evacuation incident in this universe according to the following criteria:

   - Size of evacuation;

- Type of incident (natural, technological, or malevolent act);
- Category of hazard (e.g., railroad accident, hurricane, fixed site hazmat incident, etc.);
- Year of occurrence;
- Special issues encountered;
- Type of community (urban, suburban, or rural); and
- State or region.

4. Provide a statistical and quantitative summary of the results obtained during the profiling phase (e.g., distribution of evacuation size, percentage of natural vs. technological hazards, etc.).

5. Identify 50 evacuation occurrences of sufficient size and complexity to challenge local and regional emergency response capabilities and prepare a case study for each that includes the following information:

   - Community context,
   - Threat conditions,
   - Consequences,
   - Emergency response,
   - Investigator comments, and
   - References.

6. Develop and apply a method for identifying the critical factors affecting the efficiency of emergency evacuations which considers:

   - Direction and control (evacuation decision-making process),
   - Emergency communications,
   - Notification of emergency personnel and local officials,
   - Citizen action,
   - Traffic movement and control,
   - Law enforcement, and
   - Re-entry.

2.0 BACKGROUND

2.1 Previous Studies

An extensive literature review was conducted both on the general topic of public evacuation, and on specific evacuation experiences. This review involved a thorough search of the Internet, news retrieval services, online reference databases, journals, books, and conference proceedings. There were no radiological-related evacuations identified in this study.

In the late 1980s, the Nuclear Management and Resources Council (NUMARC) funded a study to identify and analyze the factors affecting emergency evacuations (Weston, 1989). This study, which is the most relevant to the current study, identified 250 evacuation incidents between 1980 and 1987 meeting the established criteria of greater than 1,000 people, more than one facility, and on the U.S. mainland. This translates into approximately one major evacuation every 1.7 weeks. In the Weston (1989) study, evacuations due to technological hazards accounted for 67%, while those due to natural disasters accounted for 33%. Approximately 2.4% of the incidents involved evacuations of more than 50,000 people, 14% involved between 10,000 and 50,000 people, and 83.6% involved fewer than 10,000 people. The study identified four factors that significantly affected the positive outcome of evacuations: (1) field-scale training and drills, (2) cooperation among government agencies, (3) use of an Emergency Operations Center (EOC), and (4) use of door-to-door notification and vehicle public address (PA) systems to alert the endangered public.

In the mid-1980s, the Federal Emergency Management Agency (FEMA) funded a study of evacuations resulting from chemical accidents (Sorensen, 1987). This research was conducted partly in response to the Union Carbide chemical plant explosion in Bhopal, India, in 1984 and a general concern over emergency preparedness in the chemical industry. The study identified 293 evacuations due to chemical accidents between 1980 and 1984. Fifty-eight of these incidents involved evacuations of more than 1,000 people. Although there were numerous injuries associated with exposure to chemicals, no injuries were reported that were strictly related to the evacuations. The study did not identify factors affecting the efficacy of chemical evacuations. However, some data from the Sorensen (1987) report were used in the Weston (1989) analysis.

Evacuation behavior at the Three Mile Island Nuclear Power Plant (TMI) in 1979 was particularly well studied (see Stallings, 1984; Cutter and Barnes, 1982). The emergency evacuation at TMI led to several other studies related to how the public might respond to a nuclear power plant emergency.

Zeigler and Johnson (1984), as well as Johnson (1984), concluded from their research that the public would over-respond to evacuation orders in the event of a nuclear power plant accident. This conclusion was based mainly on a telephone survey of Long Island residents conducted in June 1982 that asked them to predict what they would do if there were an emergency at Shoreham Nuclear Power Station in Suffolk County, approximately 100 km (60 mi) east of New York City. Zeigler and Johnson (1984) and Johnson (1984) also did some comparison with the

Brunn, Johnson, and Zeigler (1979) post-TMI telephone survey. They concluded that evacuees beyond the 16-km (10-mi) Emergency Planning Zone (EPZ) would make it more difficult for those closer to the plant to evacuate quickly. Therefore, they concluded that the EPZ should be expanded beyond the 16-km (10-mi) radius.

Sorensen (1986) questioned the assumption of Zeigler and Johnson (1984) that there would be significant shadow evacuations. The conclusions of Sorensen (1986) were based on two sources: NUREG/CR-1215 (Flynn, 1979), which included the results of a telephone survey conducted by NRC after the TMI emergency, and the conclusions of Stephens and Edison (1982), which was an analysis of news media coverage of the TMI emergency. Sorensen's model suggests that evacuation response is dictated by awareness of risk, personalization of that risk, evaluation of alternative actions, and then deciding a course of action. Therefore, evacuation behavior would be normal and predictable and not based on dread of radiation. Furthermore, Sorensen (1986) concluded that the public would not panic during such an event.

Lindell and Barnes (1986) examined why the public would be more inclined to evacuate in response to a radiation emergency than to a natural disaster. Their conclusions were based on a questionnaire given to 137 undergraduate students at the University of Washington. The survey asked them to predict what they would do for two scenarios: (1) radiation release from a nuclear power plant, and (2) dioxin release from a herbicide factory. Their data suggest that the over-response at TMI was due, in part, to the confusing and conflicting information disseminated to the public, and they recommended providing the public with accurate information and alternative protective actions to avoid over-response. Lindell and Barnes (1986) also noted that over-response is characteristic of hazardous material accident evacuations.

Another large body of research is related to the study of hurricane evacuations. (References are listed in Section 6.0). Several states in the southeastern United States have independently, and in conjunction with federal agencies, such as FEMA and the U.S. Department of Transportation (DOT), undertaken hurricane evacuation studies to address behavioral and transportation issues. For example, the State of Florida commissioned a task force in 1999 to find solutions to issues encountered during some of Florida's large-scale hurricane evacuations, most notably the Hurricane Floyd evacuation in 1999. The Governor's Hurricane Task Force Report identified improvements in the areas of decision-making, traffic management, congregate care center management, and dissemination of emergency public information. One of the important conclusions of the report was that the Internet should be used as a means of disseminating emergency information on available evacuation routes, congregate care center locations, traffic information, and precise areas requiring evacuation. Other recommendations included reversing traffic lanes (reverse-laning) along all major evacuation routes and increasing congregate care center capacity in many counties.

Drabek (1994) studied disaster evacuations and the tourist industry and concluded that the tourist industry is particularly under-prepared for a disaster-related evacuation. Drabek (1999) studied the response of 118 companies to seven disaster events and concluded that companies need better policies to address disaster preparation. This is of particular concern in states such as Florida that have a high tourist population and an above-average concentration of commercial nuclear power plants.

Perry (1981, 1984) has published two comprehensive textbooks on emergency management and evacuation planning that include sections on the emergency decision-making process and the psychosocial effects of evacuation. Although now dated, these books are still useful for evacuation planning. Most other evacuation studies have focused strictly on the social and behavioral aspects of emergency evacuations. Quarantelli (1984, 1985, 1992a, 1992b), Riad et al. (1998, 1999), Perry (1979), and Perry and Lindell (1991), for example, deal with evacuation behavior. Several related studies are listed in Section 6.0 of this report.

2.2 Information Sources

No specific evacuation databases were found during an intensive information review. However, several online databases containing evacuation information were identified and examined. These databases included:

- Environmental Protection Agency (EPA) Accidental Release Information Program (ARIP);
- Department of Defense (DOD) Hazardous Materials Information Resource System (HMIRS);
- Chemical Incidents Reports Center (CIRC) Database;
- Agency for Toxic Substances and Disease Registry (ATSDR) Hazardous Substances Emergency Events Surveillance (HSEES);
- Federal Railroad Administration (FRA) Railroad Accident/Incident Reporting System (RAIRS); and
- Monterey Institute of International Studies Terrorism Incidents Database.

Other non-database websites and online services were also examined for information, including:

- News archives, such as Associated Press (AP), USA Today, Cable News Network (CNN) Online, and local newspapers;
- DIALOG Information Service, specifically for AP and UPI, especially for older events;
- National Technical Information Service (NTIS);
- SciSearch Research Library;
- Miscellaneous accident reports, such as those at Fireworld.com and Fluoridealert.org;
- Disaster relief news stories, such as those at Disasterrelief.org and the Church World Service Emergency Response Program (CWSERP) Disaster News Network;
- National Transportation Safety Board (NTSB) accident reports;
- Federal news updates, such as FEMA National Situation Updates;
- Federal libraries, such as the FEMA Library;
- Miscellaneous research universities, such as Dartmouth College Flood Archives, University of Delaware Disaster Research Center, University of Colorado Natural Hazards Center, Florida State University Hurricane Research, and University of Michigan; and

- Miscellaneous websites including American Red Cross, DOT, Army Corps of Engineers, NRC, U.S. Forest Service, National Oceanographic and Atmospheric Administration (NOAA), and state emergency management agencies.

2.3 Data Collection

A few limitations of this study must be discussed in order to put the results within context. First, it is not possible to find every single evacuation that fits within the criteria specified in Section 1.3. Some events are not documented or records are too poor to identify whether or not an event fits the established criteria. This is particularly true for the older events, and therefore older events could be under-represented in the database. Second, evacuations resulting from natural disasters are often complex and involve multiple evacuations over several days and affect multiple communities. This level of detail is not practical and often not possible to obtain, and therefore the number of evacuations due to natural disasters could be under-represented in the database. Third, it is not practical to obtain information on all of the evacuations as a result of the September 11, 2001, malevolent acts due to the overwhelming number of evacuations on this date and the fact that the evacuations were secondary to the attacks themselves. Many of these evacuations were actually early release of workers from government and commercial facilities, as opposed to community evacuations. However, it should be noted that the number of evacuations caused by malevolent acts could be under-represented in the database.

3.0 METHODS

3.1 Development of Evacuation Universe

Extensive research of the information sources identified in Section 2.2 was conducted to establish a universe of evacuations. Hundreds of evacuations were identified and then screened against the following criteria:

- U.S. mainland public evacuations;
- Evacuations occurring between January 1, 1990, and June 30, 2003;
- Evacuations involving more than 1,000 people; and
- Evacuations of people from more than a single building or industrial facility.

Upon completion of the screening process, 230 evacuations met the criteria and are listed in Appendix A, Table A.1. Each of these evacuations was then profiled based on:

- Size of evacuation;
- Type of incident (natural, technological, or malevolent act);
- Category of hazard (e.g. railroad accident, hurricane, fixed site hazmat incident, etc.);
- Year of occurrence;
- Special issues encountered;
- Type of community (urban, suburban, or rural); and
- State or region.

A statistical and quantitative summary of the information gathered during the profiling of the universe of evacuations is presented in Section 4.1. This information provided the basis for selection of 50 incidents for detailed study.

3.2 Case Study Selection

From the universe of evacuation incidents identified in Table A.1 in Appendix A, 50 incidents were selected for further analysis. Selection was based on a ranking scheme designed to identify incidents of sufficient complexity to challenge local and regional emergency response capabilities and to provide sufficient detail to identify the factors contributing to evacuation efficiency.

Each evacuation incident was profiled according to evacuation size, community preparedness, incident type, year of occurrence, existence of special issues, community type, and region in the United States. A weight was assigned to each of these factors, and these weights were then multiplied by the ratings shown in Table 3-1. The total ranking, R_j, was obtained by summing the products of the weights and the ratings for each factor:

$$R_j^{Norm} = \left(\frac{R_j - R_{min}}{R_{max} - R_{min}} \right) * 100$$

The minimum and maximum possible ranking values are 21 (R_{min}) and 63 (R_{max}), respectively. Rankings were normalized over this range to a 100-point percentage scale using the following equation:

$$R_j = \sum_{i=1}^{7} \left(weight_{i,j} * rating_{i,j} \right)$$

Table 3-1. Weights and Ratings Used to Rank the 230 Evacuation Incidents

Factor	Weight	Rating
Number of evacuees	5	3 = >5,000 evacuees 2 = 2,000 to 5,000 evacuees 1 = <2,000 evacuees
Preparedness level	5	3 = Within an EPZ [<16 km (<10 mi) from a commercial nuclear power plant] 2 = Within a hurricane-prone region 1 = None of the above
Hazard type	3	3 = Technological hazard or malevolent act 1 = Natural disaster
Year	3	3 = 2000-2003 2 = 1997-1999 1 = 1990-1996
Special issues	3	3 = Special issues encountered 1 = Few or no special issues encountered
Community	1	3 = Urban 2 = Suburban 1 = Rural
Region of U.S.	1	3 = North, South, or Midwest (i.e., Eastern half of the United States 1 = West, Southwest, or Northwest (i.e., Western half of the United States)

Fifty evacuation incidents were then selected from the top 100 ranked incidents, and a case study analysis was performed for each using data from the evacuation form shown in Appendix B. Expanding the selection area to the top 100 evacuation incidents served two purposes: first, it reduced the uncertainty associated with the profiling, and hence, the ranking process, and second, it allowed two more evacuations due to malevolent acts to be included in the case study analysis.

The rationale for the weighting scheme shown in Table 3-1 is based on several considerations. First, larger-scale evacuations require greater coordination and planning and would be a better test of a community's response capabilities than smaller evacuations.

Second, it was assumed that evacuation incidents occurring in a nuclear power plant EPZ or in a hurricane-prone area would have emergency procedures that are more relevant to this study. Therefore, evacuations fitting either of these two criteria received a higher rating.

Third, evacuations due to technological hazards and malevolent acts received a higher rating than evacuations due to natural disasters, since the latter commonly involve some advance notice, while the former usually involve little or no advance warning. In addition, some studies have shown that the public reacts differently, usually over-responding to evacuations related to technological events (Lindell and Barnes, 1986). However, recent large-scale hurricane evacuations, most notably Hurricane Floyd, 1999, have shown that public over-response, or shadow evacuations, can be just as significant, and more so, in a natural disaster evacuation.

Fourth, more recent evacuation incidents were viewed as more relevant. This is because the emergency procedures are current, often reflecting new procedures implemented since September 11, 2001. In addition, emergency responders have a better recollection of the event itself, often providing more useful and more accurate information. Furthermore, beginning around 1997, information became more readily available via the Internet. Therefore, events occurring in 1997 or later received a higher rating. The highest rating went to events occurring since 2000.

Fifth, evacuations involving special issues, such as evacuation of special facilities (e.g, nursing homes, hospitals, or schools) or unusual evacuation methods (e.g, air or boat) or unusual circumstances (e.g., shadow evacuations, traffic issues), received a higher rating than those not involving special issues. Again, the existence of special issues requires greater coordination and planning and would be a better test of a community's response capabilities.

Sixth, urban evacuations received a higher rating than suburban evacuations, which in turn received a higher rating than rural evacuations. More densely populated communities would better challenge a community's response capabilities than less densely populated communities.

The seventh and final factor was the region in which the evacuation occurred. This factor was developed to ensure that evacuation incidents occurring in regions with larger numbers of commercial nuclear power plants, generally the eastern half of the United States, ranked higher.

3.3 Evacuation Efficiency

Each evacuation case was scored based on the number of issues encountered during the evacuation, as determined from the responses provided in the evacuation questionnaire. Each evacuation was rated 0 (no issues encountered) or 1 (one or more issues encountered) for each of the following seven variables:

- Direction and control (evacuation decision-making process),
- Emergency communications,
- Notification of emergency personnel and local officials,
- Citizen action,
- Traffic movement and control,
- Law enforcement, and
- Re-entry.

If one of these variables was unknown and missing from the dataset, it was coded as a zero for the purpose of creating the score. Because so few data points were missing, this had little impact on the results. These values were then summed for each incident. The raw scores were as follows:

- Sixteen cases with no issues,
- Twenty-one cases with one issue,
- Eight cases with two issues,
- Three cases with three issues,
- One case with four issues,
- One case with five issues, and
- No cases with six or seven issues.

Table 3-2. Distribution of Evacuation Cases

Evacuation Efficiency	Frequency	Percent
0 issues	16	32
1 issue	21	42
2 issues	8	16
3 or more issues	5	10

Based on these results, each case was grouped into the following categories: 0 issues, 1 issue, 2 issues, and 3 or more issues as shown in Table 3-2. Thus, the evacuation efficiency score (i.e., the value of the outcome variable) is an ordinal number ranging from 0 to 3 (the lower the score, the more efficient was the evacuation).

3.4 Regression Analysis

A regression analysis is a statistical technique used to identify relationships between a dependent variable, such as the evacuation efficiency score, and one or more independent variables, such as questions from the case study questionnaire. The results of the regression analyses are contained in Section 4.3 and Appendices F through K. All data preparation and analyses were carried out using SAS 8.02 for Windows.

Each variable in the questionnaire was compared to the efficiency score using an ordinal logit model, which is a generalized linear model. In generalized linear regression, the relationship is constrained to be a straight line and maximum likelihoods are used to determine the best fit. An ordinal logit model was chosen because the dependent variable (i.e., efficiency score) is neither normally, nor Gaussian, distributed and it is an ordinal random variable. Since hazard type is often associated with other variables, the regression results were also adjusted for hazard type.

The resulting chi-squared value (probability or *p*-value) from the likelihood ratio tests were performed to test if each variable was significantly associated with the efficiency score. A *p*-value is the probability of observing the difference in the data by random chance. Thus, if $p < 0.05$, there is less than a 5% chance that this association would have occurred if there were no association, and the hypothesis that there is no association is rejected in favor of the hypothesis that there is an association. A variable with a *p*-value of less than 0.05 is considered to have a statistically significant association to the efficiency score. If the *p*-value is between 0.05 and 0.10, the variable is considered to have a marginal (or weak) statistical association to the efficiency score. Often a $p < 0.01$ is considered to show a highly significant statistical association.

3.4.1 Qualifications to Data Analysis

Although a vast quantity of data and information was acquired during the case study analysis, 50 cases are a relatively small dataset on which to perform a statistical analysis. Because of the small dataset, some associations may not have been identified. In addition, the statistical associations that were identified could merely represent "noise" in the data. In order to avoid missing a significant association, *p*-values as high as 0.10 were examined. It should be noted that an association implies a correlation, but does not necessarily imply a causal relationship (i.e., it does not necessarily imply "cause" and "effect").

Survey data frequently involve missing values because interviewees either do not have all of the information or do not remember. However, missing values (i.e., unknowns) in the questionnaire responses generally represented less than 10% of the data. Furthermore, unknown data points were entirely random and were based on interviewees' knowledge or recollection of the event, as opposed to a reluctance to answer the question. Therefore, pairwise deletion of missing values was used, which is the most common method of handling missing data. This means that if a case is missing data for a particular variable, it is not included in the computation of association for that variable. For verification purposes, the regression analyses were performed on a select number of imputed datasets, and the results were similar to those obtained using the pairwise deletion method, confirming the appropriateness of pairwise deletion for this analysis.

3.5 Correlation Analysis

Correlation coefficient (r) is a statistical measure of the interdependence of two or more random variables. Fundamentally, the value indicates how much of a change in one variable is explained by a change in another. The larger r is in absolute value, the stronger the correlation. Positive r values indicate a direct relationship between variables and negative r values indicate an inverse relationship (i.e., a rise in one value is associated with a drop in the other variable). The value of r that is statistically significant depends on the sample size. In this analysis, correlation coefficients greater than $|0.03|$ are statistically significant.

Correlation coefficients were calculated for variables suspected of having a correlation to one of the variables used to define the evacuation efficiency score (see also Section 3.3). Data preparation and analysis were carried out using SAS 8.02 for Windows. The results of the correlation analysis are contained in Section 4.4 and Appendix L.

4.0 ANALYSIS

The analysis consists of a statistical summary of the 230 evacuation incidents contained in the universe (Section 4.1), a detailed analysis of the 50 case studies (Section 4.2), a regression analysis (Section 4.3), and a correlation analysis (Section 4.4).

4.1 Statistical Summary of Evacuation Universe

A total of 230 incidents were identified in the 12.5-year time frame between January 1, 1990, and June 30, 2003 (see also Appendix A). Fewer evacuation incidents were identified before 1997 because information prior to 1997 was not as well documented in the information sources. Considering only the post-1997 data, the frequency of an evacuation meeting the defined criteria was approximately once every two weeks. The following subsections provide a statistical summary of the profiling results.

4.1.1 Number of Evacuees

Figure 4-1 shows the size distribution of large-scale evacuations in the United States. Of the major U.S. evacuations identified, 100 (43%) involved evacuations of fewer than 2,000 people, 60 (26%) involved between 2,000 and 4,999 people, and 70 (31%) involved 5,000 or more people. Of the 17 cases that involved more than 100,000 evacuees, 15 were caused by natural disasters (hurricanes), and two were due to malevolent acts on the World Trade Center in 1993 and 2001. Of the six incidents involving 50,000-99,999 evacuees, five incidents were caused by natural disasters. Of the 207 incidents involving fewer than 50,000 evacuees, 112 resulted from natural disasters, 85 resulted from technological hazards, and 10 resulted from malevolent acts.

4.1.2 Community Preparedness Level

Three levels of community preparedness were used to profile incidents contained in the evacuation universe: (1) those communities within the Emergency Planning Zone (EPZ) of a nuclear power plant (6 incidents or 2.6%), (2) those within a hurricane-prone region (53 incidents or 23%), and (3) neither (171 incidents or 74%). Six evacuation incidents (2.6%) occurred within an EPZ and four of these incidents were analyzed as case studies. None of these evacuations were due to nuclear power plant emergencies. These six incidents included a warehouse chemical spill in Charlotte, North Carolina, Hurricane Andrew in Miami-Dade County, Florida, two Hurricane Floyd evacuations, both in southeastern Florida, a wildfire in Port St. Lucie, Florida and the Mississippi Flood of 1993. The Port St. Lucie wildfire and the Mississippi Flood did not receive a high enough ranking during the case study selection process and therefore were not analyzed as case studies.

4.1.3 Hazard Type

Figure 4-2 depicts the types of hazards responsible for large-scale evacuations in the United States. Of the 230 evacuations identified, 133 (5 8%) resulted from natural disasters, 84 (36%)

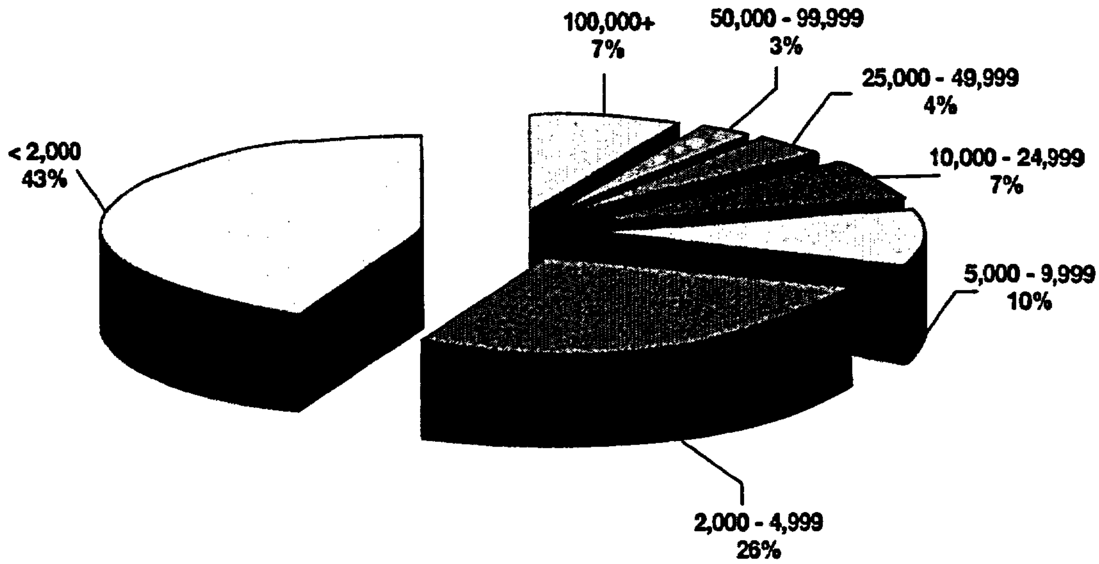

Figure 4-1. Size Distribution of Large-Scale Evacuations in the United States, 1/1/1990 - 6/30/2003

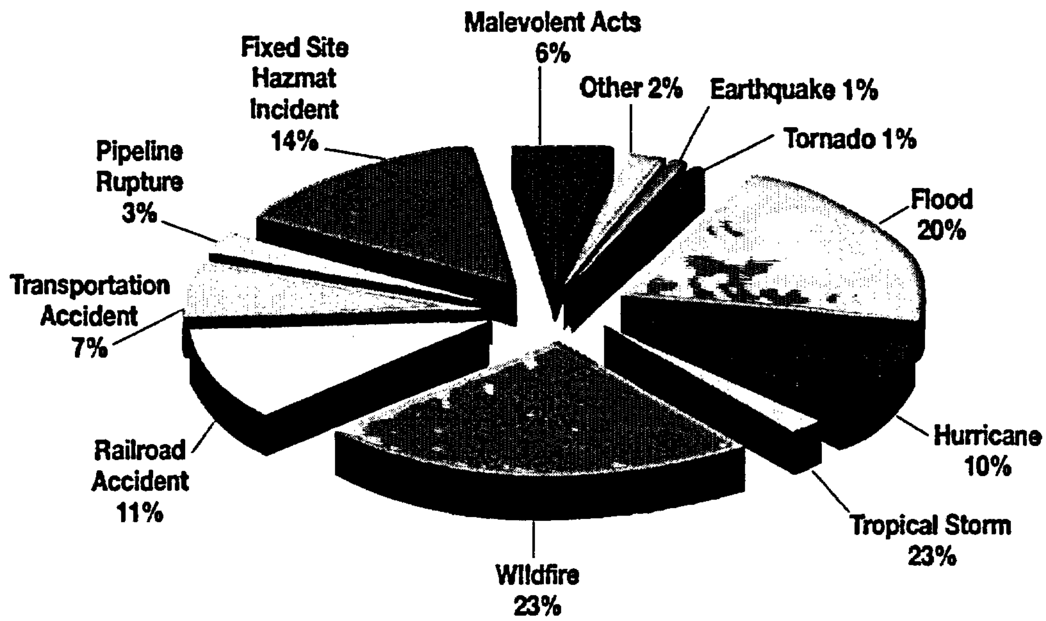

Figure 4-2. Principal Causes of Large-Scale Evacuations in the United States 1/1/1990 - 6/30/2003

resulted from technological hazards, and 13 (6%) resulted from malevolent acts. Of the 133 evacuations caused by natural disasters, two evacuations resulted from earthquakes, 56 resulted from wildfires, 47 were due to floods, and 26 resulted from tornados.

Of the 84 evacuations caused by technological hazards, 33 resulted from accidents at fixed site facilities, 25 resulted from railroad accidents (either train derailments or rail yard accidents), 15 resulted from (non-rail) transportation accidents, six resulted from pipeline hazards, and five resulted from other types of technological hazards. No radiological-related evacuations occurred in this time frame in the United States.

The 13 evacuations due to malevolent acts included five related to the September 11, 2001 attacks, three major airport evacuations, three bombings, one shooting rampage, and one hoax. However, the number of evacuations caused by the September 11, 2001 attacks could be under-represented in the database. It was not practical to capture all of these evacuations because of the overwhelming number and the difficulty in distinguishing between a true evacuation, as opposed to early work releases from government and commercial facilities.

4.1.4 Year of Occurrence

Figure 4-3 depicts the total number of evacuations each year grouped by hazard type (i.e., natural, technological, and malevolent act). A total of 230 incidents were identified in the 12.5-year period of time between January 1,1990, and June 30, 2003, with a yearly average of 18, or more than once every three weeks. However, considering only the post-1997 data, the yearly average is nearly 26, or approximately once every two weeks. Events prior to 1997 were generally not as well documented, and therefore, more difficult to identify. Thus, the number of large-scale evacuations is not necessarily increasing over time.

The number of evacuations in 2002 was nearly double that of other years. The primary reason for the unusually high number of evacuations in 2002 was the high occurrence of wildfires.

4.1.5 Special Issues

Approximately 55 (24%) of the evacuation incidents involved a special issue. A special issue includes evacuation of special facilities (e.g, nursing homes, hospitals, or schools) or unusual evacuation methods (e.g., air or boat) or unusual circumstances (e.g., shadow evacuations, special traffic law enforcement issues). For example, many people were transported by ferries to Liberty State Park in New Jersey during the evacuation of Lower Manhattan following the World Trade Center attacks.

4.1.6 Community Type

The evacuated communities were predominantly suburban, accounting for 116 of the 230 evacuation incidents (or approximately 50%). Rural communities accounted for 77 evacuation

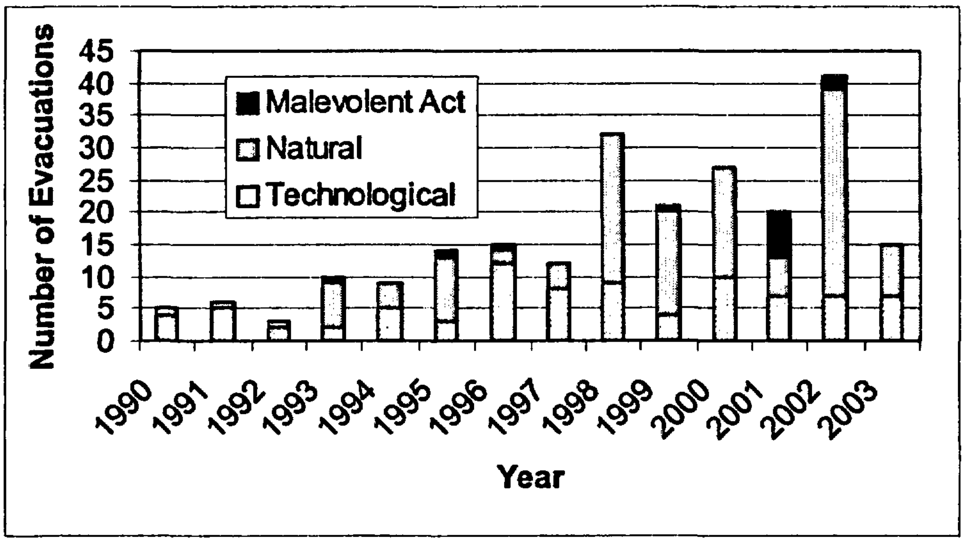

Figure 4-3. Total Number and Type of Large-Scale Evacuations in the United States, 1/1/1990–6/30/2003
(Data for 2003 represents only the first six months)

incidents (34%) and urban communities accounted for only 37 incidents (16%) in the evacuation universe.

4.1.7 Region of the United States

Evacuation incidents were randomly distributed across regions of the United States (Figure 4-4). Slightly less than half (110 incidents) occurred in the western half of the United States and slightly more than half (120 incidents) occurred in the eastern half of the United States. Large-scale evacuations were generally located near population centers. A large number of evacuations occurred in coastal areas which are prone to hurricanes and are typically industrial centers.

4.2 Case Study Analysis

This section describes the evacuation case study analyses. This information was acquired via personal interviews and published reports, using the questionnaire contained in Appendix B. A statistical summary of the 50 evacuation case study questionnaire responses is contained in Appendix C, and a description of the individual cases is contained in Appendix D.

4.2.1 Community Context

Suburban and residential communities represented the majority of the 50 cases analyzed and accounted for 36 (72%) and 41 (82%), respectively. Manufacturing and industry were the most common economic bases and accounted for 21 (42%) of the cases. Evacuations resulting from

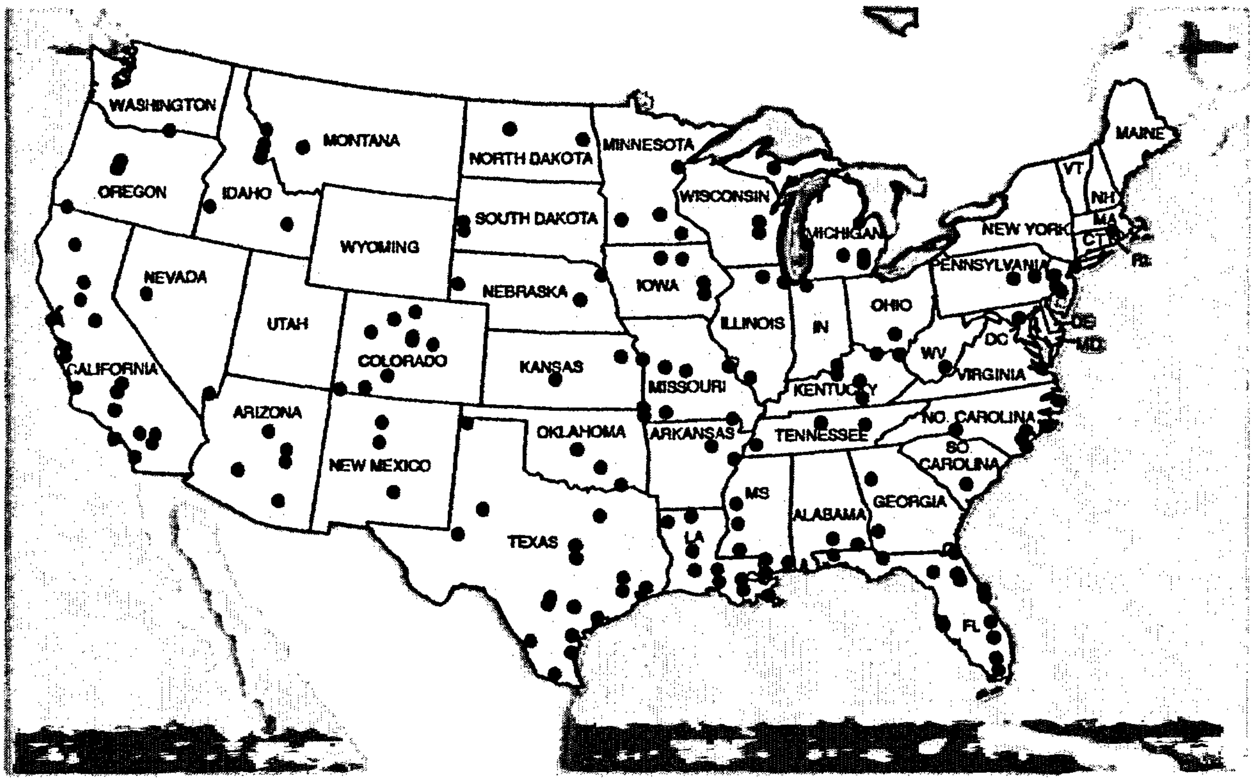

Figure 4-4. Distribution of Large-Scale Evacuations in the U.S. Since 1990

natural disasters, such as the Biscuit Fire near Cave Junction, Oregon that burned over 2000 km^2 (500,000 acres), generally covered a much larger land area than those resulting from either technological hazards or malevolent acts.

4.2.2 Preparedness Activities

Forty-seven (94%) of the cases analyzed involved communities that had a written emergency plan, and 40 (80%) had plans containing an evacuation section. In addition, 86% of respondents said that the plans were used in the emergency. However, only 12% stated that their plans conformed to NUREG-0654/FEMA-REP-1, Rev. 1, and only one plan contained an evacuation time estimate (ETE).

All 50 of the communities questioned said they provided training to emergency response personnel. In addition, 40% had tested their plan in a full-scale field exercise, and 32% had recently conducted a full-scale field exercise. Interviewees stated that they thought training and exercises had contributed to the effectiveness of their evacuations. In one instance, the CSX train derailment in Baltimore Maryland, a full-scale drill, using a MARK Train in an Amtrak tunnel, was conducted approximately six weeks prior to the actual incident.

Public awareness of the hazard, of evacuation procedures, and of alerting methods was often cited as contributing to evacuation efficiency. In addition, cooperation from evacuees was repeatedly cited as contributing to evacuation efficiency.

4.2.3 Threat Conditions

There were three classes of threat conditions considered: technological hazards, natural disasters, and malevolent acts. Of the 50 evacuation cases analyzed, 33 (66%) resulted from technological hazards, 14 (28%) resulted from natural disasters, and 3 (6%) resulted from malevolent acts. Forty evacuation cases (80%) occurred during the day and 10 (20%) occurred at night. Eight (16%) of the 50 evacuation incidents had unusual circumstances associated with them.

4.2.4 Consequences

All 50 evacuation cases saved lives and reduced the potential number of injuries. Injuries from the hazard occurred in 18 cases while injuries due to the evacuation process occurred in only two cases. In one case, the Mims Fire, a police officer monitoring an evacuation barricade was run over by an individual trying to enter the evacuated area. During an evacuation due to a chemical spill in Superior, Wisconsin, approximately 35 police and fire fighting personnel, who were aiding in the evacuation activities at nursing homes, health care homes, and patrolling roadblocks, were treated for dizziness and eyes, nose, and throat irritations.

Only six cases involved deaths from the hazard and of these six, only one case involved deaths during the evacuation itself. This occurred during the East Bay Hills Fire of 1991 when 19 people died while fleeing a wildfire in the steep hills near Berkeley, California. The rapid fire progression, thick smoke, and very hilly terrain created the situation leading to these deaths. Eleven people were killed when the fire caught up to them and eight died in the narrow smoke-filled streets during the evacuation. Many of the fatalities included individuals who were unable to evacuate because of age or disabilities. In one instance, an Oakland police officer and five civilians were found dead at a narrow point in the road where there appeared to have been a traffic accident. However, the East Bay Hills Fire evacuation overwhelmingly saved lives that would have otherwise been lost.

4.2.5 Emergency Response Operations

Emergency response operations include the following five components and associated subcomponents:

- Direction and control,
- Notification and warning,
- Traffic movement and control,
- Sheltering, and
- Re-entry.

Other factors, such as shadow evacuations and the evacuation of special institutions, are discussed at the end of this section.

4.2.5.1 Direction and Control

Direction and control includes the following: the evacuation decision-making process; the command, control, and coordination process; emergency communications; and emergency response activities.

Decision Making

The decision to evacuate was made by a single individual in 40 (80%) of the cases while the remaining 10 (20%) cases involved two or more individuals in the decision-making process. The fire chief was involved in the decision to evacuate in 25 (50%) of the cases while the police chief was involved in 11 (22%) of the cases. Only 6 (12%) of the cases encountered any issues during the decision-making process.

Command, Control, and Coordination

Coordination among agencies was rated as high in 45 (90%) of the cases. An overwhelming factor cited for evacuation effectiveness was a high level of coordination and cooperation among agencies and an effective command structure (i.e., the command structure was well understood, agencies worked well together, and emergency responders were empowered to make decisions).

Command, control, and coordination processes were preplanned in 76% of the cases and ad hoc in 24%. The majority of evacuations analyzed (68%) used an emergency operations center (EOC), and 90% used an incident command post (ICP).

Emergency Communications

Radios were the predominant method of emergency communications and were used in 92% of the cases; however, multiple methods were used in 40% of the cases. There were issues with emergency communications in 14 (28%) of the cases. In 13 of these 14 cases, the major communication issues were associated with radios that were not on the same frequency. Five of the 14 cases with communication issues were due to jammed cell phone networks. However, the wide availability of cell phones, and multiple methods of communication, was helpful in many instances.

Emergency Response

Emergency response personnel mobilized to the scene in less than 15 minutes in 74% of the cases and 54% of the time the evacuation was completed in less than three hours. Only two cases (4%) had issues associated with notification of emergency response personnel and senior local officials. In the CSX train derailment in Baltimore, Maryland, the procedure for the train engineer required notifying CSX first. The CSX office then contacted the Baltimore Fire Department. Because of the communication difficulties inside the tunnel, which delayed the initial contact to the CSX office, and the routing through the CSX main office, the Baltimore Fire Department was not notified for almost an hour. The second case with notification issues was a chlorine gas leak in Henderson, Nevada where the fire department received an early 911 call of a strong odor near the chemical plant. Because the plant frequently has an odor, the battalion chief elected to wait until a more positive report came in on the leak.

The elapsed time between the start of the hazard and the decision to evacuate is dependent upon the type of hazard that led to the evacuation. Evacuations resulting from natural disasters generally involve more time between the start of the hazard and the decision to evacuate and are often more unpredictable than evacuations resulting from technological hazards (hurricanes and wildfires are good examples of this unpredictability). Technological hazards usually involve a more localized area (e.g., a chemical spill), and the decision to evacuate is usually made almost immediately. Thus, emergency personnel have little time to plan for the evacuation and often rely on existing training to quickly assess and respond to the event. Evacuations resulting from malevolent acts are often similar to those resulting from technological hazards.

4.2.5.2 Notification and Warning

Multiple methods of notification were the most common, occurring in 35 (70%) of the cases. These methods usually involved sirens, telephone, radio and television broadcasts, public address (PA) systems, and door-to-door notification. Twelve (24%) of the cases involved issues related to warning and subsequent citizen action. In one of these cases, an ammonia leak in Morro Bay, California, the community being evacuated spoke predominantly Spanish. When the door-to-door notification was conducted in English, some of the residents did not understand the instructions. This is an area where understanding the demographics would have identified this factor and basic preplanning could have improved the evacuation efficiency.

In 26 (52%) of the events, a portion of the affected community refused to evacuate. This was quite common in hurricane events where residents live in the area and believe they understand the risk and want to stay through the storm. Refusing to evacuate was less common in the technological evacuations.

In 22 (44%) of the cases, people spontaneously evacuated before being told to do so (12 of these cases were natural disasters). When people spontaneously evacuate before being told to do so or refuse to evacuate, the efficiency of the evacuation is often impacted.

Reverse-911 telephone notification systems were used in 5 (10%) of the case studies. This method was not as effective as it could have been due to implementation issues. For example, for the Cerro Grande Fire evacuation at Los Alamos and White Rock, New Mexico, the database of telephone numbers was not current and for the Riverview, Michigan evacuation, people hung up the phone before hearing the entire message, indicating that public awareness of these systems should be improved.

4.2.5.3 Traffic Movement and Control

This section includes both traffic and law enforcement.

Traffic

Road conditions were favorable in the vast majority of cases and traffic accidents occurred during only 4 (8%) of the evacuations studied. However, other traffic issues, such as traffic jams, were reported in 14 (28%) of the cases. Reverse-laning (i.e., making all lanes outbound from the area of the emergency) was not widely used and accounted for only 6 (12%) of the cases analyzed. The major reason cited for not using reverse-laning was the potential difficulty in getting emergency vehicles to the scene. Evacuees were given specific instructions in 39 (78%) of the cases and were told to use specific routes in 31 (62%) of the cases.

Law Enforcement

Issues related to law enforcement occurred in only 3 (6%) cases and looting or vandalism occurred in 5 (10%) cases (interviewees did not necessarily interpret looting or vandalism as a law enforcement issue). The police secured the evacuated area in 38 (76%) of the cases, and police, in combination with others, secured the area in 46 (92%) of the cases.

4.2.5.4 Congregate Care Centers

Public emergency shelters, or congregate care centers, were used in 80% of the cases and were managed by the Red Cross 60% of the time. Schools were the most widely used as congregate care centers. Generally, less than 10% of evacuees registered (i.e., stayed) at congregate care centers. However, in three instances, over 20% registered at congregate care centers. Lessons learned from several evacuation cases were that tracking and registering of evacuees could be improved through increased use of the Internet.

4.2.5.5 Re-Entry

In only four cases (8%), were issues encountered during the re-entry process. The fire and/or police chief authorized re-entry in approximately half (50%) of the cases and there was only one instance of a major issue during the re-entry process. Re-entry proceeded under no special controls in 80% of the cases.

4.2.5.6 Other Factors

Shadow Evacuations

Shadow evacuations, defined as evacuations by persons outside of any officially declared evacuation zone(s), occurred in 18 (36%) of the 50 case studies examined. Of those 18 cases involving shadow evacuations, traffic movement was impacted in only five of the cases and there was no impact on congregate care center capacity, according to the individuals interviewed. These five cases were all in Florida and included Hurricane Andrew, Hurricane Floyd (3 cases), and the Mims Fire. In the Mims Fire, Interstate 95 was closed due to poor visibility from the smoke and significantly contributed to the traffic congestion. The hurricanes that had traffic movement problems were exceptionally large, with two cases involving over 600,000 evacuees. The Governor's Hurricane Task Force has since identified improvements in the areas of decision making, traffic management, congregate care center management, and dissemination of emergency public information, that are expected to improve the efficiency and effectiveness of future large hurricane evacuations, and thus, reduce impacts from shadow evacuations.

Special Institutions

Eighteen (36%) of the cases involved the evacuation of one or more special institutions, such as a nursing home, hospital, prison, or school. Evacuation of special institutions was most often preplanned. In some cases, there was a lack of trained emergency responders to drive the buses, ambulances, and other transport vehicles used in these evacuations. In at least one case, a decision was made to leave the patients in the hospital with the air handling system set to recirculate the interior air, rather than risk moving the patients outside into the contaminated atmosphere.

Pets and Livestock

Evacuation and care of pets and livestock was cited as an issue in at least three of the case studies. Most often pets and livestock were transported by their owners to the local fairgrounds where they were housed while the evacuation order remained in effect. However, in two cases analyzed, animals were left behind at residences. In those two cases, it was later recommended that mutual aid agreements be established between state agriculture departments and city and county animal control organizations to handle animal control, including feeding abandoned pets.

4.3 Regression Analysis

The following subsections discuss the results of the multiple ordinal logistic regression analyses. Appendices F through K contain more detailed results.

4.3.1 Introduction

Each variable was initially examined individually to determine which variables were most strongly associated with the evacuation efficiency score. This association is described by the chi-squared values and their associated p-values as described in Section 3.4.

Factors that were statistically significant ($p < 0.05$) for the score include:

- The type of hazard that led to the evacuation,

- Whether there were traffic accidents during the evacuation,
- Type of re-entry process,
- The number of deaths from the hazard,
- The number of injuries caused by the evacuation,
- Whether the National Guard was used for law enforcement,
- Whether there were instances of looting or vandalism,
- Whether the fire chief participated in the authorization for re-entry,
- Whether people spontaneously evacuated before being told to do so,
- Whether anyone refused to evacuate,
- Whether the community had any experience with the hazard,
- Whether schools were used as congregate care centers,
- Number of deaths caused by the evacuation,
- Whether public buildings were used as congregate care centers,
- Who managed the congregate care centers,
- Whether the mayor participated in the authorization for re-entry,
- Whether the public was notified by NOAA,
- The elapsed time between the start of the hazard and the decision to evacuate, and
- Whether any major roadways were unavailable for use.

Factors that were marginally statistically significant ($p = 0.05 - 0.10$) for the score include:

- Whether an Emergency Operations Center (EOC) was used,
- The time to complete the evacuation,
- Whether the public was notified door-to-door,
- Whether special institutions were evacuated,
- The population density during the evacuation,
- Whether the community's emergency response agencies regularly conduct emergency drills and exercises,
- The size of the evacuated area,
- Whether the area is more prone to hazards than average, and
- The level of community awareness regarding the alerting methods used.

Cross tabulations of all variables with significant or marginally significant associations to the evacuation efficiency score are provided in Appendix G.

Given that this is an observational study, a significant association between two variables does not imply that one variable caused the other variable. For example, a significant association between having a traffic accident and having an increase in evacuation issues does not imply that the accident caused the other issues.

A significant association does not imply the direction of the association. Presence of the factor could be related to either an increase or a decrease in evacuation efficiency. The direction of each association is discussed in the next section.

4.3.2 Regression Analysis Results

There is a statistically significant association between hazard type (i.e., natural, technological, and malevolent act) and the evacuation efficiency score, $p = 0.0310$. There is a greater probability of encountering evacuation issues during evacuations due to natural disasters than during evacuations due to technological hazards.

Association between hazard type and all categorical variables were tested using Fisher's exact test. Median values were tested for each hazard type for all continuous variables using the exact non-parametric median test (see Appendix H).

Many variables are statistically associated with hazard type, and thus the effect of certain factors may depend on the type of hazard that led to the evacuation. For example, there is an association between hazard type and the elapsed time between the start of the hazard and the decision to evacuate, $p = 0.0226$. In natural disasters, the decision to evacuate generally takes longer than for evacuations due to either technological hazards or malevolent acts (see Table 4-1). In addition, the regression analysis shows that the elapsed time is significantly associated with the evacuation score.

Table 4-1. Elapsed Time Between Start of the Hazard and the Decision to Evacuate (Hours)

Hazard Type	Number of Events	Mean	Median	Minium	Maximum
Natural Disaster	14*	105	108	0.5	168
Malevolent Act	3	0.72	0.25	0.16	1.75
Technological Hazard	33	0.881	0.5	0.03	6.00

* The elapsed time between the start of the hazard and the decision to evacuate was known for all 50 cases

The regression results were then adjusted for effects that may be due to hazard type. The adjusted chi-squared values are contained in Appendix I and the adjusted *p*-values are contained in Appendix J. Appendix K shows cross tabulations between different variables and evacuation efficiency score, broken down by hazard type.

<u>Whether there were traffic accidents during the evacuations (sample size (n) = 46; 4 missing data points)</u>

Traffic accidents are highly significantly associated with evacuation efficiency, $p < 0.0001$. There were only four cases with traffic accidents reported during the evacuation. There is not a significant relationship between hazard type and traffic accidents, $p = 0.180$. After adjusting for hazard type, there is still a highly significant association between traffic accidents and the evacuation score, $p = 0.0006$. Traffic accidents during an evacuation are associated with a higher probability of other evacuation issues and lower relative evacuation efficiency.

Type of re-entry process (n = 49; 1 missing data point)

The type of re-entry process is significantly associated with the evacuation efficiency score, $p = 0.0003$. The relationship between hazard type and the type of re-entry is not significant, $p = 0.202$. After adjusting for hazard type, there is still a significant association between the type of re-entry and the evacuation score, $p = 0.0004$. When the re-entry process is controlled, there is an increased likelihood of evacuation issues. However, this association does not imply a causal relationship.

The number of deaths from the hazard (n = 50; no missing data points)

The number of deaths from the hazard is significantly associated with the evacuation efficiency score, $p = 0.0007$. In only six evacuations were there deaths from the hazard. The more deaths there were from the hazard, the greater the probability of having other evacuation issues. After adjusting for the effect of hazard type, this association is still significant, p = 0.0021.

The number of injuries caused by the evacuation (n = 47; 3 missing data points)

The number of injuries caused by the evacuation is significantly associated with the evacuation score, $p = 0.0009$. Only two cases had injuries caused by the evacuation. A wildfire in Mims, Florida in 1998 had one injury and a railroad accident in Superior, Wisconsin in 1992 had 35 injuries associated with the evacuation. Given the small number of cases with injuries, it was not possible to test for a relationship between hazard type and the number of injuries. After adjusting for the effect of hazard type, this association was still significant, $p = 0.0013$.

Whether the National Guard was used for law enforcement (n = 50: no missing data points)

Use of the National Guard is significantly associated with the evacuation efficiency score, $p = 0.0032$. After adjusting for hazard type, there is a marginally significant association between this variable and the score, $p = 0.0752$. However, there is a significant relationship between using the National Guard for law enforcement and hazard type, $p = 0.0096$. Given the small sample size within each hazard type, and the fact that the association between the variables depends on hazard type, it is hard to make any concrete conclusions that using the National Guard for law enforcement is related to evacuation efficiency.

The four cases that involved the National Guard alone were large evacuations, ranging from 2,500 to 20,000 evacuees, and averaging 10,375 evacuees. In the five cases in which both the police and the National Guard jointly handled law enforcement, the evacuations were even larger, ranging from 15,000 to 650,000 evacuees and averaging 210,000 evacuees. This is important to note because the regression analysis revealed a strong association between use of the National Guard and evacuation issues. However, the National Guard did not necessarily contribute to the evacuation issues; it is more likely that they were used when evacuations were larger and potentially more complex.

Whether there were instances of looting or vandalism (n = 50; no missing data points)

Looting or vandalism is significantly associated with the evacuation efficiency score, $p = 0.0043$. There is not a significant relationship between this variable and hazard type, $p = 0.170$. After adjusting for hazard type, this variable is still significant. $p = 0.0225$. There were five cases with instances of looting or vandalism. Of those five cases, one had one issue, two had two issues and two had three or more issues associated with the evacuation.

Whether people spontaneously evacuated before being told to do so (n = 43; 7 missing data points)

Spontaneous early evacuation is significantly associated with the evacuation efficiency score, $p = 0.0048$. There is not a significant relationship between this variable and hazard type, $p = 0.836$. After adjusting for hazard type, this variable has a significant association with the evacuation efficiency score, $p = 0.0330$. When people spontaneously evacuate before being told to do so, there is an increased probability of encountering other issues during the evacuation. The relationship of this variable to hazard type is shown in Table 4-2.

There is an association between hazard type and early evacuation, $p = 0.00221$ using Fisher's exact test. There is an increased probability of early evacuations occurring during natural disasters relative to malevolent acts and technological hazards, which is probably due to the significant advanced warning that evacuees are given for natural disasters. Table 4-2 shows that spontaneous early evacuation occurred in almost 85.7% of natural disaster evacuations, but in only 37% of technological hazard evacuations.

Whether the fire chief participated in the authorization for re-entry (n = 49; 1 missing data point)

This variable is significantly associated with the evacuation efficiency score, $p = 0.0097$. However, after adjusting for hazard type, the association is no longer significant, $p = 0.277$.

Whether anyone refused to evacuate (n = 47; 3 missing data points)

Refusal to evacuate is significantly associated with the evacuation efficiency score, $p = 0.0126$. There is not a significant relationship between this variable and hazard type, $p = 0.276$. After adjusting for hazard type, the association between this variable and the evacuation efficiency score is still significant, $p = 0.0388$. There is an increased probability of having other evacuation issues during the evacuation when individuals refuse to evacuate.

Whether the community had any experience with the hazard (n = 49; 1 missing data point)

Community experience with the hazard is significantly associated with the evacuation score, $p = 0.0168$. There is a significant relationship between this variable and hazard type, $p = 0.0310$. All 14 natural disaster evacuations were in communities that had prior experience with the hazard. Therefore, for natural disasters, it is not possible to assess the effects of community experience on evacuation success. Two out of three communities that had evacuations due to malevolent acts had prior experience with the hazard. One of these evacuations had no evacuation issues and the other had one evacuation issue. The community with no prior experience had three evacuation issues. In the technological hazard evacuations, there was not a significant difference in evacuation success between the communities that had prior experience and those that did not; $p = 0.776$. After adjusting for hazard type, there was not a significant association between this variable and evacuation success, $p = 0.219$.

Whether schools were used as congregate care centers (n = 39: 11 missing data points)

Schools were the most common form of community congregate care center. Use of schools is significantly associated with the evacuation efficiency score, $p = 0.0187$. There is a marginally significant relationship between this variable and hazard type, $p = 0.0702$. After adjusting for hazard type, this variable is still significant, $p = 0.0\ 174$. When schools are used, there is an increased probability of other issues impacting the evacuation. However, this is likely an "effect" and not a "cause".

Table 4-2. Frequency of Spontaneous Early Evacuations by Hazard Type

Hazard Type	Number of Spontaneous Early Evacuations	Percentage of Cases*
Natural Disaster	12	85.7
Malevolent Act	0	0
Technological Hazard	10	37
Overall	22	51.2

*Percentage is based on total number of responses (i.e., missing data points were omitted)

Number of deaths caused by the evacuation (n = 49; 1 missing data point)

The evacuations in this analysis saved lives that may have otherwise been lost. There was only one case with deaths caused by the evacuation. Nineteen people died in the process of evacuating during the East Bay Hills Fire near Berkeley, California. This incident had four evacuation issues associated with it and it was among the least efficient evacuations. However, even the East Bay Hills fire evacuation ultimately saved lives.

Whether public buildings were used as congregate care centers (n = 39; 11 missing data points)

This variable is significantly associated with the evacuation efficiency score, $p = 0.0220$. There is not a significant relationship between this variable and hazard type, $p = 0.607$. After adjusting for hazard type, there is a marginally significant association between whether public buildings are used as care centers and the evacuation efficiency score, $p = 0.0532$. When public buildings are used, there is an increased probability of other issues associated with the evacuation. However, this does not imply a causal relationship.

Who managed the congregate care centers (n = 39; 11 missing data points)

The American Red Cross managed the care centers in 60% of the cases. There is a significant association between who manages the centers and the evacuation efficiency score, $p = 0.0253$. After adjusting for hazard type, there is only a marginally significant association between who manages the centers and evacuation efficiency score, $p = 0.0839$. When the Red Cross managed the centers, there was an increased probability of evacuation issues. However, this does not imply a causal relationship. It could just be that the Red Cross is used in the larger, more complex evacuations, which are more likely to encounter issues.

Whether the mayor participated in the authorization for re-entry (n = 49; 1 missing data point)

This variable is significantly associated with the evacuation efficiency score, $p = 0.0289$. There is not a significant relationship between this variable and hazard type, $p = 0.186$. After adjusting for hazard type, this variable is still significantly associated with the evacuation efficiency score, $p = 0.0181$. There are six evacuations in which the mayor participated in the authorization for re-entry. When the mayor participated in the authorization for re-entry, there was an increased probability of issues with the evacuation. However, this does not imply a causal relationship.

Whether the public was notified by NOAA (n = 49; 1 missing data point)

In only one instance was the public notified by the NOAA to evacuate. This was a large-scale hurricane evacuation that had three evacuation issues associated with it. Although notification by NOAA was shown to have a statistically significant association to lower relative evacuation efficiency, the statistically small sample size makes it inappropriate to draw any conclusions.

The elapsed time between start of hazard and decision to evacuate (n = 41; 9 missing data points)

Prior to adjusting for hazard type, there is a significant association between the elapsed time between the start of a hazard and the decision to evacuate, and the evacuation efficiency score, $p = 0.0452$. However, after adjusting for hazard type, there is no association, $p = 0.405$.

Whether any major roadways were unavailable for use (n = 47; 3 missing data points)

There is a significant association between this variable and the evacuation efficiency score, $p = 0.0463$. Furthermore, there is a significant relationship between hazard type and whether roadways are unavailable for use, $p = 0.0380$. For natural disasters, there is an increased probability of other issues associated with the evacuation if major roadways were unavailable for use. After adjusting for hazard type, there is no longer an association to the evacuation efficiency score, $p = 0.135$.

Whether an Emergency Operations Center (EOC) was used (n = 49; 1 missing data point)

Before adjusting for hazard type, use of an EOC is marginally associated to the evacuation efficiency score, $p = 0.0549$. However, after adjusting for hazard type, the association is no longer significant, $p = 0.394$. For the natural disaster evacuations and the malevolent acts, an EOC was always used. For the technological hazard evacuations, an EOC was used approximately 53% of the time.

Time to complete the evacuation (n = 37; 13 missing data points)

Time to complete the evacuation is marginally associated with the evacuation score, $p = 0.0596$. However, this association is no longer significant after adjusting for hazard type, $p = 0.802$. As shown in Table 4-3, evacuations due to natural disasters take longer to complete on average.

Whether the public was notified door-to- door (n = 49; 1 missing data point)

This variable has a marginally significant association with the evacuation efficiency score, $p = 0.0756$. After adjusting for hazard type, there is an even greater association, $p = 0.0559$. When the public is notified door-to-door, there are fewer associated evacuation issues, and thus, a higher probability of evacuation efficiency. Due to the structure of the data, a test for a relationship between hazard type and door-to-door notification could not be performed.

Whether special institutions were evacuated (n = 44; 6 missing data points)

This variable has a marginally significant association with the evacuation efficiency score, $p = 0.0787$. However, after adjusting for hazard type, this variable is no longer significant, $p = 0.1078$. Due to the structure of the data, a test for a relationship between this variable and hazard type could not be performed.

The population density during the evacuation (n = 46; 4 missing data points)

This variable has a marginally significant association with evacuation efficiency score, $p = 0.0787$. However, after adjusting for hazard type, this variable is not significantly associated, $p = 0.237$.

Whether the community's emergency response agencies regularly conduct emergency drills and exercises (n = 49; 1 missing data point)

This variable has a marginally significant association with the evacuation efficiency score, $p = 0.0796$. Furthermore, there is a marginally significant relationship between this variable and hazard type, $p = 0.0947$. After adjusting for hazard type, there is no longer a significant association between this variable and the evacuation efficiency score, $p = 0.139$.

Table 4-3. Time to Complete the Evacuation (Hours) by Hazard Type

Type	Number of Events*	Mean	Median	Minimum	Maximum
Natural Disaster	14	9.73	8.00	0.600	22.0
Malevolent Act	3	0.705	0.705	0.660	0.750
Technological Hazard	33	2.09	1.50	0.330	8.00

*The time to complete the evacuation was known for all 50 cases

The size of the evacuated area (n = 42; 8 missing data points)

This variable has a marginally significant association with the evacuation efficiency score, $p = 0.0889$. After adjusting for hazard type, this variable is not significantly associated with evacuation efficiency, $p = 0.977$. In general, the larger the evacuated area, the more issues encountered during the evacuation. Natural disasters generally have the largest evacuation areas (see Table 4-4), and thus, a greater number of issues associated with the evacuation.

Whether the area is more prone to hazards than average (n = 50; no missing data points)

This variable has a marginally significantly association with the evacuation efficiency score, $p = 0.0916$. Furthermore, there is a significant relationship between this variable and hazard type, $p = 0.0237$. After adjusting for hazard type, there is no longer an association with the evacuation efficiency score, $p = 0.284$.

The level of community awareness regarding the alerting methods used (n = 49; 1 missing data point)

Familiarity with alerting methods has a marginally significant association with the evacuation efficiency score, $p = 0.0954$. After adjusting for hazard type, there is an even more significant association between the level of community awareness of the alerting methods and the evacuation efficiency score, $p = 0.0013$. Sixty percent of the evacuations with a low level of community awareness had 2 or more issues associated with the evacuation. About eighteen percent of the evacuations with medium or high levels of awareness had two or more issues associated with the evacuation.

Table 4-4. Evacuation Area (km^2) by Hazard Type

Type	Number of Events*	Mean	Median	Minimum	Maximum
Natural Disaster	14	708	156	4.5	2600
Malevolent Act	3	7.97	2.6	1.3	20
Technological Hazard	33	10.5	7.8	1.3	72.8

*The evacuation area was known for all 50 cases.

4.4 Correlation Analysis

Correlation coefficients (r) and associations were computed for variables that could be correlated to variables used to define the evacuation efficiency score. Tables 4-5 through 4-9 provide correlation coefficients and p-values.

The p-values were calculated using Fisher's exact test. This is equivalent to testing the hypothesis that the correlation coefficient is zero using an exact test. If the p-value is small, the hypothesis that there is no association (correlation is zero) is rejected in favor of the hypothesis that there is a significant association (non-zero correlation). Cross tabulations for the variables discussed in this section are provided in Appendix L.

Instances of looting or vandalism are positively correlated with law enforcement issues, $r = 0.477, p = 0.0235$. There is a marginally significant, positive correlation between the National Guard being used for law enforcement and law enforcement issues, $r = 0.320, p = 0.0800$. This could be because when there are significant law enforcement issues, the National Guard is more likely to be called out (see Table 4-5).

Table 4-5. Correlations and Associations with Law Enforcement Issues

Variable Name	Variable Description	n	r	P-value
loot_vand	Were there any instances of looting or vandalism?	50	0.477	0.0235
nat_guard	Was the National Guard used for law enforcement?	50	0.32	0.078
police	Was the Police used for law enforcement?	50	0.0745	1

n = sample size
r = correlation coefficient
p = p-value for test that r =0 calculated using Fisher's exact test

Table 4-6. Correlations and Associations with Warning and Subsequent Citizen Action Issues

Variable Name	Variable Description	n	r	P-value
adhoc	Ad hoc command, control and coordination processes	50	0.013	1
door_door_pn	Was the public notified door-to-door?	49	0.069	0.731
ebs_pn	Was the public notified by emergency broadcast system?	49	-0.08	1
multiple_pn	Was the public notified by multiple methods?	49	-0.06	0.721
noaa_pn	Was the public notified by NOAA?	49	0.253	0.245
pa_system_pn	Was the public notified by a PA system?	49	-0.154	0.331
radio_television_pn	Was the public notified by radio/TV?	49	-0.178	0.321
sirens_pn	Was the public notified by a siren?	49	-0.1	0.665
telephone_pn	Was the public notified by telephone?	49	0.117	0.454

n = sample size
r = correlation coefficient
p = chi-squared value using Fisher's exact test

Table 4-7. Correlations and Associations with Traffic Issues

Variable Name	Variable Description	n	r	P-value
Adhoc	Ad hoc command, control and coordination processes	50	0.0668	0.718
evac_instruct	Were people given specific instructions about where to go when they evacuated?	46	-0.437	0.00890
evac_route	Were people told to use specific routes?	46	-0.284	0.0818
road_haz	Were any major roadways unavailable for use?	47	0.352	0.037
shad_evac	Did people evacuate from areas outside the designated evacuation area?	42	0.149	0.501
traff_accid	Traffic accidents during the evacuations?	44	0.339	0.0555

n = sample size
r = correlation coefficient
p = chi-squared value using Fisher's exact test

Table 4-8. Correlations and Associations with Emergency Communication Issues

Variable Name	Variable Description	n	r	P-value
Adhoc	Ad hoc command, control and coordination processes	49	0.165	0.285
cell_phone	Was communication between field emergency responders and EOC by cell phone?	49	-0.04	1
Multiple	Was communication between field emergency responders and EOC by multiple ways?	49	-0.066	0.754
Pager	Was communication between field emergency responders and EOC by pager?	49	-0.091	1
Radio	Was communication between field emergency responders and EOC by radio?	49	-0.027	1
Telephone	Was communication between field emergency responders and EOC by telephone?	49	0.129	0.392

n = sample size
r = correlation coefficient
p = chi-squared value using Fisher's exact test

Table 4-9. Correlations and Associations with the Decision-Making Process

Variable Name	Variable Description	n	r	P-value
Adhoc	Ad hoc command, control and coordination processes	50	-0.0634	1
bdry_crss	Were political boundaries crossed (i.e., more than one county or state involved)?	45	-0.0159	1

n = sample size
r = correlation coefficient
p = chi-squared value using Fisher's exact test

None of the variables tested were significantly correlated with issues related to warning and subsequent citizen action (see Table 4-6).

People being given specific instructions about where to go when they evacuated is negatively correlated with traffic issues, $r = -0.438, p = 0.0089$. In other words, when people are given specific instructions about where to go when they evacuate, there are fewer traffic-related issues. There is a marginally significant and negative correlation between people being told to use specific routes and traffic-related issues, $r = -0.284, p = 0.0818$.

There is a significant and positive correlation between major roadways being unavailable for use and traffic-related issues, $r = 0.353, p = 0.0370$. There is a marginally significant and positive correlation between traffic accidents occurring during the evacuations and traffic-related issues, $r = 0.339, p = 0.0555$ (see also Table 4-7).

None of the variables tested are significantly correlated with either communication issues (see Table 4-8) or issues related to the decision-making process (see Table 4-9).

4.5 Discussion of Results of Statistical Analyses

This section discusses the results of the regression and correlation analyses only and does not discuss opinions expressed by emergency response personnel during the interview process. It should be noted that several other variables were identified as affecting the efficiency of evacuations but were not identified as statistically significant in the regression analysis. These other variables are discussed in Section 4.2.

After adjusting for hazard type and eliminating those variables that are "results" rather than "causes" of evacuation efficiency, two variables had a statistically significant association with a more efficient evacuation:

- Community familiarity with alerting methods and
- Door-to-door notification.

The following variables had a statistically significant association with a less efficient evacuation:

- Traffic accidents,
- Number of deaths from the hazard,
- Number of injuries caused by the evacuation,
- People spontaneously evacuating before being told to do so,
- People refusing to evacuate, and
- Looting or vandalism.

Evacuation efficiency was measured by an "evacuation efficiency score" that was based on the following variables:

- Decision-making issue,
- Emergency communications issues,
- Notification of response personnel and local officials issues,
- Citizen action issues,
- Traffic movement and control issues,
- Law enforcement issues, and
- Re-entry issues.

The correlation analysis revealed that two variables, identified as affecting the efficiency of evacuations, were also correlated to variables used to define the efficiency score. These two variables were:

- Traffic accidents and
- Looting or vandalism.

The correlation analysis showed that "traffic accidents" is positively correlated with "traffic movement and control issues." There is also a positive correlation between looting or vandalism" and "law enforcement issues. None of the variables tested are significantly correlated with "citizen action issues," communication issues," or "decision-making issues". While "traffic accidents", roadways unavailable for use", and "looting or vandalism" probably do have an impact on the efficiency of an evacuation, it should be noted that these variables are not totally independent of the evacuation efficiency score.

The regression analysis also showed no statistical association between the type of command, control, and coordination process (i.e., ad hoc or preplanned) and evacuation efficiency.

5.0 CONCLUSIONS

Large-scale evacuations of greater than 1,000 people occur approximately once every two weeks in the United States. A total of 230 evacuation incidents were identified that fit the profile criteria. Fifty incidents were selected for detailed case study analysis using a questionnaire containing over 80 questions. Case study selection was based on a ranking scheme designed to identify incidents of sufficient complexity to challenge the local and regional emergency response capabilities. Each of the 50 cases received an "evacuation efficiency score" based on whether issues were encountered in the following seven areas:

- Decision-making,
- Emergency communications,
- Notification of response personnel and local officials,
- Citizen action,
- Traffic movement and control,
- Law enforcement, and
- Re-entry.

These evacuations proceeded efficiently and effectively in terms of evacuee health and safety, security, and issues related to coordination, decision-making, and emergency response. Only two cases (or 4% of those studied) had enough issues to negatively impact the efficiency of the evacuation, having encountered four and five issues, respectively. Nearly a third of the 50 evacuations were highly effective, having encountered no issues during the evacuation and nearly three-quarters were very effective, having encountered one or no issues. Eight cases encountered two issues and three cases encountered three issues.

The two lowest ranked evacuations on the evacuation efficiency scale were the East Bay Hills Fire near Berkeley, California (4 issues) and the Mims Fire (5 issues), a wildfire in Mims, Florida. These two cases involved complications, such as poor visibility, due to the nature of the hazard causing the evacuation (i.e., the wildfire). The Mims evacuation involved injuries, but only the East Bay Fire involved deaths due to the evacuation. In this particular instance, special circumstances, including steep hills and narrow roads combined with poor visibility due to the wildfire, were directly responsible for the deaths that occurred during the evacuation.

The most common issues encountered during evacuations included:

- Emergency communications (impacting 28% of cases),
- Traffic (impacting 28% of cases), and
- Citizen action (impacting 24% cases).

The regression analysis identified two variables that were statistically significant for a more effective evacuation:

- Community familiarity with alerting methods, and
- Door-to-door notification.

The regression analysis identified that the following variables were statistically significant for a less effective evacuation:

- Traffic accidents,
- Number of deaths from the hazard,
- Number of injuries caused by the evacuation,
- People spontaneously evacuating before being told to do so,
- People refusing to evacuate, and
- Looting or vandalism.

In addition to the regression analysis, responses collected during the interview process revealed that:

- Multiple methods of emergency communications contribute to evacuation efficiency,
- High coordination among agencies and community cooperation contribute to evacuation efficiency,
- Shadow evacuations generally have no significant impact on congregate care center capacity or traffic movement and control, and
- Evacuation of pets/livestock and special institutions requires preplanning.

Furthermore, the evacuation research also identified that many communities are engaged in activities to improve their emergency response capabilities including:

- Upgrading emergency response capabilities and modernizing communication systems,
- Developing transportation analyses and assessments to improve traffic flow,
- Improving local education awareness, and
- Developing interagency and cross-boundary coordination plans.

An overwhelming factor cited in contributing to the efficiency and effectiveness of an evacuation was a high level of coordination and cooperation among agencies and an effective command structure (e.g., the command structure was well understood, agencies worked well together, and emergency responders were empowered to make decisions).

Public awareness of the hazard, of evacuation procedures, and especially of alerting methods was often cited as contributing to the efficiency and effectiveness of an evacuation. In addition, community familiarity with alerting methods was statistically associated with evacuation efficiency. Cooperation from evacuees was repeatedly cited as contributing to safe, efficient, and effective evacuations.

The evacuation research also identified that many communities are actively engaged in activities to improve their emergency response capabilities, including modernizing communication systems, developing transportation analyses and assessments to improve traffic flow, improving local education awareness, and developing interagency and cross-boundary coordination plans.

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10. SUPPLEMENTARY NOTES

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11. ABSTRACT *(200 words or less)*

This study examines the efficiency and effectiveness of public evacuations of 1,000 or more people, in response to natural disasters, technological hazards, and malevolent acts, occurring in the United States between January 1, 1990 and June 30, 2003. A universe of 230 evacuation incidents was identified and a subset of 50 incidents was selected for case study analysis. Case study selection was based on a profiling and ranking scheme designed to identify evacuation incidents of sufficient complexity to challenge the local and regional emergency response capabilities. Case study analysis included completion of a detailed survey for each incident. Advanced statistical methods, including Fisher's exact test, multiple ordinal logistic regression analysis, and correlation analysis, were used to identify factors contributing to evacuation efficiency. The analysis identified that community familiarity with alerting methods and door-to-door notification were statistically significant for a more efficient evacuation. The following factors were statistically significant for a less efficient evacuation: traffic accidents, number of deaths from the hazard, number of injuries caused by the evacuation, people spontaneously evacuating before being told to do so, people refusing to evacuate, and looting or vandalism. All 50 evacuation cases studied safely evacuated people from the area, saved lives, and reduced the potential number of injuries from the hazard.

Volume I contains the Main Report. Volume II contains appendices supporting case studies.

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