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Likelihood of organizations in the Los Angeles area implementing an earthquake early warning system

Author
Riopelle, Deborah

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Likelihood of organizations in the Los Angeles area implementing

an earthquake early warning system

A dissertation submitted in partial satisfaction of the

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in Community Health Sciences

by

Deborah Denise Riopelle

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ABSTRACT OF THE DISSERTATION

Likelihood of organizations in the Los Angeles area implementing

an earthquake early warning system

by

Deborah Denise Riopelle

Doctor of Public Health in Community Health Sciences

University of California, Los Angeles, 2020

Professor Deborah Glik, Chair

ABSTRACT

The probability that a strong earthquake will strike Southern California in the near future is high. Although the San Andreas Fault is the fault probably most familiar to people living in in the area, in reality four faults (San Andreas, San Jacinto, Elsinore, and Imperial) produce about half of the significant earthquakes in the region. Additionally, countless other known and unknown faults contribute to earthquake risk in the area. For decades, scientists and disaster experts have been working on developing an earthquake early warning system for Southern California that would provide approximately 10-90 seconds of warning that strong shaking is heading to the area, giving individuals and organizations the opportunity to take protective action before the shaking arrives. This dissertation study explores the potential uses of earthquake early warning by organizations and assesses the potential for implementation of an early warning system by organizations in the four sectors studied.

This study used a mix method approach. For the quantitative component of the study we conducted telephone interviews with 192 representatives of organizations in four institutional sectors which included education, emergency services, health care, and utilities and transportation. The qualitative component consisted of semi-structured interviews with three key informants from each of the same sectors. Findings from each component were then compared and combined to triangulate results as well as provide a fuller picture of potential uses, barriers to, and supportive factors for implementation of earthquake early warning by organizations in Southern California.

In general, support for implementing the earthquake early warning system by the organizations in the study was mixed. The best predictors of organizations being highly likely to implement earthquake early warning included low perceived financial barriers to implementation, high perceived risk from earthquakes, and belief that even 10 seconds of warning could reduce injuries in a major earthquake. Many key informants expressed interested in the system, but also enumerated many perceived barriers to its implementation at their organization.

Earthquake early warning has come a long way since the data were collected for this study, particularly in terms of communications technology and our ability to disseminate alerts to many individuals very quickly. However, many of the barriers identified in this study have not been addressed. Additionally, the new technology, messages, and mechanisms for warning individuals have not been evaluated. More research is needed if earthquake early warning is to be useful and feasible for use by organizations and businesses in Southern California.

The dissertation of Deborah Denise Riopelle is approved.

Nadereh Pourat

Michael Prelip

Kimberley Shoaf

Michele Wood

Deborah Glik, Committee Chair

University of California, Los Angeles

2020

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Curriculum Vitae

Deborah D. Riopelle

EDUCATION

University of California, Los Angeles	MS	Public Health	1993
University of California, Irvine	BA	Social Ecology	1981

CURRENT POSITION

September 2014 – present
Center for the Study of Healthcare Innovation, Implementation & Policy (CSHIIP)
VA Health Service Research & Development (HSR&D)
VA Greater Los Angeles Healthcare System

- Data Security Lead
- IRB & Research Compliance Administrator
- Administrative Lead for Center's VA National Clinician Scholars Program and Advanced Fellowship in Health Services Research

October 2010 – September 2014
Veterans Emergency Management Evaluation Center (VEMEC)
Research Management Analyst

- Strategic planning and program development
- Administrative management
- Research project management
- Investigator/Project Lead: *Assessing the Nature and Scope of Emergency Management Collaborations between VA Medical Centers (VAMCs) and non-VA Organizations*

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CHAPTER 1: INTRODUCTION

1.1 Southern California is Earthquake Country

Almost everyone living in California has heard about "the big one" – the massive earthquake that will occur along the San Andreas Fault wreaking havoc and causing major destruction throughout California, especially in densely populated and developed urban areas like Los Angeles County. A popular earthquake myth for decades predicted that most of California would break off and fall into the Pacific Ocean when "the big one" struck. I grew up in Southern California and my mother always believed "the big one" was imminent and that living on the coast as we did, we were destined to sink into the sea when it occurred. She frequently admonished me and my siblings to always be prepared to act quickly; when the earth begins to move, rush to the nearest doorway and stand there until the shaking stops. As a young child, I was never sure how standing in a doorway would help if we were going to sink into the ocean. However, every time the ground shook, I made a beeline for the nearest doorway and held on. Once, when an early morning earthquake suddenly woke me from a sound sleep, I managed to fly over the railing and out of the top bunk, not bothering to use the ladder, so intent I was on getting to the "safety" of the bedroom doorway. A little warning would have been nice.

Over the years, I have learned about earthquakes and two major earthquake myths I grew up with have been debunked. First, I no longer run to the nearest doorway when the earth starts moving. Experience has shown that doorways are not the safest place to be during an earthquake, unless you happen to be in an old adobe house that is likely to crumble when the earth begins to move (Jones & Benthien, 2011). "Drop, cover, and hold on" are now the watchwords for personal safety in earthquakes. Second, I do not need an inflatable boat or life jacket in my emergency preparedness supply kit. Scientists tell us that California will not fall into the ocean – regardless of how strong “the big one” is when it strikes. When “the big one” occurs along the San Andreas fault, the state will move horizontally, more north and southward (Jones & Benthien, 2011). However, one concept remains true: “the big one” still looms large in the foreseeable future.

There is good reason California is known as earthquake country. Although the San Andreas Fault is the fault probably most familiar to people living in Southern California, in reality four faults (San Andreas, San Jacinto, Elsinore, and Imperial) produce about half of the significant earthquakes in the region. Additionally, countless other known and unknown faults contribute to earthquake risk in the area. The magnitude 6.7 Northridge earthquake of 1994 occurred on a previously unknown fault in the San Fernando Valley of Southern California and resulted in 57 deaths, more than 5,000 injuries, and property damage estimated at more than 20 billion dollars. Looking forward, earth scientists tell us we can expect more of the same. According to the Uniform California Earthquake Rupture Forecast, Version 3 (Field, et al., 2015), there is a greater than 99% probability of 6.7 magnitude or greater earthquake occurring in California within the next 30 years. The probability for such a quake happening in Southern California is 97%, and for the Los Angeles region, it is 67% (USGS, n.d.-h).

Significant earthquakes, like other natural and man-made hazards, impact the communities in which they occur in a variety of ways. Major events can result in countless injuries and deaths, as well as considerable damage to the physical environment, including buildings, transportation systems, and other critical infrastructure such as water, gas, and power lines. A large primary earthquake event will inevitably trigger secondary hazards leading to additional health and environmental impacts and further devastation. For example, fires resulting from the 1906 San Francisco earthquake are believed to have caused more damage to the area than the earthquake itself (United States Geological Survey (USGS), n.d.-b). Additionally, major events severely strain and cause breakdowns in a community's infrastructure, often devastating support services during a time when they are needed most.

Preparing for and mitigating impacts of the "big one" and the multitude of smaller, yet significant, earthquakes that will likely come before is an ongoing process. Efforts to educate and motivate residents of California to prepare for disasters generally and earthquakes specifically are myriad. Personal preparedness advice and educational materials are abundant. Ongoing preparation activities and response trainings are undertaken by public and private organizations as well as households and individuals. One of the largest events is the Great California ShakeOut, for which 4,671,757 participants from the Southern California Coastal Region registered in 2019 (Southern California Earthquake Center, 2020). California has numerous laws and programs designed to mitigate the impact of earthquakes through insurance plans and requirements for retrofitting of public and residential structures. For example, in 1994 California enacted SB 1953 requiring all hospitals in California to meet new earthquake seismic retrofit requirements (Office of Statewide Health Planning and Development, n.d.). And then there are alert systems.

Various types of warning systems are used around the world to alert people of impending natural events - hurricanes, floods, fires, tsunamis, and earthquakes - as well as human-generated events such as accidental and intentional releases of chemicals or toxins, explosions, and industrial accidents. Warning systems vary greatly in their design and execution, depending in large part on the type of event involved, the amount of warning time possible before the event occurs, and the technology available for detecting and assessing events as well as disseminating crucial information to the potentially impacted population. Developing and implementing effective warning systems involves consideration of not only the type of event, but also the potential targets for and uses of the warnings as well as the social, psychological, physical, and technological environments in which the warning system will operate. Developing effective warning systems for earthquakes has been especially challenging due to the unpredictability and sudden impact of earthquakes, which more so than other types of disasters, leaves little or no time to disseminate or respond to warnings.

As far back as 1868, after a 6.8 earthquake on the Hayward Fault in Northern California, Californians have flirted with the idea of an early warning system for earthquakes (USGS, 2019). Over the past several decades, an earthquake early warning system has been under development in California. As technology has evolved, both for the detection of seismic movement and the dissemination of information, earthquake early warning has become a reality, at least in a fashion. The system in place today has many more seismic sensors than the earlier versions and uses much more sophisticated communication technologies, including mobile telephone applications to disseminate warnings (Lin, 2020). This study was a part of the development of the early system and sheds light on how the system can move forward as it continues to be developed.

1.2 Purpose and Significance of the Research

The purpose of this dissertation study was to explore factors associated with the perceived likelihood of organizations implementing a new warning technology purported to reduce the impacts and improve response to a low probability, high impact earthquake occurring in Southern California. Even though this is a state-wide system, this study focused specifically on the Los Angeles area due to the potential devastating impacts from a large earthquake owing to its dense, heterogeneous population and its economic and cultural significance. The design, measures, and data collection instruments for this needs assessment study were based on a proposed warning system and a scenario involving a hypothetical earthquake starting near the southern border of California and moving northward towards Los Angeles along the San Andreas fault. Focusing specifically on organizations in Los Angeles County that provide vital services to the general public (e.g., schools, police, fire departments, hospitals and other healthcare facilities, utility companies, transportation agencies, and departments of public works) and using an earthquake warning technology that was under development as a prototype, this study examined the potential for adoption of an innovative technology to assist with disaster preparedness and response. In other words, this study sought to identify potential early adopters of an earthquake warning system.

Much of what the literature says about warning systems and responses to warnings is based on situations different than those associated with earthquake early warning systems. In an extensive review of the warning literature, the Disaster Research Center at the University of Delaware found a wide variation in the design and application of warning systems. According to Tierney (2000), warning and alert systems for both natural and human-generated hazards vary greatly in many ways including technology, reliability, length of the warning time, human mediation, channels used to issue warnings, settings, goals and objectives, In conclusion, the author advised considerable caution in generalizing from one system to another, and particularly to an earthquake early warning system (Tierney, 2000). However, Tierney goes on to say:

> "The literature on warning systems of all types stress the importance of developing integrated systems that address not only the warning technologies but also the organizational and socio-behavioral aspects of the warning process. Put simply, no matter how sophisticated and reliable, warning technologies will not function effectively unless close attention is paid to involving users in the

> development of warning systems, to tailoring those systems to their needs, and to understanding the social factors that affect warning system performance and human warning response behavior." (Tierney, 2000, p. 76).

The crucial premise of needing to integrate users' needs and understanding the social factors affecting response behaviors for effective warnings has been reinforced over the years, most recently in the ever-increasing rate of California's devastating wildfires and in the current COVID-19 pandemic.

Earthquake early warning systems currently used around the world are tailored to local environments, needs, and social behavioral factors. For example, Mexico City's public earthquake early warning system Seismic Alert System (SAS), operating since 1991, provides emergency messages to government officials, operators of vital services, and the general population as much as 30-72 seconds before damaging ground motion reaches Mexico City. Japan started development of a wide-ranging earthquake early warning system in 1998 that was first implemented for several lines of the Shinkansen, the Japanese high-speed or "bullet" train. It is only in more recent years that the Japanese system has been expanded to include public warnings to the general population. Both systems are described in more detail in Chapter 2.

In California, a network of seismic monitors has been developed and expanded over decades. The monitors continually detect and record ground motion and transmit data to a processing facility located on the Pasadena campus of the California Institute of Technology (Caltech). While the data were primarily used in basic science research, as early as 1989, California Department of Conservation, Divisions of Mines and Geology (CDMG) and other organizations were interested in using the system for earthquake early warning. As the number of seismic monitors grew and information technology improved, uses for the data expanded. Now, the data are used not only in basic research, but also to help guide earthquake-related emergency response activities and to disseminate early earthquake warnings. The history and status of the California system is described more extensively in Chapter 2.

Even though the number of seismic monitors in the California monitoring system has grown tremendously and the technology for collecting and disseminating information has improved dramatically, the earthquake early warning system in Southern California is still in its nascent stages. It is felt by some that if we develop a fully functional earthquake warning system in Southern California, targeted at the public as well as businesses and industries, it would go a long way in reducing injuries, deaths, and damages when “the big one” occurs. It could also reduce the impacts of other smaller yet significant earthquakes. However, we are still uncertain as to the actual utility of the system for individuals and organizations. Despite years in development and a lot of money spent, extremely little research has been conducted on how to best use the system to maximize the benefits for both individuals and organizations. This dissertation study explores some of these issues by examining how potential target organizations might use real-time earthquake warnings and by identifying organizations most likely to be early adopters of such a system.

1.3 Research Approach

As stated before, little social research has been done on earthquake early warning systems. Understanding how organizations and individuals would respond to a real-time earthquake warning and what factors would support or hinder their response is key to having an effective system. This needs assessment study was conducted early in the development of the California warning system to identify how organizations would use the system, specific issues that might arise related to its use, and how this information could be incorporated into the design of the system to encourage and support its adoption. Originally, the warning system was targeted to organizations in health-related, emergency management, education, and public infrastructure sectors of the community. At that time, the technology for rapid and wide-spread dissemination of warnings to individuals was still to be developed. Targeting organizations involved consideration of not only human behavior, but also of community and organizational priorities and policies, availability of and proficiency with technology, organizational perception of risk and risk management strategies, and ultimately, the utility and benefits of investing in the system. The initial implementation of the warning system within an organization could be potentially burdensome in terms of resources such as time, money, technology, and training. Adoption of the warning system by an organization would be voluntary; thus, addressing these issues upfront was especially important to "selling" the system for wide-spread adoption and use.

The approach used in this needs assessment study was to gather information from stakeholders in specific types of organizations about the potential use of earthquake early warnings by their organization and in other organizations with similar missions. Since this was a new technology and there was little prior social research on its use, I employed a pragmatic mixed methods approach. Initial domains of meaning were comprised factors that have been shown to make a difference in preparedness activities, which were used in both the quantitative and qualitative study components. For the qualitative study, I also considered new domains that were generated during interviews, following a grounded theory approach (Strauss & Corbin, 1990). The quantitative component of the research, a telephone survey, was designed to identify factors that might influence adoption of a warning system and to answer other questions developed with input and knowledge from experts in the field. The qualitative component employed semi-structured interviews with key informants. While there were a number of predetermined domains of interest, the data were also analyzed so that new and emergent domains would be identified.

The results from both components were then combined to create a fuller picture of how organizations view earthquake early warning with an eye to helping guide implementation of the system as well as future research. For the purposes of the study, organizations from four community sectors were identified – healthcare, emergency management, education, and public infrastructure – and stakeholders from each were interviewed. The specific aims of the study were to describe how selected organizations in Southern California might implement and use a new technology such as an earthquake real-time warning system, and to identify what types of organizations would be most likely to implement an earthquake warning system such as the one proposed at the time.

More specifically, we conducted this study to find out how potential uses of an earthquake warning system vary by institutional sector and if organizational purpose, structure and experience in previous earthquakes was associated with the perceived likelihood of an organization implementing an earthquake warning system. We also wanted to know how selected organizations in Southern California would use a new technology such as an earthquake early warning system and if these uses would be targeted at safety of individuals or at maintaining organization functionality and business continuity. We also wanted to examine if organizational purpose or functions were associated with the perceived likelihood of an organization implementing a new technology that might reduce the impacts and improve the response of a low probability, high impact disaster.

1.4 Chapter Organization

Chapter 2 begins by providing background on earthquake risk and impacts to contextualize the potential benefits of earthquake early warning. Other types of warning systems are also discussed briefly to show how earthquake warning is in many ways quite different than warning systems used for many other types of natural and human-generated events such as hurricanes and industrial accidents. However, earthquake warning is similar to a few types of events such as flash floods and tsunamis, which is also discussed. The current state of earthquake early warning, including a description of systems that have been implemented in other parts of the world, primarily Mexico and Japan, and the history and status of early warning in California is described.

Although the approach used for this study was inductive in nature, asking what types of organizations might use an earthquake early warning system and how two conceptual constructs were used to help guide the analysis and understand the findings and their significance. Thus, Chapter 2 also provides general descriptions of these concepts. First, adoption and diffusion of innovations is discussed with a focus on organizations. This conceptual framework provides insight into by whom and why a technological innovation, such as earthquake early warning, is or is not adopted. Part of the decision to adopt may involve perception of risk, which is also discussed in this chapter.

Research methods are described in Chapter 3. This research employed a mixed methods approach that included a telephone survey for quantitative data analysis and key informant interviews for qualitative data analysis. First, phone interviews were conducted with a purposive sample of representatives from organizations in four institutional sectors of interest: 1) education, 2) emergency services, 3) health care, and 4) utilities and transportation.

Subsequently, qualitative data were collected in key informant interviews with representatives from three organizations in each of the four institutional sectors. Key informant interview questions were designed to clarify and expand on information obtained in the larger cross-sectional survey. Chapter 3 describes in detail the data collection methods and analytic approaches for both the quantitative and qualitative components as well as how the results were triangulated to validate findings and to add detail or provide explanation.

Analyses and results for data collected in the telephone survey, including the beginning development of a predictive model for the perceived likelihood of earthquake early warning system implementation are described in Chapter 4. In Chapter 5, qualitative analysis results of the key informant interviews are described and results from the two analyses, quantitative and qualitative, are compared. Triangulation of results included examining how the qualitative results supported or did not support the quantitative findings as well as using qualitative results for elucidating and expanding on concepts and results from the telephone survey.

Finally, Chapter 6 summarizes and discusses key findings of the study, considering how the results are or are not consistent with other research findings and with the conceptual ideas presented in Chapter 2. The current state of earthquake warning in Southern California, improvements in communication technology, and other issues such as risk communications and new technologies are discussed with an eye to what the study findings have to say moving forward regarding earthquake warning in the present environment. Although much has changed in the intervening years since the study was conducted, little social science research has been conducted in the field as the system has been developed. Further evaluations and applied research focusing on selection of warning targets, warning messaging, structuring of specific aspects of the system, and/or identifying appropriate and realistic intervention outcomes could help ensure success of an early warning system in earthquake-prone California. There is still much to learn and do, and findings from this study can help to guide us as the earthquake early warning system is further developed and implemented.

CHAPTER 2: LITERATURE REVIEW

2.1 Earthquakes: Risk and Impacts

Earthquakes of sufficient magnitude occurring in populated areas can cause injuries, deaths, property damage, and major disruptions in physical and social environments. National Earthquake Information Center identifies approximately 20,000 earthquakes each year around the world. Based on historical records, about 15 magnitude 7 or greater earthquakes happen each year (USGS, n.d.-i). From 2000 to 2019, an average of 1,760 magnitude 5.0 or larger earthquakes occurred annually throughout the world (USGS, n.d-g). The largest recorded earthquake in the world, the Valdivia Earthquake, occurred in Southern Chile in 1960. The magnitude 9.5 earthquake killed approximately 5,700 people, injured around 3,000, left some 2 million homeless and caused property damage in amounting to roughly $550 million (USGS, n.d.-f). The earthquake triggered a tsunami that caused fatalities and property destruction as far away as Hawaii, Japan, and the West Coast of the United States (USGS, n.d.-f). Another one of the world's largest recorded earthquakes, the magnitude 9.1 Sumatra - Andaman Islands Earthquake struck Southeast Asia and East Africa in 2004. The earthquake and subsequent tsunami killed more than 283,100 people, displaced over one million, and 14,100 were listed as missing (USGS, n.d.-d). In 2011, Japan also experienced a magnitude 9.1 earthquake, the Great Tohoku Earthquake. According to USGS, "At least 15,703 people killed, 4,647 missing, 5,314 injured, 130,927 displaced and at least 332,395 buildings, 2,126 roads, 56 bridges and 26 railways destroyed or damaged by the earthquake and tsunami" (USGS, n.d.-e).

The second largest recorded earthquake in the world and the largest in the United States was a magnitude 9.2 quake that occurred in the Prince William Sound south of the coast of Alaska on Good Friday in March of 1964 and lasted 4-5 minutes (USGS, n.d.-c). The resulting tsunami from this earthquake killed numerous villagers in the coastal village of Chenega, 23 people in the town of Valdez (one-third of its population) and caused deaths and damage as far away as Oregon and California (Brocher, 2014). The earthquake and tsunamis together caused 129 deaths and over $2 billion in property losses in 2013 dollars (Brocher, 2014). Since this earthquake, Alaska has experienced over 144 earthquakes above a magnitude 6.0, most recently the magnitude 7.0 earthquake that hit Anchorage on November 30, 2018. The 2018 Anchorage earthquake caused landslides, liquefaction (loss of soil strength and stiffness due to saturation), major damage to roadways, breaks in water and gas lines, power outages, and extensive personal property and infrastructure damage, both minor and major. Many schools, businesses, and organizations closed for time (USGS, n.d.-a; Falsey, et al., 2018). There were no fatalities, but according to a report from the Alaska Department of Health and Social Services reported on in the Anchorage Daily news, an estimated 160 people showed up in local emergency rooms to be seen for earthquake-related injuries. Most were suffering with minor medical issues such as cuts, bruises, and muscle injuries from falls and impacts from falling objects. Other reasons cited for ER visits included mental health issues such as anxiety, interruption of usual care for pre-existing conditions, and other non-life-threatening physical ailments (Magee, 2018).

Alaska is one of the most seismically active regions in the world and the U.S. state that is the most "earthquake-prone." However, earthquakes occur throughout the United States and have the potential to cause devastating damage and disruption. According to Noji in The Public Health Consequences of Disasters, "A major earthquake affecting a large city has the potential to be the most catastrophic natural disaster for the United States (Noji, 1997)." The impact of predicted higher-magnitude earthquakes in the United States could "potentially kill and injure thousands of people, result in billions of dollars in property loss, and cause severe disruptions to the economy (Noji, 1997).

Along with Alaska, California is also a very "earthquake-prone" area of the United States. In Southern California alone, its many faults generate about 10,000 earthquakes each year, most of them not felt by the human population. Only a few hundred of these quakes are greater than magnitude 3.0, and far fewer, about 15-20, are greater than magnitude 4.0 (USGS, n.d.-g). The San Andreas, San Jacinto, Elsinore, and Imperial faults generate about half of the significant earthquakes in the area, as well as many of the minor ones. (Jones & Benthien, 2011). The San Andreas fault, which runs from the Gulf of California northward through western California to near San Francisco is probably the most significant and well-known fault.

Historically, there have been 19 significant (magnitude 4.8-6.7) earthquakes in the Los Angeles area since the year of 1920. The most significant have been the Long Beach Earthquake in 1933 (magnitude 6.4), the San Fernando Earthquake in 1971 (magnitude 6.6), the Whittier Narrows earthquake in 1987 (magnitude 6.0), and the Northridge earthquake in 1994 (magnitude 6.4) (USGS, n.d.-g). Each of these earthquakes resulted in deaths, injuries, and considerable property damages. Impacts from these earthquakes are summarized in Table 2.1.

Table 2.1 Significant Los Angeles area earthquakes since 1920[1,2]			
DATE	**MAGNITUDE**	**LOCATION**	**LOSS OF LIFE & PROPERTY[3]**
1994, January 17	6.7[4]	Northridge	57 dead; more than 9,000 injured; about $40 billion in property damage
1987, October 1	6.0	Whittier Narrows	8 dead; $358 million in property damage to 10,500 homes and businesses
1971, February 9	6.6	San Fernando	65 dead; more than 2,000 injured; $505 million in losses
1933, March 11	6.4	Long Beach	115 dead; $40 million in property damage

[1]Excerpted from California Department of Conservation table "Significant California Earthquakes." (California Department of Conservation, n.d.)
[2] "Significant" defined as magnitude greater than or equal to 6.5, or that caused loss of life or more than $200,000 in damage.
[3]Damage estimates not adjusted for inflation
[4]Most other sources report the Northridge Earthquake as 6.4 magnitude

Looking forward, there is a 60% probability of an earthquake measuring greater than or equal to magnitude 6.7 occurring in the Los Angeles area within the next 30 years, 46% probability for a magnitude 7 or greater, and 31% probability of a 7.5 magnitude or greater earthquake USGS, n.d.-h).

Earthquake Impacts

When looking at impacts from earthquakes it is easy to see the stark contrast in the numbers of deaths, injuries, and displaced persons that occur in other parts of the world when compared to what has occurred in Southern California. The Sumatra - Andaman Islands Earthquake in East Asia resulted 283,100 deaths and the Great Tohoku Earthquake in Japan 15,703 deaths. The most deaths reported in Southern California was from the Long Beach Earthquake in 1933 at 115. This is due in large part to the tsunamis triggered by the earthquakes in Chile, Sumatra, Japan, and Alaska. The tsunamis increased the devastating human impacts exponentially. In Southern California, more common are non-fatal injuries, most due to falls and falling objects (Peek-Asa et al., 2003; Shoaf, et al., 1998). There are numerous factors that influence the impacts a given earthquake has on the community and local population which are discussed next.

In addition to deaths, injuries, and physical damage, large earthquakes also generate economic, social, and health costs. The degree and range of impacts an earthquake has are determined by a myriad of factors, some immutable and other subject to modification or elimination. For purposes of the discussion here, factors influencing what impacts a given earthquake will have are broadly categorized into four areas: characteristics of the earthquake itself, characteristics of the natural and built environments, social and behavioral factors, and secondary hazards. Both the impacts and the factors influencing impacts are important to consider when determining how an earthquake early warning system might be used and what benefits may be realized through its implementation.

Characteristics of the earthquake itself, such as magnitude and when and where it occurs, are extremely significant determinants of impacts. Simply put, larger earthquakes generally generate more adverse impacts. However, even with large earthquakes there are mitigating conditions that can affect the extent of an earthquake's impact. For example, damages in terms of economic cost tend to increase with magnitude, but this is affected by location (rural vs. urban areas), amount of disaster assistance available for an event, differences in defining and/or documentation of costs, differences in preparedness and/or vulnerability in affected areas (Shinozuka, et al., 1998). As will be discussed later, earthquake early warning systems operate on the principle that the earthquake originates far enough away from the warning target area and that will be of a sufficient magnitude to warrant taking protective actions.

Densely populated and urban, the Los Angeles area has the potential to suffer extreme damage and disruption from any major earthquake. According to the 2010 US Census, the population of Los Angeles County was estimated at 9,830,420 growing to 10,039,107 by 2019 with approximately 2,419 persons per square mile (United States Census Bureau, n.d.). The total number of housing units was estimated at over 3.5 million in 2019 with a rate of 45.8% of owner-occupied housing from 2014-2018. The 2020 Greater Los Angles Homeless Count conducted by the Los Angeles Homeless Services Authority estimate that there were 66,436 homeless people living in Los Angeles County with 41,290 living in the city of Los Angeles (LA Homeless Services Authority, 2020).

Another major area of concern when calculating the potential impact of a large earthquake on a community is the built environment. In Mexico City, one of the most densely populated cities in the world, a magnitude 8.1 earthquake in 1985 resulted in between 9,500 and 35,000 fatalities, 30,000 injuries and the collapse of 412 multistory buildings (Berkeley Seismology Lab, 2008). Another large earthquake, magnitude 7.1, struck the area September 2017 causing an elementary school to collapse killing 37 people and the destruction of a church where 15 people were killed. In contrast, California has one of the most comprehensive building codes for earthquake resistance (Northridge Earthquake Report) put in place to ensure that buildings meet the "minimum requirement intended to protect life safety and prevent collapse" (California Seismic Safety Commission, State of California, 1995). The California Building Code (CBC) allows for damage, which means buildings may not be habitable or functional after a moderate or large earthquake but are not likely to collapse. Requirements for essential buildings, such as hospitals and fire stations, are more stringent than for other buildings (e.g., houses, apartment buildings, offices, retail businesses, and schools). Following each major earthquake in California, changes have been made in the CBC to improve the performance of buildings in earthquakes. However, new codes usually only apply to new buildings and even retrofitted buildings may not be fully compliant to the current code (Peer-Pacific Earthquake Engineering Research Center, 2018).

Research on human behavior response to earthquakes is not extensive, but in general indicates that most people respond rationally and take protective actions, although in different ways and influenced by a variety of factors (Goltz, 2020). In Goltz's study of behavioral response in 12 earthquakes that occurred between 2005 and 2018 in different parts of the world, he looked at three primary responses: doing nothing, taking protective action (e.g., drop, cover, and hold), or running outside. Not surprisingly, behavioral response was associated with the strength of the ground shaking. As shaking intensity increases, people are more likely to move to a perceived area of safety (Goltz, 2020). Employing variations of "drop, cover and hold" and evacuation are the protective actions believed likely to be effective. However, no one action is appropriate in all locations. Evacuation is only advisable from buildings that are likely to collapse and when a safe place can be reached quickly. Thus, in an urban environment such as the Los Angeles area with strong building codes, in most cases the best protective response to strong shaking or the warning of imminent strong shaking would be to move away from hazardous situations and to "drop, cover, and hold." However, in Mexico where buildings tend to collapse, evacuation is probably a more protective response.

Earthquakes can also trigger secondary hazards that may cause more damage or danger than the initial earthquake shaking. Earthquake ground movement can cause ground settlement and displacement, liquefaction, landslides and rock falls, tsunamis, floods, fires and falling debris. (Seismic Resilience, n.d.) While there is some risk that coastal areas in Los Angeles

County could be affected by a tsunami caused by an earthquake on a large offshore fault or by massive submarine landslides, almost all tsunamis affecting California thus far have been small and have done little or no damage (California Department of Conservation, n.d.), unlike earthquakes and subsequent tsunamis in other parts of the world as described earlier. Of more concern in relation to earthquake early warning are fires. As mentioned before, fires after 1906 San Francisco earthquake are believed to have caused more damage than the earthquake itself (USGS, n.d.-b). Many people involved in the early development of the earthquake early warning believed that one of the significant benefits of earthquake early warning would be the opportunity to, before ground shaking begins, shut down industrial processes and equipment that could cause fires. One example was shutting down the power grid so that swinging power lines would not connect with each other and spark major blazes.

Understanding how a major earthquake can impact an area and the factors that influence these impacts is essential to determining how earthquake early warning might be used and what benefits might be gained. Additionally, it is important to understand how earthquake warning systems work. In the next section we compare earthquake early warning to other warning systems, describe two earthquake warning systems used in other parts of the world, and discuss more specifically earthquake early warning for California.

2.2 Earthquake Early Warning Systems

Much of what is in the literature about warning systems and responses to warnings is based on situations different than those associated with earthquake early warning systems. As mentioned earlier, Tierney found a wide variation in the design and application of warning systems and advised considerable caution in generalizing from one system to another, and particularly to an earthquake early warning system (Tierney, 2000). As summarized by Tierney (Tierney, 2000), warning systems differ in technologies involved, reliability, time needed to achieve accuracy in forecasts/predictions, reliance on human mediation, channels used to issue warnings, familiarity with and routinization of procedures, system settings, and system goals and objectives. Warnings differ in part based on the type of hazard involved (e.g., chemical spills, hurricanes, flash floods, tsunamis, and earthquakes) and some warnings are considered "all hazard" like the Emergency Broadcast System. Warning times can vary from seconds and minutes to hours or days depending on the hazard and the time needed to recognize and accurately assess the danger. For example, hurricane warnings can be issued days before, tsunami warnings minutes to hours, and earthquake warnings seconds. Warnings or alerts may be non-audible (e.g., strobe lights), audible/nonverbal (e.g., sirens), automated human voice, or in text. Some systems, both automated and non-automated, may trigger the shutdown of processes or equipment. Earthquake warnings differ from most other natural hazards in that events are "sudden onset" with current detection and dissemination technology only allowing for a warning period of several seconds to a minute and a half.

With the increased use of smartphones and other social media platforms, there are many more channels now through which to issue alerts, both official and non-official. Wireless emergency alert systems have been developed with the capability of geo-targeting notifications and some research has been conducted on public response to these types of alerts, including earthquake alerts. For example, Wireless Emergency Alerts (WEAs), developed and operated through a partnership of the Federal Emergency Management Administration (FEMA), the Federal Communications Commission (FCC), and wireless providers, are short emergency text messages (SMS) issued by authorized public authorities. Messages are broadcast from cell towers to any WEA-enabled mobile device in a locally targeted area. (FEMA website) Several types of messages can be issued, but the most applicable to earthquake early warning are alerts issued about natural or human-made disasters, and other current or emerging hazardous events. These alerts moreover are automatically enabled on newer smartphones, hence technically anyone with a smart phone can get them unless they choose to disable the application. WEA alerts should be differentiated from Shake Alert, which is a dedicated application that a person voluntary chooses to download on a mobile device.

Recent research on warnings and alerts has given us new insights into factors affecting responses, especially in this new age of wireless and geotargeted alerts. The Study of Terrorism and Responses to Terrorism (START) research team found that two important pieces of information, guidance on what to do and information on time until impact, were the message elements most likely to influence and prompt appropriate protective action. In a report to the Department of Homeland Security, WEA Messages: Impact on Physiological, Emotional, Cognitive and Behavioral Responses, Glik and her research team found that several study participants' primary concern and what most affected their response to an alert was how physically close the threat was to them (Glik, 2016). Another study by Kim et al. (2019) looked at influences on taking protective action upon receiving WEA messages and found that only one in five people took immediate protective action. The study also showed that individual characteristics (e.g., language spoken at home, prior exposure, and desensitization to emergency alert messages), the messages themselves, and other situational factors all influenced what protection actions were taken (Kim, et al., 2019). These factors and their significance in earthquake early warning will be discussed in more detail in Chapter 6.

Earthquake Early Warning Systems around the World & Locally

Earthquake early warning systems are currently being developed or in use in several countries around the world, including Taiwan and Australia (Gibson, et al., 1996; Wu, et al., 1999), and more extensively in Japan and Mexico. To illustrate the diverse purposes of warning systems, systems found in Japan, Mexico, and California are described below.

Earthquake early warning in Japan

The Japan Meteorological Agency (JMA) was developing a system they called the "Nowcast" Earthquake Information system as far back as 1998. Currently, the Japan Ministry of Transportation is the Urgent Earthquake Detection and Alarm System (UrEDAS). UrEDAS provides rapid "real-time" information on location, depth, and magnitude of earthquakes for several lines of the Shinkansen (the Japanese high-speed or "bullet" train), including the line that runs through the Seikan Under-Sea Tunnel between Honshu and Hokkaio (Nakamura, 2007). The railway in this tunnel is 787 feet below the ocean's surface and is the deepest railway line in the world. When strong ground motion is detected, the Ministry of Transportation uses UrEDAS generated information to assess the safety and stability of running trains (Nakamura, 2007). Earthquake early warning also provides rapid and precise estimations of damage to gas pipelines. This "real-time" information is then used in deciding whether gas supplies should be shut down to prevent secondary disasters or may be continued so that service failures are minimized (Tokyo Gas, n.d.). The JMA early warning system has also been used to warn workers at the construction site of a high-rise building in Yokohama of approaching strong shaking. Warnings allow workers to take appropriate safety measures such as stopping elevators at the nearest floor and setting tower cranes in a safe position (Kanda et al., 2006).

In October 2007, the Japan Meteorological Agency launched the Earthquake Early Warning service which uses media channels such as television and radio to issue warnings to the public (Hoshiba, et al., 2008). Japan now also has an app for smartphones and tablets called Yurukeru Call that provides users with earthquake early warnings via push notifications in both Japanese and English (RC Solutions Co., n.d.). According to the company's website, the app allows users to see real-time information on a custom-made map. A few seconds to several tens of seconds before the ground movement occurs at the user's location, information on estimated seismic intensity, estimated arrival time, epicenter, magnitude of the earthquake, and estimated maximum seismic intensity is provided. Based on the magnitude of the earthquake, a message is displayed such as "Please protect yourself until the shaking subsides" and a countdown to the expected arrival time is given.

Earthquake Early Warning in Mexico City, Mexico

Mexico City has had a public earthquake early warning system in place and operating since 1991. As described by Espinosa-Aranda et al., The Seismic Alert System (SAS) provided emergency messages to government officials, operators of vital services, and the general population as much as 30-72 seconds before damaging ground motion reaches Mexico City from a large earthquake occurring in the Guerrero Gap (the Pacific Ocean off the west coast of Mexico, between the ports of Acapulco and Zihuatanejo) (Espinsoa-Aranda, et al., 1996). A Radio Warning System disseminates audio warnings through commercial AM/FM radio stations and other audio mechanisms to residents of Mexico City, public schools, emergency service agencies, utilities and transportation agencies and some industries. Each agency has a specially designed radio receiver that receives the earthquake alert (Espinosa-Aranda et al, 1996). The government also developed and disseminated a brochure about SAS to increase general awareness and to provide instructions on how to respond to the alert. Response recommendations include turning off utilities, opening emergency doors, helping people who require assistance (e.g., children, the infirmed, etc.), and either taking cover inside or evacuating the building (Espinosa-Aranda, et al. 1996).

Mexico now has a larger seismic detection system and can provide alerts to other cities across Mexico. The expanded system is called the Mexican Seismic Alert System (SASMEX) and disseminates very simple alert messages indicating that an earthquake has been detected and is likely to be felt. It does not provide any information on time when shaking will occur or how intense the shaking will be. Specially adapted weather radios provide alerts to schools and critical facilities and 12,000 pole-mounted speakers sound sirens and verbal notices. SASMEX also posts alerts to a dedicated Twitter account (Allen, 2018). Many people would like to receive warning via their cell phones but due to technological challenges, as of 2018, SASMEX was unable to generate push notifications to smartphones or other internet connected devices (Allen, 2018).

As far back as 1989, organizations involved in the development of seismic monitoring systems for California have attempted, albeit on a limited basis, to involve potential users in the process of developing these monitoring systems for use also as earthquake early warning systems. As part of an earthquake warning feasibility study completed in 1989 by the California Department of Conservation, Divisions of Mines and Geology (CDMG), two surveys were conducted to collect information from potential earthquake warning system users about their current perceived earthquake risk, organization-specific information on potential uses of an earthquake early warning system, and the extent to which the respondent thought earthquake early warning could be applied to facility operations (Holden, et al., 1989). Overall, conclusions from the results of the 1988 CDMG surveys suggest that while there was some interest in earthquake warning, many potential uses would require longer warning times (60-120 seconds) than were being put forward. Many of the potential uses that were reported related to personnel safety. Another finding indicated there was significant concern among the responding organizations about false alarms and potential users “appear to be reluctant to pay for” an earthquake early warning system.

When this dissertation research was conducted, the proposed warning system would use data collected by seismic monitors throughout the area set up to detect and record ground motion and transmitted to a processing facility located on the Caltech campus in Pasadena, California. Warning would then be pushed out to internet-connected computers at organizations participating in the program. To receive warnings, the organization would need to have internet-connected computers and in most cases monitored by a human being unless the computer system was integrated with other automated systems within the organization. The dissertation study was conducted to ascertain more about how this might be implemented within an organization including possible messages and methods of dissemination once the warning arrived at the local site.

Since this research was conducted, the seismic monitoring system in California has been augmented and is now much denser leading to more accurate monitoring of ground movement. While the basic process of transmitting seismic data to CalTech to be analyzed and then pushed out to the community is similar, the devices used to receive the information and the targets are vastly different. Current technologies and messaging will be discussed in detail in the last chapter as well as their implications for moving forward with earthquake early warning in California, but a brief update is described next.

While the original focus of the system was to warn organizations and the individuals within those organizations, current technologies allow almost anyone with a smart mobile device to download one of several earthquake warning apps, thus shifting the focus to individuals. Several apps are available such as MyShake, QuakeAlertUSA and for Los Angeles County residents, ShakeAlertLA, which was developed by UC Berkeley, Early Warning Labs, and the city of Los Angeles respectively (Lin, 2020). ShakeAlertLA for Los Angeles area residents provides users with notifications when a 4.5 or greater earthquake happens that will affect Los Angeles County. Like the Japanese app, ShakeAlertLA's alert is both audible and in text format with a message saying, "Earthquake! Earthquake! Expect strong shaking. Drop, cover, and hold on. Protect yourself now!" In addition to providing a notification, the app includes an earthquake alert map and other information about preparing for and recovering after an earthquake.

It should be noted here that the ShakeAlertLA threshold for sending alerts was originally set at M5.0, the magnitude of shaking where objects begin to fall off shelves and shaking may be considered hazardous. However, after the magnitude 7.1 2019 Ridgecrest Earthquake, the threshold was lowered to magnitude 4.5 because people in the Los Angeles area complained that they did not receive an alert and expressed doubt in the reliability of the system (Lin, 2019; McDonnell, 2019). The epicenter of the Ridgecrest Earthquake was 125 miles from Los Angeles and although shaking was felt in the Los Angeles area, there was no damage reported there. It should be noted here as well that even with the lower threshold, people in Los Angeles would still not have gotten notification for this earthquake since the shaking in Los Angeles still did not meet the lower threshold needed to trigger an alert.

Even though the focus seems to have shifted to individuals, some organizations are also using the system. Two cities in California have implemented limited earthquake early alert systems early on. In 2001, the town of Calistoga in Napa Valley, tested its fire siren for use as part of its earthquake early warning system. The system was set up to notify firefighters that a seismic event had occurred and to automatically open the fire station doors. It was also set up to sound a 30-second siren to alert residents in a five-mile radius of downtown (Podger, 2001). By 2011, the City of Palm Springs in the Coachella Valley had implemented a warning system that can be used to automatically open fire station doors and shut off gas valves (Fox News, 2011). More recently, other institutions in the Los Angeles area have also implemented earthquake early warning alerts. These include the Los Angeles County Metropolitan Transportation Authority (MTA), which has a system designed to slow trains, and Los Angeles City hall with a public address system; a condominium tower in Marina Del Rey also uses a public address system to disseminate warnings; and a system installed by Early Warning Labs at Cedars-Sinai Medical Center where an audible alert is programmed to go out when an alert is triggered (Lin, 2020).

2.3 Theoretical Concepts and Frameworks Guiding the Research

Three different theoretical concepts and frameworks were used to help guide the design of the study. These included adoption of innovation, perception of risk, and organizational disaster preparedness.

Adoption of Innovation

The focus of this study was to explore how a new technology such as earthquake early warning might be adopted by various organizations in Los Angeles County. To help frame the research approach, we used diffusion of innovations theory as a guide. Diffusion of innovations theory has been used to explain the spread of new ideas and practices in a wide variety of settings for over 60 years. Diffusion is a process by which an innovation is adopted, and it involves the concepts of channels of communication used over time to members within a social system (Rogers, 1962). An innovation is defined as an idea, practice or object perceived as new by an individual or the entity adopting it. Rates of adoption are influenced by five attributes of the innovation: 1) relative advantage, 2) compatibility, 3) complexity, 4) trialability, and 5) observability, as well as the type of innovative decision (collective, optional, authority), the communication channels used, nature of the social system, and promotion efforts (Rogers, 1962). Adopters are categorized in terms of time it takes to adopt an innovation. Categories include 1) innovators, 2) early adopters, 3) early majority, 4) late majority, and 5) laggards. One of the aims of the early earthquake warning promoters was to identify innovators and early adopters who would implement the warning system so that its functionality and value could be demonstrated to others who were skeptical about or resistant to its use.

Although early adoption of innovation theory focused almost exclusively on the individual as the adopter, criticisms of this approach eventually led to the study of organizations as adopters. The following section discusses some of what the literature and research show regarding the relationship between organizational adopter characteristics and likelihood or rate of innovation adoption.

Drawing on Rogers' theory of diffusion of innovation (Rogers, 1962), Brown's perspective on diffusion and adoption of innovation (Brown, 1981), and research findings in both management and industrial marketing literature, Frambach proposed an integrated model of adoption of technological innovations in organizations (Frambach, 1993). Identifying the organization as the adopter, Frambach looks at how the categories of 1) adopter characteristics, 2) information characteristics, 3) innovation characteristics, and 4) competitive environmental characteristics predict who will be an early adopter. Based on a review of the relevant literature, he draws the following conclusion about adopter characteristics. Probability of early adoption increases with 1) the size of the organization 2) the level of complexity or degree of specialization of the organization; and 3) greater extent to which members participate in informal networks. Conversely, probability of early adoption decreases with 1) degree of formalization and 2) with the degree of centralization in the organization.

Additionally, Damanpour has researched and written extensively about organizations and innovation from structural and management perspectives. In his body of work, Damanpour has examined innovation and how it relates to organizational size (Damanpour, 1992), organizational performance (Damanpour, et al.,1989), organizational complexity (Damanpour, 1996), and organizational structure (Damanpour & Gopalakrishan, 1998), as well as studied patterns of innovation adoption within organizations (Gopalakrishanan & Damanpour, 1994).

Damanpour defined innovativeness as typically measured by the rate of the adoption of innovations within an organization. Based on his meta-analysis of the relationship between organizational innovativeness over a dozen potential determinants the organizational variables Damanpour found that were significantly related to innovativeness are summarized in Table 2.2 (Damanpour, 1991).

Table 2.2 Organizational variable significantly related to innovativeness	
Variable	**Definition**
Specialization	Typically measured by the number of different roles or job titles in the organization
Functional differentiation	The extent to which the organization is divided into different units
Professionalism	Reflects level of professional knowledge of the organizational members
Centralization	The extent to which the decision-making autonomy is dispersed or concentrated within an organization
Managerial attitude toward change	Extent to which managers or members of the dominant coalition are in favor of change
Technical knowledge and resources	Reflects organization's technical resources or potential and is measured by the presence of a technical group or technical personnel.
Administrative intensity	Administrative ration measured by the number of managers over the total number of employees in the organization
External communication	Degree to which the organization members are involved and participate in extra-organizational professional activities
Internal communications	Reflects the extent to which organizational units or members communicate and the extent to which units share decisions.

Determinants that were found not to be significant in Damanpour's meta-analysis of the relationship between organizational innovativeness and potential determinants included managerial tenure (length of service and experience of the manager) and vertical differentiation (the number of levels in an organization's hierarchy below the chief executive level). Damanpour also found that the type of organization (manufacturing vs service, for profit vs. not-for-profit) and the scope of the innovation (low vs. high) are more likely to moderate the relationship between the primary determinants and organizational innovativeness than the type of innovation (administrative vs. technical, product vs process, and radical vs. incremental) or the stage of the adoption (initiation vs. implementation) (Damanpour, 1991).

Perception of Risk

In addition to adoption of innovation, theories of perception of risk were also considered in designing the study and identifying potential factors influencing an organization's opinions about earthquake early warning and its potential utility for the organization and the people who work there. Perception of risk is a complex phenomenon with many facets. Here we concentrate perception of risk associated with hazardous events.

Theories of individuals' perception of risk assert that a person's reaction to a threatening event can arouse a diverse collection of emotional, cognitive, and behavioral responses (Bennett and Calman, 1999; Covello, 2003; Fischoff, 1995, 2005; Fischhoff, et al., 2003; Glik, 2007; Sandman, 1989) and higher risk perceptions can stimulate proactive behaviors. However, because there is an emotional aspect involved, a high perception of risk can also create resistance to risk communication and recommended actions. In general, assessment of risk increases when the hazard is manmade, causes a dreaded disease or condition, is involuntary, is localized in one geographic area, is the source of disagreement among experts, is difficult to detect with regard to exposure, or is out of a person's control (Fischoff, et al., 1981).

Organizations and Disaster Preparedness

Insofar as implementation of an earthquake early warning system can be regarded as a "disaster preparedness activity" and an innovation, a brief discussion of factors associated with organizational disaster preparedness is also relevant here. According to Mileti, "three factors have been consistently identified in the research as having positive influence on disaster preparedness among non-emergency organizations" (Mileti, 1999). The three factors and their relationship to organizational disaster preparedness include: 1) organizational size – larger organizations have a greater concern for disaster preparedness; 2) Perceived risk – the level of perceived risk of organizational manager is positively correlated to preparedness; and 3) information seeking about environmental hazards is positively correlated with organizational preparedness. Mileti goes on to say that among businesses in the private sector, the strongest predictors of preparedness level are size, previous disaster experience, and owning rather than leasing business property (Mileti, 1999).

2.4 Earthquake Early Warning: How does it Fit In?

Looking at the impacts earthquakes have, particularly given characteristics of the location or area in which they occur, can help determine what is important to consider when deciding on the target of earthquake warnings and how individuals and organizations should use and respond to warnings. Due to the population density and urban nature of the Los Angeles area, earthquake warning response should probably focus on personal safety and prevention of damage and injury from secondary hazards. Because building codes are relatively stringent and building collapse is less of a risk than in other places in the world, evacuation as an immediate response to an earthquake warning is generally not recommended and may in fact increase the rate of injuries due to incidents of falling and being hit by falling objects. Warning systems vary greatly on many aspects, all of which should be considered when determining the feasibility of implementing a warning system. One of the most unique and significant characteristics of earthquake warning is the very short amount of time between receiving the warning and the occurrence of the event, making the need to act almost instantaneous. And finally, to facilitate widespread and effective implementation of a new technology such as earthquake early warning, it is helpful to identify innovators and early adopters who will help with diffusion.

CHAPTER 3: STUDY DESIGN AND METHODOLOGY

This needs assessment study involves finding out the types of organizations that might be interested in implementing an earthquake early warning system, and what could be done with the system if implemented. As this system existed in a nascent form at the time of data collection and is still evolving, the study focuses on potential users of the proposed system, their perceptions of the system's feasibility and utility, and how it might be best designed and implemented.

Two different types of research questions correspond to the availability of two types of data sets which generated the mixed methods design used. The first set of questions is exploratory and descriptive and focuses on potential uses for earthquake early warning. The second set of questions is related to and informed by the results of the first set of questions, but also driven by theoretical concepts such as adoption of innovation, perception of risk, risk communication and by previous disaster research. Analysis related to the second set of questions examines the associations between organizational factors and likelihood of adoption of the technology. Both sets of questions can be addressed using the study's survey data and quantitative analysis techniques, but both also benefit from having qualitative key informant interview data as well from which to draw details and depth of understanding not found in the quantitative data.

However, before describing the research, this chapter begins with a description of the earthquake early warning system on which this dissertation is based: the TriNet Seismic Computerized Alert Network (SCAN). The research question sets, both qualitative and quantitative, are then reviewed and reasons for using a mixed methods design for this study is discussed. The chapter ends with descriptions of the specific research designs, data collection methods, measures, and data analysis strategies employed within each of the quantitative and qualitative components of the study and how the results from each component were triangulated.

3.1 The TriNet Seismic Computerized Alert Network (SCAN)

To help put the research questions and methods into context, the TriNet earthquake early warning system and how it was presented to study respondents is described in the following section.

What is TriNet SCAN?

TriNet was a limited five-year collaborative project of the California Institute of Technology (Caltech), the USGS, and the California Division of Mines and Geology (CDMG). From 1997 to 2001, these three groups worked together to expand, upgrade, and fully digitalize a network of seismic monitors placed throughout Southern California. The networked monitors continually detect and record ground motion and transmit data to a processing facility located on the Caltech campus in Pasadena, California. Data produced by this network were at the time of the TriNet project and continue to be used both in basic research and emergency response activities. However, as part of the TriNet project, the participating organizations also wanted to explore the possibility of using the system to provide real-time earthquake warnings. The TriNet group named the nascent earthquake warning system the Seismic Computerized Alert Network or SCAN.

Described on the original TriNet website (TriNet, 2001), the technological concept behind SCAN is relatively simple. As monitors in the TriNet seismic network detect major ground motion, notification is sent via digital data transmission technologies to a distant site, in this case the processing facility at Caltech, signaling that an earthquake has begun. Based on the premise that digital signals travel faster than the energy waves produced by an earthquake, a signal arrives at the distant site in advance of shaking or ground motion. This signal is the "warning" that ground shaking has begun and is headed in the direction of that location.

The amount and reliability of information that can be generated from a series of signals from seismic monitors depends on the density of the network of monitors that exist. The more monitors there are, the better the information. At the time of the study, the TriNet system had about 100 seismic stations. An "ideal" network, a network that would produce the optimal data for a warning system, would have at least 1,000 stations (ASB Consulting/EQE International, 2001).

How much warning time a specific site, defined as a geolocated person, organization or object, would need to receive a warning depends on numerous factors. The timing and intensity of ground shaking arriving at a site distant from the earthquake epicenter depends on the magnitude of the earthquake, the location of the receiving site in relation to the epicenter and fault, and local soil conditions (Jones & Benthien, 2011). Thus, the amount of warning time a site receiving warning would be subject to also depends on these factors. For a specific location to receive any warning, an earthquake would have to be of a fairly large magnitude with the epicenter a good distance away from the warning recipient. Longer potential warning times for the Los Angeles area, such as up to one minute, have been estimated for large earthquakes that start further away, for instance in the very Southern part of the state near the Salton Sea, California.

However, for earthquakes occurring on one of the numerous faults running through the Los Angeles county area such as the Whittier and Santa Monica faults and the Newport-Inglewood-Rose Canyon fault zone, warnings would not be possible as the timing between feeling the earthquake and sending and receiving a message is too short. This is because a significant factor in figuring out how much warning time a site would receive is information processing time. For signals to be used as earthquake warnings by people outside of the Caltech facility, the incoming data would have to be processed and sent electronically to other sites. The amount of time needed by the system to recognize an event, process the information, and issue a warning is estimated to be about 10-20 seconds (ABS Consulting/EQE International, 2001). Thus, the potential warning time would be the amount of time for the ground motion to travel from the epicenter to the site receiving the alert, minus the time needed for "processing" information through the Caltech laboratory. If the site receiving a warning performs additional information processing and/or disseminates the warning further, the time for these activities would also have to be subtracted from the potential warning time.

Given these parameters, the "early warning" that the TriNet SCAN system would be able to provide Los Angeles area users was limited to less than a minute and in some cases only a few seconds. Many have questioned the utility of such short warning times while others maintain that even a few seconds of warning could allow for actions that would reduce the potentially devastating human and material impacts of a large earthquake. Utilization of "early warning" would also be limited to very infrequent major earthquakes that start a long distance away from the warning recipient. Again, there are mixed opinions about whether this is a good argument for or against moving forward with development of the system. Those in favor say that, due to the potentially catastrophic impact a major earthquake would have on Los Angeles and surrounding areas, this is exactly the kind of system that needs to be in place. Others think that there are more pressing and immediate health and safety issues needing resources and attention than a system that will benefit a limited number of people in an event that may not occur anytime in the near future.

The TriNet Studies and Planning Activities in Real-Time Earthquake Early Warning project evolved out of the desire to explore these and other SCAN-related issues that could help guide further development and possibly implementation of an earthquake early warning system for California. As mentioned before, TriNet was a collaborative project of the California Institute of Technology (Caltech), the USGS, and the California Divisions of Mines and Geology (CDMG). This group contracted with EQE International, a risk management consulting firm to assess real-time earthquake warning policy and planning issues. The project involved four tasks: 1) identification of potential earthquake early warning users, 2) review of seismic alert communication issues, 3) identification of policy issues, and 4) planning of a pilot project. The overall project was funded by the Federal Emergency Management Agency (FEMA) and the state of California Office of Emergency Services (OES). The UCLA Center for Public Health and Disaster Relief (CPHDR) was sub-contracted to lead Task #1.

Task #1 of the TriNet project included questionnaire development, data collection, and data analyses of a telephone survey designed to identify potential users of an earthquake early warning system. The telephone survey data was used in the quantitative component in this dissertation study. As the project manager, I was integrally involved in the development of the questionnaire and the data collection activities for Task #1. I also managed and analyzed the survey data and was primary author of the Task #1 Report. This dissertation study includes additional analyses of these survey data, analyses of qualitative data collected in key informant interviews conducted by myself and others from UCLA CPHDR (not part of the original TriNet project) and the triangulation of data from both sources.

The hypothetical SCAN prototype used for this study

Other than the seismic monitoring part of the system that sends data to Caltech, none of the other system components described in the following paragraphs actually existed at the time of the study. The hypothetical SCAN prototype used to illustrate a potential earthquake early warning system to study participants would push earthquake data from the central processing facility at Caltech to computers at user sites via the Internet. This data would include epicenter location, origin time, current rupture length, current magnitude based on current rupture length, and the number of stations reporting ground motion. To receive the data, computers at user sites would have to be on and connected to the Internet. This means having a 24 hour a day, seven day a week Internet connection if the organization wanted to receive a warning any time an earthquake might occur. Alternatively, user organizations would also be able to program their part of the system so that only earthquakes at or above certain magnitudes would trigger a response at their site(s).

When the earthquake data arrived at the site, user-end software would take the information and calculate estimated local ground motion, probability of local shaking, arrival time of ground motion, and potential level of damage at the user's location based on the latitude and longitude of the location, local soil conditions, and facility characteristics (ABS Consulting/EQE International, 2001). Based on the user organization's needs, the data pushed from Caltech could then be used in a variety of ways. For example, warning information could appear as a written message on a computer screen, such as "There is a 50% probability of strong ground shaking in 40 seconds," or a warning might simply say, "EARTHQUAKE!" Warning data could also be programmed, based on thresholds determined by the user organization, to automatically disseminate warnings throughout the organization via the organization's computer network; issue audible or visual alerts such as bells or flashing lights; and/or automatically shut down or start up mechanical or computerized operations. User organizations would have software that would allow them to program individually selected thresholds and responses into the system at one or more of their locations.

3.2 Research Questions and Study Design

Research questions and hypotheses

The first set of research questions explores the realm of potential uses for earthquake early warning as perceived by organizations providing vital services to the general public and having special functions when community disasters or emergencies occur. These organizations include educational institutions, emergency service providers, health care agencies, and utility and transportation services found in a mostly urban, very populated area of Southern California. Specifically, the first set of research questions and related hypotheses are:

Research Question Set #1

Question 1A
How would selected organizations in Southern California use a new technology such as an earthquake early warning system?

H.1A Potential uses for earthquake early warning will fall into three primary domains – life safety, property protection, and operational continuity.

Question 1B
How do potential uses of an earthquake early warning system vary by institutional sector?

H.1B The saliency of each of these domains of earthquake early warning uses does not vary across organizational sectors.

In addition to exploring and providing a descriptive picture of how different types of organizations envision using earthquake early warning, this study was designed to help develop a model that would answer a second set of research questions and test related hypotheses. The questions here focus on what factors are associated with the perceived likelihood of an organization implementing a new technology such as earthquake early warning. Constructs in these questions are drawn from the conceptual framework and empirical findings in adoption of innovation theory, theory of perceived risk, and the literature on disaster preparedness and response and risk communication described in Chapter 2.

Specific research questions and hypotheses are:

Research Question Set #2

Question 2A

How is organizational purpose associated with the perceived likelihood of an organization implementing a new technology that might reduce the impacts and improve the response of a low probability, high impact disaster?

H.2A.1 Institutional type (sector) is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2A.2 Providing earthquake-related education activities for the public is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

Question 2B

What structural factors are associated with the perceived likelihood of an organization implementing a new technology that might reduce the impacts and improve the response of a low probability, high impact disaster?

H.2B.1 Organizational size is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2B.2 Number of organization sites is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2B.3 Ownership status of facility buildings is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

Question 2C

What historical factors are associated with the perceived likelihood of an organization implementing a new technology that might reduce the impacts and improve the response of a low probability, high impact disaster?

H.2C.1 Experiencing damage from previous earthquakes is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2C.2 Having persons at the organization sustain <u>injuries</u> in previous earthquakes is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2C.3 <u>Experiencing a disruption of services</u> due to previous earthquakes is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

<u>Question 2D</u>
What <u>cognitive</u> factors are associated with the perceived likelihood of an organization implementing a new technology that might reduce the impacts and improve the response of a low probability, high impact disaster?

H.2D.1 The <u>level of perceived risk from earthquakes</u> is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2D.1 <u>Belief that injuries would be reduced</u> with an early warning system is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2D.3 <u>Exposure to information</u> about earthquake early warning is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

<u>Question 2E</u>
What <u>practical</u> or <u>implementation-related</u> factors are associated with the perceived likelihood of an organization implementing a new technology that might reduce the impacts and improve the response of a low probability, high impact disaster?

H.2E.1 <u>Financial barriers</u> are not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2E.2 Having <u>technical resources</u> for implementing an earthquake early warning system is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2E.3 <u>Current use of an earthquake warning system</u> is not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

H.2E.4 <u>Anticipated uses</u> for earthquake early warning in an organization are not associated with perceived likelihood of implementation of an earthquake early warning system such as SCAN.

Of particular interest in examining questions in this second set of questions was to determine what factors or variables predict which organizations perceive themselves as <u>least</u>

likely, as well as which perceive themselves as most likely, to implement a warning system such as the one under consideration. As discussed in Chapter 2, understanding what organizations are least or most likely to adopt a new technology can be used to facilitate and/or inform policy regarding the diffusion of technology into various parts of the community. Null hypotheses following the research questions were generated based on similar constructs and relationships found in previous research on organizational adoption of innovation and disaster preparedness, as well as operational definitions of variables found in the data sets analyzed. The large number of hypotheses listed here is indicative of the exploratory nature of this needs assessment study.

Mixed methods study design

As stated before, due to the two sets of research questions, and the availability of two different types of data, a mixed methods approach was used for this study. In general, mixed methods designs involve:

> "…the incorporation of one or more methodological strategies, or techniques drawn from a second method, into a single research study, in order to access some part of the phenomena of interest that cannot be accessed by the use of the first method alone. The use of mixed method design makes the study more comprehensive or complete than if a single method was used. (Morse & Niehaus, 2009, p. 9)

In this case, the major or core method is quantitative, and the supplemental method is qualitative. More specifically, the design used in this study is based on the sequential explanatory design as described by Cresswell's *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (Cresswell, 2003).

A sequential explanatory design, one of Cresswell's six major designs for mixed methods research, is defined as:

> "…characterized by the collection and analysis of quantitative data followed by the collection and analysis of qualitative data. Priority is typically given to the quantitative data, and the two methods are integrated during the interpretation phase of the study." (Cresswell, 2003 pg. 223)

The primary reason to employ this type of design is to use the qualitative results to help explain and interpret the quantitative findings.

Quantitative data for this study were obtained in a cross-sectional survey of potential earthquake early warning system users in Los Angeles County between March and September 2000. In this survey, telephone interviews were conducted with a purposive sample of representatives from organizations in four institutional sectors of interest: 1) education, 2) emergency services, 3) health care, and 4) utilities and transportation. Additionally, qualitative data were collected in key informant interviews with representatives from three organizations in each of these four institutional sectors. Key informant interview questions were designed to clarify and expand on information obtained in the larger cross-sectional survey.

Analyses of data from both sources were conducted separately using analytical methods appropriate for the type of data, quantitative or qualitative, under examination. In general, quantitative analyses were conducted first and results from these analyses were used to help design the thematic framework used for the qualitative analyses. After analyses were complete, findings from each piece of the study were compared and integrated as appropriate. Thus, final study results and related discussions based on shared as well as unique findings from the two methodologies used are presented.

3.3 Mixed Methods Research Approaches

The use of mixed or multiple methods in research emerged from a theoretical split between the two dominant research paradigms in the social and behavioral sciences: the positivist or empirical paradigm and the constructivist or phenomenological paradigm. The positivist philosophy asserts that the only source of knowledge or "truth" is what can be observed in the physical world. On the other hand, in constructivism reality consists of objects and events only as they are perceived and understood, or in other words "constructed," in the minds of human beings. The positivist paradigm is generally associated with the use of quantitative methods in research and the constructivist, or phenomenological, tradition is linked with the use of qualitative methods (Tashakkori & Teddlie, 2010).

The positivist paradigm and quantitative methods are generally associated with words such as internal and external validity, reliability, and objectivity and research designs that show relationships or effects (i.e., are predictive) to add to the knowledge base or to measure change (Denzin & Lincoln,).Research conducted under this paradigm involves the rigorous testing of hypotheses by means of manipulating quantitative data (Atkinson & Hammersley, 1994) and is strongly linked with mathematics, statistics, and deductive reasoning.

The constructivist paradigm and qualitative research, on the other hand, is associated with asking why and how, understanding complex phenomenon, and generating and testing new ideas. It is associated with words such as relative, subjective, interpretive (Denzin & Lincoln, 2018). Often, these new ideas and theories are described as emerging from or being "grounded" in data that has been systematically gathered and analyzed (Strauss and Corbin, 1994), in an inductive rather than a deductive process.

At first, this split between the positivist and constructivist camps led to a theory of incompatibility; a view of the world in which these two paradigms cannot co-exist within the same research study due to their inherently different underlying philosophies. Eventually, however, pragmatism emerged as a viable alternative to the incompatibility thesis. While agreeing that philosophical beliefs have an important role in research, pragmatism maintains that established theory, resource availability, and political and social contexts also influence research decisions and practice. The pragmatic paradigm rejects the belief that research has to be "either/or" and promotes the use of mixed or multiple methods as a means to focus on "what works" for the research questions under investigation (Biesta, 2010).

Why use a mixed methods approach for this study?

There are many reasons for and advantages to employing mix methods in a research study. Often mixed methods studies can answer research questions single methods cannot. They may also generate better inferences and provide opportunities for presenting divergent views (Tashakkori & Teddlie, 2010). Mixed methods research also offers the opportunity for triangulation.

Triangulation is a term used to describe the technique in which two or more data sources, data collection methods, or data types are combined in one study to examine a single phenomenon. For example, triangulation provides an opportunity to confirm findings and to offset the weakness of one method or source by using these additional methods or sources (Jick, 1979). Triangulation is also important in that it can help researchers overcome bias (Denzin, 1970) and enhance the quality and credibility of research findings (Patton, 2002). Triangulation, while providing advantages, also presents us with the primary disadvantage of using mix of methods – the possibility of obtaining different and possibly inconsistent results.

For this study, a mixed methods approach was undertaken for several reasons. First, the purpose of the research was multifaceted. In one sense, the research was exploratory in that no one really knew how organizations in Southern California might use a system like SCAN. However, the research was also undertaken to help develop a predictive model regarding what types of organizations would be most likely to implement a technology like SCAN. While quantitative analytic methods are useful for developing predictive models, they are much less useful for answering questions of how and why. In this study of earthquake early warning systems, the how and why of implementation by organizations was a large unknown and potentially key to interpreting or making the most of findings from the quantitative analyses.

Additionally, the ready availability of both quantitative and qualitative data to help answer these research questions was also influential in the decision to use a mixed methods approach. While the quantitative data and analytical methods from the telephone survey make up the core foundation for the study, the qualitative data and analytical methods in the key informant interview component enhance this foundation by providing an opportunity to supplement, validate, and explain the quantitative findings. For example, the quantitative data provide us with a very general idea of how a warning system would be used by organizations in the sample, whether it would be used to warn workers and/or to shut down equipment. Data from the qualitative interviews provide many more details about who would receive the warning as well as why some individuals would receive it and why others would not. The qualitative data also describe what equipment might be shut down, the processes used to shut down equipment or operations, and why these actions would be important or helpful to the organization. In this example, the richness of information provided by the qualitative data not only adds details unavailable from the quantitative findings, but also helps explain why some types of organizations might choose or not choose to use earthquake warnings in a certain way.

In the following sections of this chapter, the quantitative and qualitative methods used in the study are described in detail. Additionally, the approach used to triangulate results from each method is articulated.

3.4 Quantitative Methods

For the quantitative portion of this study, data were collected in structured telephone interviews with a sample of purposively selected representatives from organizations in the four institutional sectors of interest mentioned above: 1) education, 2) emergency services, 3) health care, and 4) utilities and transportation. Over a period of seven months in the year 2000, interviews were conducted with 191 organizational representatives knowledgeable about their institution's emergency preparedness and response procedures and policies. In these interviews, respondents were asked about organizational earthquake experience, perceived risk from earthquakes, emergency preparedness and response resources, and perceptions of an earthquake early warning, including perceived likelihood of implementing an early warning system at the organization. The following section of Chapter 4 describes: 1) the creation of the sample, 2) development of the interview instrument and measures, 3) data collection activities, and 4) general data analysis strategies employed in the quantitative component of the study.

Sample development

Potential respondent organizations for the telephone survey were purposively selected from publicly available lists of organizations in Los Angeles County in the four institutional sectors of interest. By combining lists from a wide variety of sources, we created a comprehensive, albeit not exhaustive list of potentially eligible organizations in Los Angeles County. The appropriate contact person within each organization was identified, and this information was incorporated into a database from which the study sample was drawn. The final sample included 223 contacts, of which 191 completed telephone interviews. The sample development processes are described in more detail below.

Sources of respondent lists

To begin with, potential respondent information was collected from a variety of sources. Primary sources included public use lists such as the California Office of Emergency Services Mutual Aid Region Directory (emergency services), a list of Los Angeles County Department of Health Services health care sites by service planning area (health care), and listings of LAUSD schools (education). Also, internet searches were conducted for individual organization web pages, lists of specific types of organizations, and telephone directories. We also used personal contacts/referrals from experts in the field. These lists were compiled to maximize the potential of creating a sub-sample of organizations in each sector that varied by type and size and that were distributed geographically across Los Angeles County.

Sample selection

From the sample database, potential respondents were purposively selected to represent a range of organizational types and locations within the sector. Table 3.1 illustrates the general selection guidelines used in each sector to facilitate obtaining this range. Additionally, within categories of organizational types, there was an attempt to have both public and private entities represented, as applicable.

Sample selection continued throughout most of the data collection process to help insure a range of respondent types in the final sample. For example, as each wave of data collection was near completion, non-responders were analyzed by type and location so that they could be replaced with similar organizations in the following wave.

Table 3.1 Sample selection guidelines by institutional sector for telephone survey

Sector	**Geographic guidelines**	**Types of organizations**
Education	School districts by region	Pre-schools K-12 schools Colleges and universities Technical schools
Emergency Services	Los Angeles County Civil Defense Areas / OES Mutual Aid Regions	Local government (county & city) Law enforcement Fire services
Health Care	Los Angeles County Service Planning Areas	Umbrella organizations (e.g., HMOs, county departments) Hospitals Outpatient clinics Other inpatient care facilities (e.g., nursing homes, rehabilitation facilities)
Utilities & Transportation	Los Angeles County Civil Defense Areas / OES Mutual Aid Regions	Utility companies Transportation services Public works departments

Sample data management

As source lists were developed, student researchers called potential respondent organizations to verify that the appropriate contact had been identified (by title, name, and job responsibilities whenever possible) and that contact information (name, title, phone, fax, mailing address) was correct. In most cases, verification required numerous phone calls to the organization. The two main reasons for going through this laborious process was 1) to increase the likelihood that the appropriate person in the organization would be interviewed and 2) to decrease the number of calls interviewers would need to make by screening out wrong and nonworking numbers and obtaining direct lines and extensions whenever possible. After verification, contact information was entered into a MicroSoft Access database. Here contacts were sorted by sector, type of organization, and location to assist with sample selection. This database was also used to generate mailing labels for recruitment materials and call lists.

Questionnaire and measure development

Developing a questionnaire for the telephone interviews took approximately six months, entailed numerous pilot testing activities and revisions, and involved the collaborative efforts of faculty and staff from a variety of academic, scientific, and business organizations, led by the UCLA Center for Public Health and Disasters (CPHD). Following is a summary description of the questionnaire development activities and measures included in the final version of the questionnaire.

Pre-survey focus groups

Development of the telephone interview guide as well as the makeup of the sample for the survey were guided by findings from two focus groups and one telephone interview conducted during September 1999. Initially, a list of potential focus group participants was generated in discussions involving CPHD, EQE International, and USGS. Potential focus group participants were selected based on their high level of experience and expertise in the area of emergency response within the four institutional sectors selected for the study. As part of the focus group interviews, participants were asked to identify the key issues and factors important in assessing an organization’s likelihood of implementing a warning system such as SCAN. Participants also provided suggestions on specific types of organizations and personnel within each institutional sector that would be qualified to answer questions related to these topics.

Development and pilot testing of the telephone interview questionnaire

Based on findings from these preliminary focus groups, the questionnaire used for the telephone interviews was designed by persons with expertise in both survey and disaster research. This group of experts included staff and faculty of CPHD as well as representatives from Caltech, the Disaster Research Center at the University of Delaware, two private risk management companies, and a university-based survey research center.

The representatives from each of these groups had many valuable ideas about topics to address in the interview and the first version of the questionnaire was 24 pages and 74 questions long. However, limited resources put severe constraints on what could be included in the final questionnaire. Budget restrictions necessitated that the average length of time for the telephone interview be no more than 30 minutes. Over the course of development, eight versions of the interview questionnaire were designed and several of these versions were pilot tested with organizations in Los Angeles County.

Measures included in final questionnaire

The final questionnaire, summarized in detail in Table 3.2, asked about organizational characteristics (e.g., size, location, etc.), past experience with earthquakes, perception of earthquake risk, current warning systems, the likelihood of implementing an earthquake early warning system, issues related to implementing an earthquake warning system (i.e., potential uses, benefits, and barriers, as well as false alerts), and current earthquake preparedness and response activities. Just after the questionnaire was fielded, several questions were added regarding respondents' exposure to information on earthquake early warning systems. These questions were added in response to television and newspaper pieces that came out around the time the study began.

Table 3.2 Summary of final questionnaire content for telephone survey

Question #s	Topic areas	Description of question(s) [response categories]
Q1, 7-8	Respondent information	Years at organization, job title, time in position [OPEN ENDED]
Q2-6	Organizational demographics	Overall # of worksites, # of people, # of people at work site in Los Angeles County (LAC) [OPEN ENDED], ownership status of facilities [OWNS, RENTS, BOTH,, worksite city and zip code [OPEN ENDED]
Q9-11	Impacts of previous earthquakes on the organization	Damage to organization from earthquakes: (all categories coded (Y/N)) equipment/building contents, exterior structures, - minor damage to buildings, major damage to buildings, employees injured while working during earthquake, organizational operations interrupted by earthquake
Q12	Perception of the organization's risk from earthquakes	Likelihood of earthquake seriously affecting organization (LIKERT SCALED)
Q13-15	Current warning or alert systems used by the organization	Does organization have warning system for: (All categories coded (Y/N)) Fire, earthquake, bomb threat, hazardous material spills, other [Y/N] Are warnings issued through (All categories coded (Y/N)) Verbal messages on PA system, non-verbal messages on PA system, two-way radio, phones, computers, pagers, other Are warnings used to shut down or activate equipment or operations [Y/N] Description of shutdown or activation procedures [OPEN ENDED]
Q16	How current systems might be adapted for use in earthquake warning system	What parts of current warning systems could be used for earthquake early warning? (all categories coded (Y/N)) Methods used to alert workers, Manual shutdown or activation procedure, Automatic shutdown or activation procedures

Q17-19	Current earthquake response actions and potential responses with 10- and 50-second	When earthquake begins, what is done now? What would you do with 10 seconds of warning? How would you add to or enhance current response? What would you do with 50 seconds of warning? How would you add to or enhance current response or response with 10 seconds? [OPEN ENDED, POST-CODED] <u>Post-coding</u> Current earthquake responses mentioned: (All categories coded (Y/N)) life safety actions, facility-related actions, -actions to help maintain operations, computer-related actions] With 10 seconds warning would do… [NOTHING; THE SAME AS WITH NO WARNING; SOMETHING NEW/DIFFERENT; THE SAME AS WITH NO WARNING PLUS SOMETHING NEW] With 50 seconds warning would do… [NOTHING; THE SAME AS WITH 10 SECONDS WARNING; SOMETHING NEW/DIFFERENT; THE SAME AS WITH 10 SECONDS WARNING PLUS SOMETHING NEW]
Q20-24	Comparison of the impact of no warning vs. a 10-second warning vs. a 50-second warning on specified outcomes	As compared to having no warning: Coded LESS, SAME, MORE) Injuries with 10- or 50-seconds warning Damage to equipment with 10- or 50-seconds warning Loss of data with 10- or 50-seconds warning … Secondary hazards with 10- or 50-seconds warning… Effectiveness of emergency response with 10- or 50-seconds warning
Q25	Rating the benefits of earthquake warning	How important would it be to have: (LIKERT SCALED) Reduction in earthquake-related injuries Reduction in damage to equipment Prevention of loss of data Prevention of injuries/damage from.secondary hazards Increased effectiveness of emergency response Other benefits [SPECIFY]

Q26	Perceived likelihood of implementing an earthquake early warning system	In your opinion, how likely is it that organization would implement some type of earthquake early warning system? (LIKERT SCALED)
Q27-29	Potential ways of implementing an earthquake warning system at the organization	Who should receive warning? [ONLY ONE DECISION MAKER; SELECTED WORKERS; ALL WORKERS; ALL WORKERS AND OTHERS AT FACILITY] Would the system implemented most likely… [WARN WORKERS; START/SHUT DOWN EQUIPMENT; BOTH] Would organization most likely… [USE CURRENT TECHNOLOGY & SYSTEMS; ADD TO CURRENT TECHNOLOGY & SYSTEMS; INSTALL NEW TECHNOLOGY & SYSTEMS]
Q30	Possible barriers to implementing an earthquake warning system at the organization	How much of a barrier would the following items be to implementing an earthquake early warning system at the organization? (LIKERT SCALED) Technical knowledge needed to install and maintain system Employees' attitudes about warnings Management's attitudes about warnings Employees' emotional response to warnings Training personnel to respond to warnings Initial financial investment Maintenance costs Paying a monthly subscription rate [SPECIFY]
Q31-33	The impact of false alerts	How much would the activity or factor be impacted by a "false alert" … (LIKERT SCALED) Personnel time Ability to provide services Equipment operations Employee attitudes about warning system Other impact [SPECIFY] # of warnings followed by an earthquake but no damage organization would tolerate before discontinuing system? [OPEN ENDED] # of warnings followed by no earthquake organization would tolerate before discontinuing system [OPEN ENDED]

Q34-35	General organization earthquake preparedness and hazard mitigation	Does organization engage in the following activities (All categories coded Y/N) Employee education and training in earthquake preparedness Public education about earthquake preparedness and mitigation Use communication systems such as radios, pagers, etc Provide employees with preparedness supplies Non-structural mitigation Retrofitting Would organization like to start or do more: (All categories coded START DOING; DO MORE; NO CHANGE) Employee education and training in earthquake preparedness Public education about earthquake preparedness and mitigation Use communication systems such as radios, pagers, etc Provide employees with preparedness supplies Non-structural mitigation Retrofitting
Q36-38	Wrap up questions	Organization interested in participating in pilot study of earthquake early warning system? [YES/NO/MAYBE/DON'T KNOW] Would you like a copy of the executive summary of the report? [YES/NO] Other comments [OPEN ENDED]
Added questions	Prior exposure to information on earthquake early warning	Have you recently read or heard information about earthquake early warning [YES/NO] What is the most recent information you have read or heard about earthquake early warning? [OPEN ENDED] Where did you read or hear the information? [TELEVISION; RADIO; NEWSPAPER; MAGAZINE; INTERNET; OTHER] When did you read or hear this information? [OPEN ENDED]

Interviewer training

Interviewers selected and supervised by the UCLA Survey Research Center Field Studies Head collected the data. An interviewer briefing was held on March 8, 2000. The briefing included: 1) a presentation by Dr. Lucille Jones, seismologist and Chief of the USGS field office in Pasadena, California, on the basics of earthquakes and earthquake warning systems; 2) a review and discussion of the questionnaire; and 3) mock interviews. Interviewers were given a copy of the questionnaire, a glossary sheet of selected earthquake-related terms and organizations, and a brochure on earthquakes and earthquake preparedness (Putting Down Roots in Earthquake County, 1995). In addition to interviewers, SRC supervisory staff, the study's two principal investigators, the CPHD project manager, and representatives from Caltech and EQE participated in the interviewer briefing.

Respondent recruitment

Prior to any recruitment of study participants, all study materials (recruitment letters, information sheets, telephone scripts, and interview guides) and protocols were submitted to the UCLA Office for the Protection of Research Subjects (OPRS) for approval. Final approval was obtained, and recruitment activities began shortly thereafter.

Potential respondents were sent two mailings before SRC staff contacted them to request an interview appointment. The first mailing included a letter from the project administrator at Caltech explaining the study and requesting participation. It also included a one-page fact sheet about earthquake early warnings. Several days later, a second mailing was sent. This mailing included a letter from the Principal Investigators (PIs) at UCLA and an abbreviated version of the earthquake early warning fact sheet. The UCLA letter included a thorough description of the study, informed consent information as required by OPRS, and details on who to contact at

UCLA if the respondent had any questions. Since this study involved telephone interviews, we were not required to obtain signed consent forms from participants. Approximately two weeks after the letters were mailed, a postcard was sent to all potential/actual respondents encouraging/thanking them for their participation. At this point, potential respondents were also being called on a staggered basis to schedule and conduct interviews.

Data collection timeline

Data were collected over a period of seven months. Data collection began shortly after an interviewer briefing conducted on March 8, 2000 and was completed by September 30, 2000. To avoid extensive time passing between the respondents' receipt of mailed information and the actual interview, data were collected in four waves. (See Table 3.3) The start date and sector composition of each wave depended in large part on the progress of data collection in the proceeding wave.

Table 3.3 Mailing schedule of recruitment materials for telephone survey

Mailing wave	Mailing date	# sent to in sector	Sector
#1	March 3, 2000	15	Education
		15	Emergency Services
		15	Health Care
		15	Utilities & Transportation
		60	
#2	April 22, 2000	15	Emergency Services
		15	Health Care
		15	Utilities & Transportation
		45	
#3	May 22, 2000 thru June 3, 2000	30	Education
		20	Emergency Response
		12	Health Care
		62	
#4	July 22, 2000 thru August 23, 2000	17	Education
		3	Emergency Response
		17	Health Care
		19	Utilities & Transportation
		56	
All mailings	March – August 2000	62	Education
		53	Emergency Services
		59	Health Care
		49	Utilities & Transportation
		223	

After the first wave of data collection was almost complete, a more realistic assessment of the number of phone calls needed to schedule interviews as well as potential refusal rates was available. CPHDR and SRC were concerned about having enough time and resources to complete interviews across the entire sample. Since, for comparative purposes, it was necessary to have a minimum of about 50 respondents in each sector, it seemed better at this point to suspend data collection on an entire sector rather than risk being caught at the end under-sampled in all four sectors. After consulting with EQE and Caltech, we decided to temporarily suspend data collection in the education sector until further assessment could be done. Wave 2 of data collection was completed only with the emergency response, health care, and utilities and transportations sectors. Towards the end of Wave 2, remaining time and project resources were re-evaluated in light of the number of interviews still needed, including those in the education sector. Based on the findings of this assessment, we decided to resume data collection in the education sector in Wave 3.

Data management

As interviews were completed, questionnaires were logged and reviewed at SRC and then forwarded to the TriNet project manager at CPHD. The project manager was responsible for entry of the interview data into two databases. The quantitative data were entered into an SPSS v.10.0 spreadsheet. The qualitative data from several of the open-ended questions were entered into a separate Microsoft Word file that allowed for entering longer, more narrative answers. The project manager set up both databases. The project manager, with the assistance of a student researcher, completed all the data entry and data cleaning activities.

Response rates

Overall, the response rate for the survey was 85.7%. Of the 224 organizations selected to be in the sample, 192 completed interviews. Response rates ranged from 80.6% to 92.5% across institutional sectors (see Table 3.4). Two potential respondents, 0.9% of the selected sample, called CPHD and refused to participate in the study. Sixteen (7.2%) refused when contacted by the SRC interviewer. Education had the highest number of refusals, eight, followed by Utilities & Transportation with six. We were unable to contact seven respondents (3.1%). Another seven organizations (3.1%) turned out to have no eligible respondent or were determined not to be appropriate for inclusion in the survey.

Table 3.4 Telephone survey response rates by institutional sector

	Education		Emergency Services		Health Care		Utilities & Transportation		Total	
	%	(n)	%	(n)	%	(n)	%	(n)	%	(n)
Completed interviews	80.6	(50)	92.5	(49)	88.1	(52)	82.0	(41)[a]	85.7	(192)
Refused	12.9	(8)	1.9	(1)	5.1	(3)	12.0	(6)	8.0	(18)
Unable to contact	4.8	(3)	0.0	(0)	5.1	(3)	2.0	(1)	3.1	(7)
No eligible respondent	1.6	(1)	5.7	(3)	1.7	(1)	4.0	(2)	3.1	(7)
Total		(62)		(53)		(59)		(50)		(224)

[a] Includes one interview that was completed as part of the pilot testing.

On average it took six calls to schedule an interview, however, this varied significantly by sector (see Table 3.5). Health Care respondents averaged 7.8 calls to schedule an interview; Utilities & Transportation, 6.0 calls; Education, 5.9 calls; and Emergency Services, 4.4 calls (ANOVA, p=.01). One case in Health Care required 40 calls to get an interview scheduled.

Overall, 21.4% of interviews were referred to a respondent in the agency other than the person identified in the pre-mailing screening process. The number of referrals varied significantly by sector with the highest percentage of referrals found within the Utilities & Transportation sector at 32%. Twenty-four percent of Education interviews, 23% of Health Care interviews, and 8% in Emergency Services were referred to another respondent in the agency (χ^2, p=.05).

Interview times ranged from nine minutes to one hour and nine minutes with interviews lasting, on average, 26 minutes (n=190). Length of time to complete an interview did not vary significantly by interviewer but did vary by sector with Education averaging slightly shorter interviews (χ = 23.39 minutes) and Utilities & Transportation having slightly longer interviews (χ = 28.15 minutes) (ANOVA, p=.02) (see Table 3.5).

Of the 192 completed interviews, one interviewer completed 50%; a second interviewer completed 44%; and 3 other interviewers completed the remaining 6%. There was no significant difference between the two primary interviewers regarding the distribution of completed interviews across sectors.

Table 3.5 Descriptive summary of respondent contacts and completion times for telephone interviews by institutional sector

	Education	**Emergency Services**	**Health Care**	**Utilities & Transportation**	**Total**
# of completed interviews:	50	49	52	41	192
# of calls made to schedule interview:[a]					
Range	0-18	1-17	0-40	0-23	0-40
Mean*	5.9	4.37	7.83	6.00	6.05
(n)	(50)	(49)	(52)	(40)	(191)
Length of interview in minutes:					
Range	13-42	12-41	10-69	17-45	10-69
Mean**	23	26	27	28	26
(n)	(49)	(49)	(52)	(40)	(190)

[a] "0" calls indicates interview was completed on first attempt to contact respondent and did not have to be scheduled for another time.
* ANOVA, p=.01 ** ANOVA, p=.02

Quantitative data analysis strategies

All survey data was analyzed using SPSS for Windows, version 13.0. SPSS is a statistical analysis and data management software program suitable for analyzing quantitative social science data.

Sample description

The first step in the quantitative data analysis was to describe the survey sample based on the following characteristics: type of organizations within each sector; organizational respondent/representative position and tenure; organizational demographics such as number of worksites and employees; the organizations' previous experience with earthquakes; current earthquake preparedness and response activities; and types of warning systems currently being used. Definitions of the specific variables along with their frequency distributions, descriptive statistics, and results of bivariate analyses (i.e., Chi-square and ANOVA) are presented in Chapter 5.

Bivariate analyses were conducted to examine differences in characteristics across study sectors of education, emergency services, health care, and utilities and transportation. This particular stratification scheme was chosen because as the study was first developed, we hypothesized that each of the sectors would represent a somewhat homogeneous group and there might be variation across the sectors on some key variables.

Research question set #1

The second step in the quantitative analysis was to address the study's first set of descriptive research questions. These were:

> 1A. How might an earthquake early warning system be used by organizations in Southern California?

1B. Do these potential uses vary across the organizational sectors?

To answer these questions, at least in part, an analytic strategy was to generate frequency distributions using response data addressing the following areas:

1. What could be done with 10 seconds of warning?
2. What could be done with 50 seconds of warning?
3. Who should receive the warning signal?
4. Would the warning system be targeted at people, equipment, or both?
5. What benefits would it be important to see from a warning system such as this?

Bivariate Chi-square analyses were then conducted to ascertain whether responses to these questions varied significantly across study sectors. Definitions of specific variables, response categories, and descriptions of any transformations made to create new variables can be found in Chapter 5 along with the results of these analyses.

<u>Research Question Set #2</u>

The second set of research questions for this study asks what factors are associated with the perceived likelihood of an organization implementing an earthquake early warning system such as TriNet's SCAN. Table 3.6 summarizes the constructs examined to address these questions. As discussed earlier in Chapter 2, these constructs are derived from the concepts and empirical findings in adoption of innovation theory, theory of perceived risk, and the literature on disaster preparedness and response.

Table 3.6 Constructs and operational definitions for predictors of likelihood of earthquake early warning implementation

Construct	Operational Definitions
Organizational purpose	▪ Type of organization or role in the community ▪ Emergency-related activities (e.g., public education on earthquake preparedness
Structure	▪ Institutional category ▪ Size (number of employees) ▪ Number of work sites ▪ Ownership status of buildings
Historical factors	▪ Impacts of previous earthquakes ○ Damage ○ Injuries ○ Business continuity
Cognitive factors	▪ Respondent attributes ○ Perceived risk to organization ○ Exposure to earthquake early warning information
Practical issues	▪ Financial barriers ▪ Technical resources ▪ Anticipated uses for earthquake early warning system

Polytomous logistic regression analyses were conducted to examine the bivariate relationships between the factors described above and the perceived likelihood of organizations implementing an earthquake early warning system. Definitions of specific variables and associated response categories, as well as descriptions of variable transformations are presented in Chapter 4 along with the results of these analyses. In addition to these bivariate analyses, a predictive model also using multinomial logistic regression analysis methods was developed.

Use of multinomial logistic regression, like ordinal logistic regression, is appropriate when there are three or more ordered categories of the outcome variable (Kleinbaum & Klein, 2002). However, ordinal logistic regression models are only appropriate if the outcome categories are both ordered, and the proportional odds assumption is met. The proportional odds assumption requires that the odds ratio comparing different categories of the outcome variable are invariant across the different levels of comparison. The ordinal logistic model or proportional odds model produces only one odds ratio summarizing the effect across outcome levels. If the proportional odds assumption is not met, then ordinal outcome variables with three or more categories should be modeled using another regression procedure.

The outcome variable for the modeling analyses in this dissertation is “perceived likelihood of earthquake early warning implementation” with three outcome levels: not very likely, somewhat likely, and very to extremely likely. Multinomial logistic regression modeling was used for the analyses because comparisons across the different levels of the outcome variable were not consistent and did not meet the assumption of proportional odds. This will be demonstrated and discussed in more detail in Chapter 4.

Level of statistical significance

Due to the relatively small sample size and to the exploratory nature of the study, a $p<.10$ level of statistical significance was chosen for rejecting the null hypothesis, both for the bivariate and multivariate analyses. As argued by Schumm et. al., use of this less conservative alpha is both justifiable and credible for exploratory research, small sample sizes, and in social science research and can be found in many articles published in peer-reviewed social science journals (Schumm, 2013).

3.5 Qualitative Methods

According to Patton in *Qualitative Research and Evaluation Methods,* qualitative methods are especially suitable for exploration and discovery (Patton, 2002). The primary objective of the qualitative component of this study was to explore in depth how and why SCAN might be implemented in an organization. Learning which factors might be indicative of an organization's interest in and ability to implement a system like SCAN was of particular interest. This was also an opportunity to clarify information obtained in the telephone survey and to gain additional insight into potentially appropriate strategies to use in future quantitative analyses of the survey data.

To accomplish these objectives, face-to-face semi-structured key informant interviews were conducted to collect in-depth information on organizational issues related to the potential implementation and use of SCAN. Individuals responsible for emergency management at 12 organizations in Los Angeles County, three from each sector of education, emergency services, health care, and utilities and transportation were interviewed. The following four sections describe selection and recruitment of the key informants, the data collection process, management of the qualitative data, and analysis strategies employed.

Sampling design

Qualitative purposive sampling focuses on a relatively small sample size to "permit inquiry into and understanding of a phenomenon in depth" (Patton, 2002, p. 46). The aim of purposive sampling is to select information-rich cases in order to obtain insight and understanding about a subject. There are numerous purposive sampling strategies that can be employed either alone or in combination. For this study, a combination of *stratified*, *maximum variation*, and *extreme* case sampling strategies were used.

First, three cases were chosen from each organizational sector represented in the survey sample – education, emergency services, healthcare, utilities and transportation. The assumption was that each sector, or stratum, would consist of a somewhat homogeneous group of organizations. The purpose of stratifying the sample in this way was to discover if there are any major variations between the sectors.

A maximum variation strategy, on the other hand, seeks to construct a sample in which there is maximum variation on certain key characteristics (Patton, 2002). When cases are deliberately chosen because they are different than one another, any common themes and patterns that emerge in detailed examination of the cases are of potential interest and value. In this study, cases were selected to obtain variation within the sector on organizational size and complexity, as well as degree of technological sophistication.

In addition to stratifying the sample by sector and attempting to include organizations that varied in size, complexity, and technological resources, an attempt was made to include cases that represented the two ends of the spectrum on likelihood of SCAN implementation – very likely and not very likely. Based on information obtained through other knowledgeable persons in related fields, the development process of the survey questionnaire (i.e., the focus group and pre-testing activities), and actual survey results, two organizations potentially "interested in implementing SCAN" and one "not interested in implementing SCAN" were selected for each sector. The purpose of focusing on "extreme" cases was to try to identify what makes these cases unique.

Key informant identification and recruitment

To obtain information about processes and perceptions in the selected organizations, “key informants” were interviewed. Key informants are persons who are particularly knowledgeable and articulate about the subject of interest (Patton, 2002). Potential respondents for this study were identified as being directly responsible for emergency preparedness and response at their organization and for having some background knowledge of SCAN. Identification was based on information obtained in previous interactions with the selected individuals, as well as recommendations from local experts and professionals in the fields of emergency management, risk management, and the earthquake-related sciences. Identified respondents were also encouraged to include other organizational representatives in the interview process whom they felt could provide valuable information.

The fact that individuals or groups of individuals were asked to provide information about an organization makes it important to distinguish between the “unit of data collection” and the “unit of analysis.” While quite often these units are the same in a particular study, they do not have to be. Neuendorf describes the “unit of data collection” as the unit from which the data is provided, and the “unit of analysis” as the unit by which the data are analyzed and reported (Neuendorf, 2002). In the qualitative component of the study, the units of data collection were individuals or small groups, but the unit of analysis was generally the organization, but sometimes the sector.

Potential respondents were contacted by phone and asked if they would be interested in participating in the TriNet study key informant interviews. All persons originally chosen to represent the 12 organizations in the sample agreed to participate either individually or with others from the organization. The final sample of organizations and key informants is presented in Table 3.7.

In the end, the sample of organizations and respondents for the key informant interviews included some crossover from the survey sample in that at least one organization in each stratum of the key informant sample also participated as a respondent in the telephone survey. In some cases, representatives from subunits of an organization participated in the telephone survey and then a representative from the overall organization was selected for the key informant interview. For example, the survey sample includes several schools that belong to a large unified school district. For the telephone survey, principals or vice principals of individual schools were interviewed. In the key informant sample, the person responsible for emergency preparedness and response for the entire district was interviewed.

Table 3.7 Key informant interview respondents and organizations

Sector	Key Informant(s)	Organization description
Education:	Director, Security & Emergency Preparedness Branch	Medium-sized K-12 school district with approximately 85 schools
	Director, Office of Emergency Services	Large K-12 school district with over 600 schools
	Director, Fire Safety & Emergency Planning	University with 2 main campuses and several additional sites located throughout the county; also operates approximately 40 student housing facilities
Emergency Services:	General Manager, Emergency Preparedness Department	Large city
	Emergency Services Specialist, Public Safety Division	Small city
	Battalion Chief, Command & Control Division	Fire department with approximately 150 fire stations
Health Care:	Project Manager, Western Environmental Health & Safety	Large health maintenance organization
	Executive Support Staff	Public health program
	Administrator	Convalescent facility
Utilities & Transportation:	Seismic Manager	Water and power utility company
	Emergency Preparedness Coordinator and other facility personnel	Airport
	Certified Emergency Manager, Emergency Response Section	Water company

Key informant interview guide

In order to elicit SCAN-related perceptions and attitudes in more detail than could be obtained from the quantitative data, a semi-structured guide identifying basic topic areas to be discussed during the interview was developed. Topic areas included:

1) Potential warning message dissemination within the organization, including format and content
2) How a warning system would be used within the organization
3) Ideas on potential benefits of warnings and how these might be measured
4) Technological resources the organization has or would need to implement a warning system
5) Training issues related to warning system implementation and use
6) Organizational decision-making processes regarding implementation of SCAN
7) Potential funding mechanisms for implementing SCAN in the organization
8) Interest in participating in a SCAN pilot study

While the interview guide included suggested questions and probes and was used to impose some consistency on the basic type of data collected across cases, the interview process was also designed to allow the researchers to establish a conversational style of interviewing. This less structured format allowed interviewers to explore and expand on topic areas that respondents were particularly knowledgeable of, interested in, or had strong opinions about.

Interview protocol and earthquake scenario

Prior to the interview, key informants were sent an information sheet on SCAN and asked to obtain information and opinions from other key personnel at the organization and/or to invite other key personnel to participate in the interview process. The information sheet described how an earthquake early warning system like SCAN would work, presented a map of predicted warning times for different locations in Southern California for a large San Andreas Fault generated earthquake, and gave a few examples of how earthquake early warning might be used to facilitate rapid response and hazard mitigation.

At the beginning of each interview meeting, respondents were given a computerized demonstration of how the SCAN earthquake early warning system would work in the event of a magnitude 7.8 earthquake on the San Andreas Fault starting in Bombay Beach, California and rupturing northwest for 300 kilometers.[1] The video demonstration included a series of maps showing ground movement over time and space, the type of information generated at a central processing site and examples of warning messages that could be sent to various locations in the region.

Interview participants were informed that, as SCAN is envisioned at this time, the warning message will be "pushed" from the central processing site to a computer at their location via the Internet. The computer at their location would have to be on and Internet connected to receive the warning message. Respondents were also informed that the warning information could appear as a written message on the computer screen and/or could be programmed, based on thresholds determined by the organization, to automatically sound alerts and shut down or start up mechanical or computerized operations. After this demonstration and introduction, interview participants were asked to comment generally on the SCAN system and the type of messages being proposed. Interviewers then facilitated further discussion of SCAN, using the interview guide to partially structure and focus the discussion.

[1] This demonstration was based on a scenario presented to the Western States Seismic Policy Council in September 2000 (Goltz, 2000).

Interview meetings were audio taped and included two researchers, generally with one researcher acting as primary interviewer and one as primary observer and note taker.[2] Extensive notes were taken during all interviews. Notes from both researchers were integrated for analysis. Audio tapes were transcribed, and transcriptions were also used in the analysis process.

Data management

According to Wolcott, "The major problem we face in qualitative inquiry is not to get data, but to get rid of it…winnowing material to a manageable length, communicating only the essence…" (Wolcott, 1990). For this component of the study, a computer program and a qualitative analysis framework were used to assist with the process of "winnowing," or sifting through the data to separate relevant and valuable information from information that was extraneous or of little or no value in addressing the research questions.

Electronic files of interview notes and transcripts were imported into QSR NUD*IST Vivo (NVivo), a computer software package designed to assist with the coding and analysis of qualitative data (Richards, 2000). Each electronic case consisted of full text record or "document" that included both the key informant interview transcription and the associated interviewer notes. Therefore, each document in the project file contained all the study data for one key informant interview/organization.

General qualitative analysis approach

In this study, the qualitative analysis focused on examining key informant interview data from different organizations for similarities and differences on several key factors that might influence likelihood of implementing an earthquake early warning system. Some of these factors

[2] Ten of the 12 interviews were audio taped. In two interviews there were technical difficulties and audio taping was not possible. Extensive notes were taken in lieu of the audio tape.

or concepts were pre-defined and incorporated into the key informant interview guide. Others emerged after the data were collected and as the data were analyzed.

Identifying emergent categories generally involves developing a coding scheme after responses are collected, when no useful classification system already exists, and/or the researcher wants to develop a new classification system (Neuendorf, 2002). In this study, initial coding was based on some pre-determined classifications, but due to the exploratory nature of the research questions, emergent categories were also anticipated and coded.

While the NVivo computer software was used to facilitate the management of the qualitative data by providing an electronic means by which to code and sort data, the qualitative analysis plan for the study was based on an approach entitled “framework.” This analytic approach was developed as a part of and to be used in applied qualitative research. In the “framework” approach there are five interconnected stages of data analysis. The five stages are 1) familiarization, 2) identifying a thematic framework, 3) indexing, 4) charting, and 5) mapping and interpretation (Richie & Spencer, 1994). While each stage is distinct, progression through the stages is iterative and non-linear.

The first stage in this approach is *familiarization*. In this stage, the researcher acquires an overview of the data through listening to interview tapes, reading transcripts, and studying interview notes. The purpose of this overview is to start identifying key ideas and recurrent themes in the data.

The second stage involves *identifying a thematic framework*. Through the identification of key issues, concepts and themes in the data, the researcher creates a framework by which the data can be further explored, examined, and sorted. The elements of the thematic framework evolve out of 1) issues raised by prior research and the topics listed in the interview guide; 2) issues raised by respondents during interviews; and 3) issues or themes that appear in the data as recurring views or experiences. While the first version of the thematic framework is generally highly influenced by prior research and the contents of the interview guide, the framework is adaptable, and it can change significantly as the analysis progresses. For this study, the initial framework was greatly influenced by the results of the quantitative analyses.

The third stage of analysis is *indexing*. Indexing involves reviewing, making notes on, and coding text based on the topics identified as part of the thematic framework.

In the fourth stage of analysis, the researcher begins creating an overall picture of the data through a process called *charting*. Charting involves examining the range of attitudes and experiences within themes. Charts, or matrices, can be developed showing attitudes and experiences across themes or across cases. In the last stage of this qualitative analysis approach, the researcher begins *mapping and interpreting* the data. Using the indexing and charting tools developed in previous stages of the analysis, the researcher starts defining concepts, mapping the range and characteristics of concepts and themes, examining the data for associations, and creating typologies. Typologies are classification systems that categorize a phenomenon along a continuum. Categories in typologies are not exhaustive and discrete, but rather fall along a continuum between illustrative endpoints (Patton, 2002).

The framework described here, with the assistance of the NVivo software program, was used to analyze the qualitative data from the SCAN key informant interviews. Chapter 6 describes in more detail how each of the stages was executed in the data analysis process.

3.6 Triangulation

Triangulation in a mixed methods study can have many purposes. Triangulation is used to substantiate the interpretation of findings, to supplement findings, and to validate findings across different research methods (Stake, 1995; Denzin, 1970). In this study, triangulation methods were used for both supplementation and validation.

First, triangulation techniques were used to supplement quantitative findings related to how organizations might use earthquake early warning, particularly those that seem very interested implementing a system such as SCAN. Table 3.8 provides selected examples of the areas in which the relevant coded qualitative data were matched to selected telephone survey questions to provide details and a more complete picture of findings from the quantitative survey data.

Additionally, triangulation involved comparing across the two data sets the types of organizations with the greatest and least perceived likelihood of implementing an earthquake early warning system. Types of organizations most likely to implement and types least likely to implement identified in the qualitative data were compared to the types identified by the quantitative analysis and examined as to the level of convergence between the two sets of findings. Additionally, the qualitative data were examined to provide additional insight into what factors affect the perceived likelihood of implementation by various organizations. Triangulation results are presented and discussed in Chapter 5.

Table 3.8 Triangulation: Selected examples of how qualitative data are used to substantiate and supplement quantitative findings

Domain	Telephone survey (quantitative)	Key informant interviews (qualitative)
Who would receive warning?	Response options: ▪ One decision maker ▪ Selected workers ▪ All workers ▪ All workers and others at the facility	▪ Tells us more specifically who the one decision maker or workers would be and why ▪ Tells us why or why not others at the facility would receive warning
Potential ways of implementing a warning system	Response options: ▪ Use current technology and systems ▪ Add to current technology and systems ▪ Install new technology and systems	▪ Tells us more about the technology and systems already in place and how they might be used or adapted ▪ Provides clearer picture of technological resources needed by specific types of organizations before implementation could occur
Potential benefits of warning system	Response options: ▪ Reduction in injuries ▪ Reductions in damage ▪ Prevention of data loss ▪ Prevention of secondary hazards ▪ Increase in emergency response effectiveness ▪ Other	▪ Tells us more specifically the types of injuries, damage, and loss that might be prevented ▪ Tells us how a warning system would help prevent these injuries, damage, and loss

Finally, Figure 3.1 summarizes the major categories of factors delineated in the research questions and examined in both components of the study to assess the likelihood of organizational implementation of an earthquake early warning system by the four sectors of Education, Emergency Services, Health Care, and Utilities & Transportation.

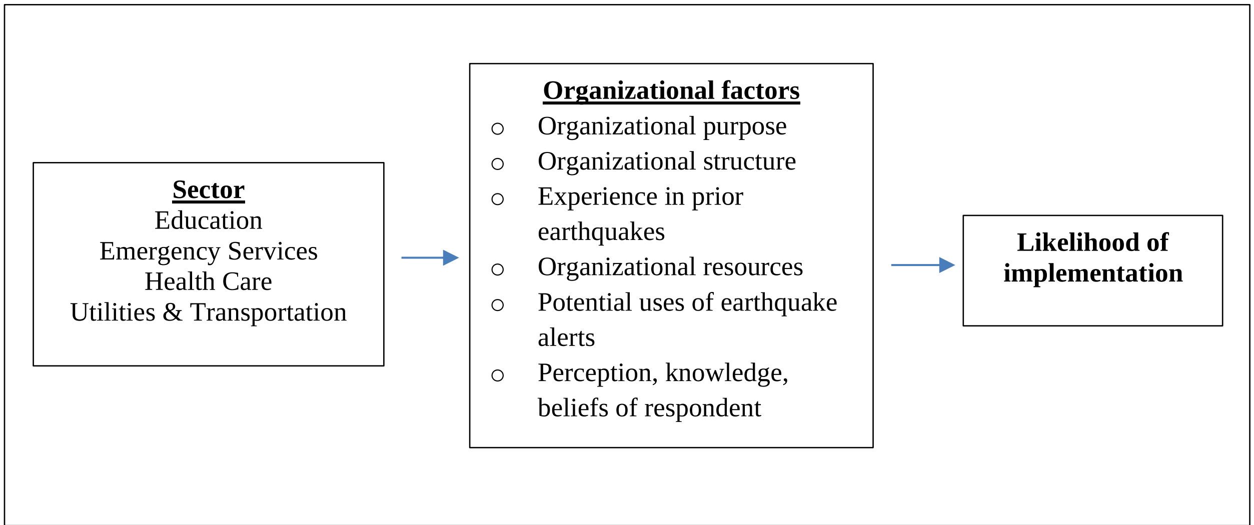

Figure 3.1 Factors examined to assess likelihood of earthquake early warning system adoption by organizations in the institutional sectors of Education, Emergency Services, Health Care, and Utilities & Transportation

CHAPTER 4: RESULTS FROM THE TELEPHONE SURVEY

The purpose of this chapter is threefold. The first objective is to describe the organizations that participated in the telephone survey component of this study. This "descriptive" picture is important because it provides the context in which the study's research questions are examined. Descriptive results are presented on: 1) the specific types of organizations found in each institutional sector; 2) the respondents; 3) organizational demographics; 4) earthquake-related characteristics of the organizations; and 5) currently used alert systems. Earthquake-related characteristics include experience or impacts in previous earthquakes, current organizational preparedness activities, and earthquake response practices related to individuals, equipment, and operations.

The second objective of this chapter is to address the first set of research questions using this data. These questions are:

1) How would organizations in Southern California use a new technology such as an earthquake early warning system?

2) How do potential uses of an earthquake early warning system vary by institutional sector?

Descriptive results are presented to answer questions 1 and 2 above. Based on survey data collected, bivariate analyses assess variations in potential uses of an earthquake early warning system as voiced by organizational representatives as well as differences between organizational sectors studied.

The third and final objective of this chapter is to address the second set of research questions. This second set of questions asks how organizational purpose, as well as structural, historical, cognitive, and practical factors relate to the perceived likelihood of an organization implementing a new technology such as an earthquake early warning system. These questions were addressed using bivariate analysis results and a model developed using polytomous logistic regression techniques, to describe the factors associated with the potential likelihood of organizations in Southern California adopting an earthquake early warning system such as SCAN.

4.1 Telephone Survey Sample Description

Types of organizations within each institutional sector

In the final sample of 192 organizations, 50 organizations were in the education sector, 49 in emergency services, 52 in healthcare, and 41 in utilities & transportation. Organizations in the education sector included pre-schools; elementary, intermediate, and high schools; and colleges and universities. Emergency services included both city and state emergency service agencies, fire services, and law enforcement agencies. Healthcare, probably the most variable within the sector, included hospitals and medical centers, outpatient service providers, convalescent and rehabilitation facilities, umbrella organizations, and an emergency medicine department. The utilities & transportation sector included public works departments, transportation services, and several different types of utility companies. Table 4.1 lists specific numbers and types of organizations found within each sector.

Table 4.1 Types of organizations in the telephone survey (n=192)

Type of Organization	**Number**
Education	**50**
Pre-schools	5
Elementary schools	13
Middle/intermediate schools	14
High schools	12
Colleges and universities	6
Emergency Services	**49**
City emergency services	16
State emergency services	1
Fire services	16
Police and sheriff departments	16
Heath Care	**52**
Hospitals/medical centers	25
Outpatient clinics/medical offices	19
Convalescent/rehabilitation facilities	5
Health care umbrella organization	2
Emergency department	1
Utilities & Transportation	**41**
Public works departments	14
Transportation services	14
Utilities	13

Respondents within the organization

The type of positions held by individual respondents within organizations of interest as well as their tenure in these positions was examined to provide a sense of whether or not respondents who had the appropriate knowledge and experience spoke on behalf of the organizations in the sample.

Respondents' job positions

The variation in types of positions held by respondents varied across organizational sectors by design. Specific positions were targeted for inclusion in each of the sectors based on the known and assumed responsibilities of the position. Every effort was made to speak with the person within the organization most knowledgeable about the organization's emergency response policies, procedures, and related equipment.

For most K-12 schools in the education sector this was the principal or assistant principal and for pre-schools, it was the director. Individuals responsible for public safety, emergency response, and/or facilities management usually completed the interview for the colleges and universities. Examples of emergency services personnel completing interviews included fire chiefs, watch commanders, police sergeants and lieutenants, city emergency services directors or coordinators, and public safety officers. Larger organizations in the healthcare sector generally had persons in positions dedicated to environmental health and safety, risk management, and/or emergency preparedness and response with whom we spoke. In smaller healthcare organizations such as clinics or medical groups, generally an administrative person whose responsibilities included emergency preparedness and response completed the interview. In utilities & transportation, respondents were usually either in a position dedicated to emergency management for the organization or were in a management position that included emergency preparedness and response as one of its responsibilities.

Respondents' tenure

Generally, respondents had been at the organization longer than they had been in their current position. On average, respondents had been at their respective organizations for almost 11 years and in their current position for approximately five years (n=192). Twenty-one respondents, 10.9% of the sample, had been in their current positions for less than one year. Fifteen of them had also only been at their organization less than one year.

The average number of years a respondent had been in their position did not vary significantly across sectors; however, average number of years at the organization did (see Figure 4.1). Respondents in the emergency services sector had been at their organization the longest, on average 14.4 years; followed by respondents in utilities & transportation at 11.7 years; healthcare at 8.8 years; and education at 8.4 years (n=192, ANOVA, p<.01)

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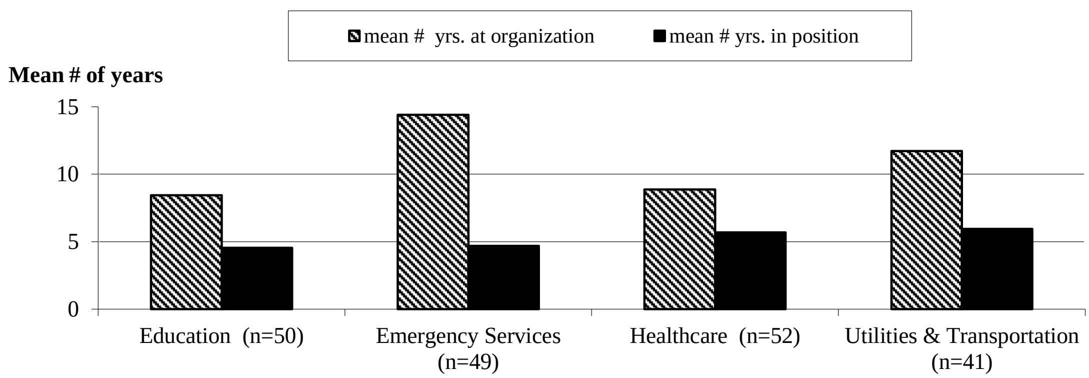


(# yrs at organization: ANOVA, p<.01)

Figure 4.1 Mean number of years interview respondent at organization and in position by sector

Organizational demographics

The organizational demographics presented here include the number of worksites the organization had in the County of Los Angeles, the number of employees both at the respondent's worksite and at all worksites in the county, and the ownership status of the organization's buildings (i.e., owned or leased). The following results show that on these demographics variables, organizations in the sample were very diverse.

Number of worksites in the county

Overall, less than half (42.7%) of the organizations in the study reported multiple worksites in the county. However, this varied significantly by sector with over 60% of emergency services and utilities & transportation reporting multiple worksites (61.2% and 63.4% respectively); 38.5% of healthcare reported multiple sites; and only 12% of education reported having more than one site (n=192, Pearson χ^2, p<.001).

The average number of worksites reported by sector also varied significantly (see Table 4.2). Respondents in the utilities & transportation sector reported, on average, 22.2 worksites in the county (n=41). This was followed by emergency services with 11.0 sites (n=49), healthcare with 3.3 (n=51), and education with the fewest at 2.2 (n=48) (n=189, ANOVA, p=.001).

Table 4.2 Number of organizational worksites in Los Angeles County by sector

	Education (n=48)	**Emergency Services** (n=49)	**Healthcare** (n=51)	**Utilities & Transportation** (n=41)	**Total** (n=189)
Range	1 – 50	1 -150	1 -30	1 -221	1 - 221
Median	1	2	1	3	1
Mean*	2.19	11.04	3.33	22.15	9.12
Standard deviation	7.08	26.21	5.12	43.79	25.73

* ANOVA, p=.001.

Number of employees

In addition to asking about the number of worksites to get a sense of the organization's size, respondents were asked the number of employees at 1) the respondent's worksite and 2) for all worksites in the county. These numbers varied widely both within and across sectors (see Table 4.3). For example, the fewest number of people reported at the respondent's work site was three in the education sector; the most was 25,000, also in education. The largest number of employees overall, 30,000, was reported in healthcare.

Table 4.3 Number of employees at respondent's worksite and at all Los Angeles County worksites by sector

	Education	Emergency Services	Healthcare	Utilities & Transport.	Total
# of Employees at Respondent's Worksite					
N	50	49	51	41	191
Range	3 - 25000	4 - 400	6 - 6000	8 - 3400	3 -25000
Median	125	50	275	120	110
Mean*	1068.48	78.45	903.82	415.66	630.39
Standard deviation	3852.53	88.72	1405.53	717.30	2148.71
# of Employees at All Worksites in County					
N	50	49	47	40	186
Range	3 -25000	7 -1200	6 - 30000	8 -9000	3 - 30000
Median	140	98	330	250	155
Mean	1203.74	739.24	1627.66	1329.25	1215.48
Standard deviation	3956.06	2289.31	4468.51	2315.56	3421.46

* ANOVA, p<.10.

Building ownership status

Of the 185 respondents answering this question, more than half, 69.7%, reported owning all of their buildings. A much smaller percentage, 21.6%, reported a combination of owned and leased buildings. An even smaller percentage, 8.6%, reported leasing all buildings. This varied by sector with the education sector most likely to own all of their buildings (83.7%); healthcare most likely to report a combination of ownership and lease (30.6%); and utilities & transportation reporting the highest percentage of leased buildings (14.6%) (see Figure 4.2).

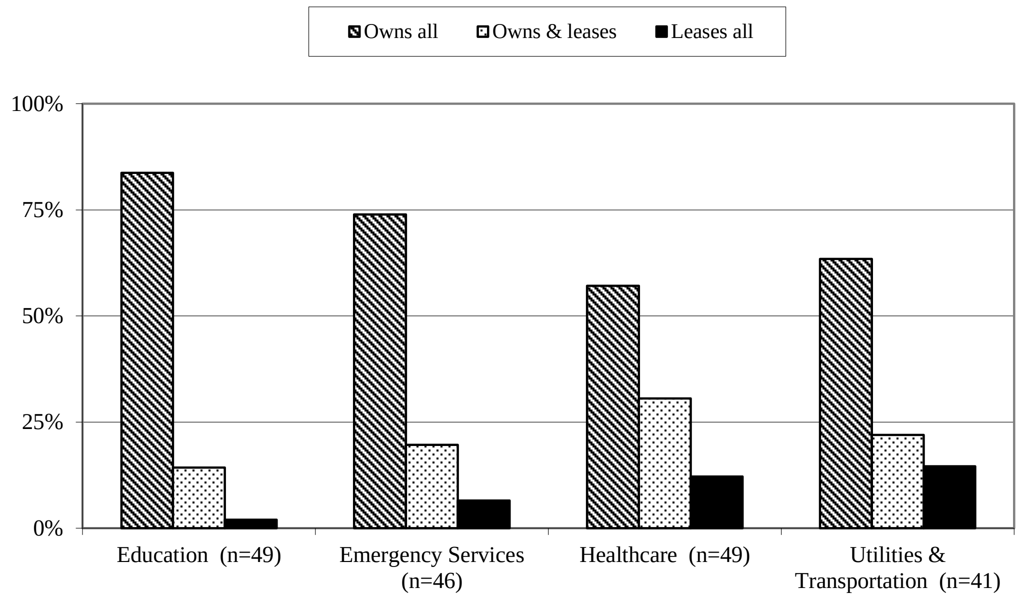


Figure 4.2 Percent of organizations owning all, owning and leasing, and leasing all buildings

When building ownership status was dichotomized into "owns all" versus "leases some or all" there was a statistically significant difference between the sectors with 83.7% of education, 73.9% of emergency services, 57.1% of healthcare, and 63.4% of utilities & transportation reporting that they own all buildings (n=185, Pearson χ^2, p=.025).

4.2 Earthquake-related Characteristics of Organizations in Telephone Survey

The interview included several sections of questions about earthquake-related issues. Respondents were asked about their organization's experience in previous earthquakes, current earthquake preparedness activities, and current earthquake response actions. These findings are presented below.

Organizational earthquake experience – damage, injuries, operational disruption

When asked about physical damage to the organization from earthquakes since 1985, 21.9% (n=42) reported no damage at all. Sixty-six percent reported minor damage to buildings; 44.3% reported damage to equipment and building contents; 38.5% percent reported damage to exterior structures; and 15.1% reported major damage to buildings. Damage reported did not vary significantly by sector.

Only eight respondents, 4.2%, reported that any of their organization's employees had been injured while working as a result of an earthquake. Five of these were in the emergency services sector, two fire departments and three city emergency services agencies. Two were utility companies and one was a healthcare organization.

Slightly less than half of the organizations overall, 49.5% (95 out of 192), reported having operations interrupted by earthquakes since 1985. Of the 84 organizations that gave an amount of time operations were interrupted, 26.2% said that it was 12 hours or less; 26.2% said it was 24 hours; and 47.6% said it was more than 24 hours. This did not vary significantly by sector.

Current earthquake preparedness activities

Respondents were asked whether or not their organization carries out a variety of earthquake preparedness and hazard mitigation activities. These activities included:

- Provide employee education and training in earthquake preparedness
- Provide public education about earthquake preparedness and mitigation
- Use communication systems such as radios, pagers, etc.

- Provide employees with preparedness supplies such as first aid kits, flashlights, etc.
- Perform non-structural mitigation such as bolting bookcases to walls
- Retrofit buildings or structures

The vast majority of respondents indicated that their organization has a communication system set up and provides employee education and training in earthquake preparedness, 95.3% and 92.7% respectively (n=192). A large percentage of organizations, 89.6 %, also reported providing employees with preparedness supplies. A slightly smaller percentage, 85.4%, had done non-structural mitigation and even fewer, 69.8%, reported retrofitting buildings or structures. It should also be noted that about 10% of respondents did not know whether their buildings had been retrofitted.

The least common earthquake preparedness activity reported among the organizations was providing public education about earthquake preparedness with only 59.9% of respondents reporting that their organization engages in this activity. This varied significantly across sectors with 93.9% of emergency services, 63.3% of education, 47.5% of utilities & transportation, and 37.3% of healthcare reporting that they provide public education on earthquake preparedness (n=189; Pearson χ^2, $p<.001$).

Respondents were also asked if increased resources were available, what would their organization like to start, do more of, or keep the same as it relates to the activities described above. Data from the question asking whether or not the organization currently does the activity were combined with data from the question asking about desired future activities to create a variable with the following possible responses:

- Does not currently do the activity, does not want to start
- Does not currently do the activity, but would like to start
- Already does the activity, would keep the same
- Already does the activity, would like to do more

.

Cases for which data were missing on one or both of the original variables, the respondent answered "don't know" on one or both of the original variables, or the respondent answered that the organization already does activity <u>and</u> would like to start doing activity were coded as "missing" for the new variable.

In general, organizations not currently engaging in a specified activity indicated that they would like to start. And, many engaging in a specified activity would like to do more (see Table 4.5). Providing earthquake preparedness education to the public was the exception to these findings. Approximately 20% of the organizations in the sample indicated that they do not currently provide public earthquake preparedness education and they do not want to start. As compared with less than 2% of respondents who said that their organization does not, nor do they want to start, providing education for employees; having a communication system; providing employees with emergency supplies; or performing non-structural mitigation. A slightly higher, although still very small percentage of respondents, 5.2%, felt this way about retrofitting buildings and structures.

Table 4.5 Percent of organizations that engage in, would like to start, or do more of specified earthquake preparedness activity**										
	Don't do, don't want to start		**Don't do, would like to start**		**No change in what already do**		**Already do, would like to do more**		**Missing****	
Earthquake-related activity	%	(n)	%	(n)	%	(n)	%	(n)	%	(n)
Provide education for employees	1.0	(2)	5.7	(11)	31.8	(61)	59.4	(114)	2.1	(4)
Provide education for the public	19.8	(38)	17.7	(34)	15.6	(30)	43.8	(84)	3.1	(6)
Have communication system	1.6	(3)	2.6	(5)	43.2	(83)	50.0	(96)	2.6	(5)
Provide employees with emergency supplies	1.6	(3)	7.8	(15)	34.9	(67)	52.6	(101)	3.1	(6)
Do non-structural mitigation	1.0	(2)	13.0	(25)	34.9	(67)	48.4	(93)	2.6	(5)
Retrofit buildings and structures	5.2	(10)	14.1	(27)	27.6	(53)	39.1	(75)	14.1	(27)

*Note: Data combined from two variables – 1) Does organization engage in activity (Y/N); and 2) if resources were available would organization want to 1-start, 2-do more, or 3-not change activity.
** Missing include cases for which data were missing on one or both of the combined variables (n=14), the respondent answered "don't know" on one or both of the combined variables (n=34), or the respondent answered that the organization already does activity <u>and</u> would like to start doing activity (n=5). For "retrofitting," 23 of 27 missing were due to respondent saying "don't know" on one or both of combined variables.

<u>Current responses when an earthquake occurs</u>

An open-ended question was asked to find out what organizations currently do when earthquake shaking starts. Interviewers probed for examples of what is done to 1) prevent injuries and save lives; 2) prevent damage to equipment; 3) prevent disruption of services or key operations; and 4) start emergency response procedures. Open-ended responses were post-coded to indicate whether the respondent mentioned organizational earthquake responses related to the following four domains: 1) life safety; 2) physical facility; 3) organizational operations; and 4) computer/data protection. Post-coding was done separately by two research assistants who then compared coding. Differences in coding were resolved through discussions involving the two research assistants and the project manager.

Overall, 96.4% of the respondents mentioned life-safety actions as part or all of their organizational response to earthquakes. Seventy-four percent volunteered earthquake responses that were categorized as pertaining to their facility and 32.3% mentioned responses related to organizational operations. Only 9.4% mentioned computer-related/data protection responses (see Figure 4.3).

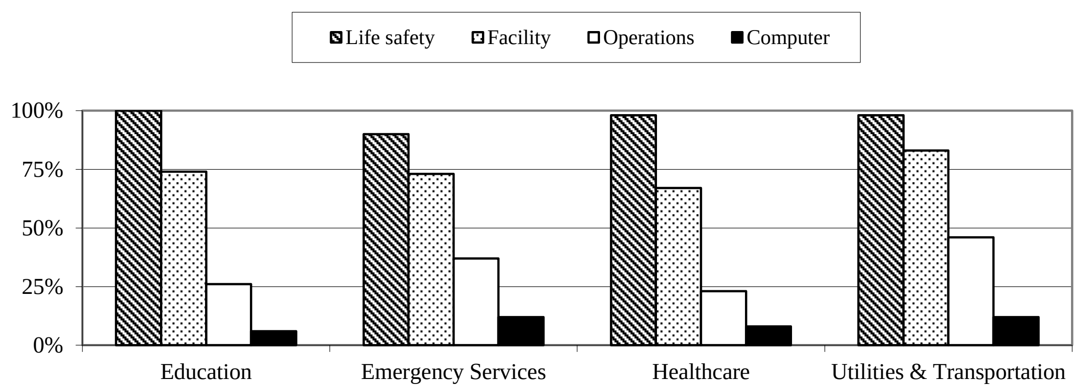


Figure 4.3 Percent of organizations reporting current type of actions taken when earthquake shaking is first felt (n=192)

The percentage of organizations reporting current earthquake response actions within a category varied significantly across sectors for actions related to life safety and operations. One hundred percent of the education sector respondents mentioned life safety responses versus

98.1% in healthcare, 97.6% in utilities & transportation, and 89.8% in emergency services (n=189; Pearson χ^2, p<.001). Post hoc analysis using the LSD (least significance difference) test indicated that the mean difference between responses from emergency services was significantly different from each of the other groups, education, healthcare and utilities & transportation at a 0.05 alpha level.

Operational or "facility" responses to earthquakes were most often mentioned by organizations in utilities & transportation. Forty-six percent of utilities & transportation respondents mentioned operations-related responses as compared to 36.7% in emergency services, 26.0% in education, and 23.1% in healthcare (n=192; Pearson χ^2, p=.070). Post hoc analysis using the LSD test indicated that the mean difference between responses from utilities & transportation was significantly different from the education group and from the healthcare group.

4.3 Alert Systems Currently Used by Organizations in Telephone Survey

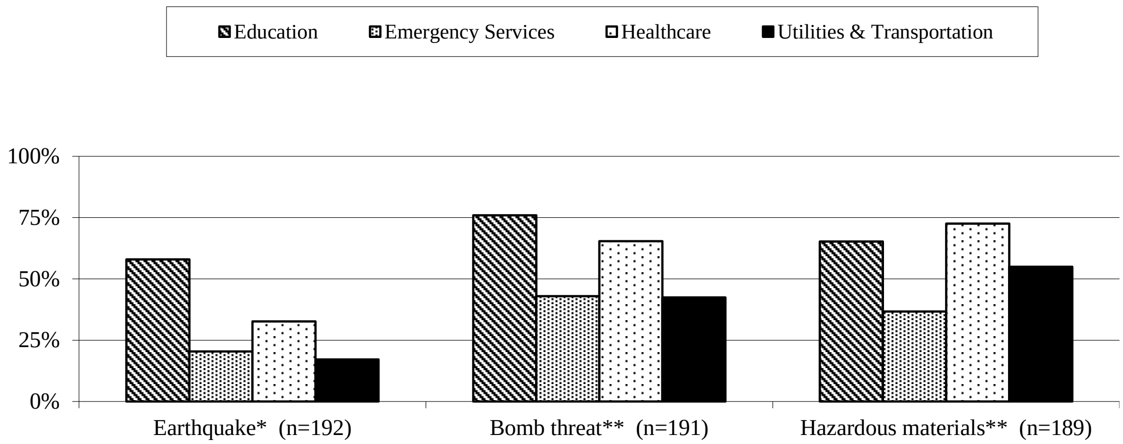
During the interview, respondents were asked a series of questions related to what type of alert systems their organization currently has in place. These questions focused on three main areas: 1) what types of events trigger alerts; 2) how alerts are disseminated; and 3) the shutdown or activation of equipment triggered by alerts. The following section describes these results.

<u>Current alert systems and methods of alert dissemination</u>

Respondents were asked if they had warning or alert systems already in place at their organizations for a variety of hazards including fires, earthquakes, bomb threats, hazardous materials spills, and other emergency situations. Almost all organizations, 181 of 192 or 94.3%, reported having fire alert systems. A little over half, 57.6%, reported alerts for bomb threats; and 56.8% reported hazardous materials spill alerts. Only 32.8% reported having earthquake alert systems. One respondent did not know if the organization had an alert system for bomb threats and three respondents did not know if there were alerts for hazardous materials spills at their organization.

The percentage of organizations with the different types of alert systems varied significantly by sector (see Figure 4.4). Fifty-eight percent of the education sector reported having earthquake alerts currently, as compared with 32.7% of healthcare, 20.4% of emergency services, and 17.1% of utilities and transportation (n=192; Pearson χ^2, p<.001). In education, 76% of respondents reported bomb threat alert systems, as compared with 65.4% of healthcare, 42.9% of emergency services, 42.5% of utilities & transportation (n=191; Pearson χ^2, p<.01). The highest percentage of hazardous material spill alert systems, 72.5% was reported by the healthcare sector, as compared with 65.3% of Education, 55.0% of utilities and transportation, and 36.7% of emergency services (n=192; Pearson χ^2, p<.01).

Additionally, 62% of the education organizations volunteered having alert systems for strangers or intruders on campus, violence on campus or in the surrounding community, and/or persons with weapons. These types of alerts were often referred to as “lock down.” About half of the healthcare organizations volunteered that they have color coded alert systems for situations involving violent or agitated patients, infant abductions, breaches of security, and other emergencies.



*Pearson χ^2, p<.001; **Pearson χ^2, p<.01

Figure 4.4 Percent of organizations with earthquake, bomb threat, and hazardous materials alert systems by sector

Alerts are disseminated in a variety of ways both within and across sectors. Overall, non-verbal signals on public address systems, telephones, and two-way radios were the most commonly reported ways to disseminate alerts. Seventy-nine percent of organizations reported using non-verbal signals, 79.2% use telephones, and 77.1% reported using two-way radios. A slightly smaller percentage of respondents reported their organization disseminating verbal alerts via public address systems and through pagers, 69.3% and 61.8% respectively. Least common was disseminating alerts through computers with only 56.3% of organizations using this method.

Except for the use of telephones, methods of alert dissemination varied significantly across sectors (see Table 4.4). Healthcare organizations were most likely to report using verbal messages on public address systems, 86.5%, as compared with education, emergency services, and utilities and transportation at 70%, 65.3%, and 51.2% respectively (n=192; Pearson χ^2, p<.01). All education organizations, 100%, reported using non-verbal signals on public address systems, as compared with 82.7% of healthcare, 70.7% of utilities and transportation, and 61.2% of emergency services organizations (n=192; Pearson χ^2, p<.001). Ninety percent of education organizations also reported using two-way radios, as compared to 78% of utilities and transportation, 77.6% of emergency services, and 64.7% of healthcare (n=191; Pearson χ^2, p<.03).

While most likely to use non-verbal signals on public address systems and two-way radios, education organizations were also least likely to use computers and pagers. Only 30% of education, as compared to 61.2% of emergency services, 65.4% of healthcare, and 70.7% of utilities and transportation, reported using computers to disseminate alerts (n=192; Pearson χ^2, p<.001). An even smaller percentage of educational organizations, 20%, reported using pagers; as compared to 69.4% of emergency services, 78.4% of healthcare, and 82.9% of utilities and transportation (n=191; Pearson χ^2, p<.001).

Table 4.4 Percent of organizations that use specified method to disseminate alerts by sector

Method of disseminating alerts	**Education**	**Emergency Services**	**Healthcare**	**Utilities and Transport.**	**Total**	**N**	**p***
Verbal message on public address system	70.0	65.3	86.5	51.2	69.3	192	<.01
Non-verbal alert on public address system	100.0	61.2	82.7	70.7	79.2	192	<.001
Two-way radios	90.0	77.6	5 64.7	78.0	77.5	191	<.03
Telephones**	72.0	79.6	76.9	90.2	79.2	192	NS
Computers	30.0	61.2	65.4	70.7	56.3	192	<.001
Pagers	20.0	69.4	78.4	82.9	61.8	191	<.001

* Pearson χ^2
** Note: Includes both landlines and mobile phones

Equipment and operational system shutdown and activation

Respondents were also asked, “Does your organization have a way to shut down or activate equipment or industrial operations in an emergency situation?” Eighty-eight percent of respondents said “yes,” 10.9% said “no,” and 1% said “don’t know.” If the respondent answered yes, s/he was also asked, “How does this work?” These open-ended responses are summarized below.

Gas and other utilities such as water and electricity were most often described as equipment or operations that are shut down in an emergency situation. Also mentioned was shutting down fuel pumps, boilers, and heating and cooling systems. In addition to these types of shutdowns, healthcare organizations reported turning off medical equipment such as dialysis machines and oxygen tanks. Respondents in the utilities and transportation group also volunteered that their organizations may close pipelines, turn off gas to customers, and stop trains and trucks. In general, generators and sprinkler systems were the most frequently described systems started in an emergency and these were often described as automatic. Forty-nine percent of respondents volunteered that their organization used backup generators or some other source of power in an emergency.

When the original open-ended answers to “How does this work?” were post-coded to indicate whether manual and automated procedures were mentioned in the description given, 28.1% of respondents only mentioned manual procedures, 15.1% only mentioned automatic procedures, and 40.1% mentioned both manual and automatic procedures; 5.6% of the respondents did not volunteer information indicating whether procedures were manual or automatic, and for 10.9% of the sample this question was not applicable.

Respondents in the education sector were least likely to volunteer that their shutdown or startup procedures are automatic, 41.9% versus 75.0%, 73.0%, and 67.4% in emergency services, utilities and transportation, and healthcare, respectively. This is a statistically significant difference (n=166; Pearson χ^2, p=.005). Education respondents were also least likely to volunteer that they have backup power sources (e.g., generators), 32.6% versus 75%, 62.2%, 58.7% in emergency services, utilities and transportation, and healthcare, respectively. This is also a statistically significant difference (n=166; Pearson χ^2, p=.001).

4.4 Potential Uses of An Earthquake Early Warning System

The purpose of this analysis was to address the first set of research questions, namely:

- How would organizations in Southern California use a new technology such as an earthquake early warning system?
- How do potential uses of an earthquake early warning system vary by institutional sector?

It was hypothesized that 1) potential uses for earthquake early warning would fall into three primary domains – life safety, property protection, and operational continuity; 2) life safety uses would be the perceived as the most important potential benefit of a warning system; and 3) saliency of potential system uses would not vary across study sectors.

To begin addressing these questions, responses about what could be done with 10 seconds of warning and with 50 seconds of warning were explored. Opinions about who should receive the warnings was also examined as well as whether respondents thought a warning system at their organization would likely be used to warn people or control equipment or mechanized processes. Finally, the perceived importance of selected benefits was examined and analyzed for differences between the study sectors. The results are presented here.

What could be done with 10 and 50 seconds of warning?

After respondents were asked what is done at their organization currently when an earthquake begins, they were asked, “What could you do with 10 seconds of warning? How could you add to or enhance what you already do when an earthquake begins?” Open-ended responses were post-coded as discussed before using two coders and then consensus coding where there were differences. The responses were coded into the four categories listed below:

With 10 seconds of warning, the organization would undertake:

- The same earthquake response actions/ would do nothing different with a warning
- The same earthquake response(s), but sooner
- New or different response(s)
- The same response(s), plus something new or different

In over half of the cases (59.9%, n=192), respondents indicated that their organization would respond the same to an earthquake if they had 10 seconds of warning as they would with no warning at all, but they would start their response sooner. Nineteen percent said they would respond the same, plus do something new, and 17.7% said they would do nothing with 10 seconds of warning. Only 3.1% of respondents said their organization would do something entirely new or different. Examples of new or different responses included:

- evacuating;
- turning off computers;
- alerting selected individuals (e.g., teachers, custodial workers, drivers, workers in the field);
- shutting off equipment and/or utilities (e.g., gas and water);
- securing patients and stopping certain activities such as surgery; and
- accessing specific emergency equipment such as two-way radios and fire trucks.

Evacuation was mentioned the most frequently, but this was only by seven of 192 respondents. Eighty-two percent of respondents did mention disseminating the warning to others in the organizations.

Respondents were then asked, “Now, what if you had 50 seconds of warning before the shaking began? How could you add to or enhance what your already do or what you could do with 10 seconds?” These answers were post-coded into the same categories as the 10-second warning question described above. In the 50 seconds of warning scenario, 32.8% of respondents said their organization would undertake the same responses, but sooner. Fifty-two percent said their organization would undertake the same responses but would also do something new or different. Five percent said their organization would do nothing with 50 seconds of warning and 9.9% said they would do something new or different. Ninety-four percent mentioned disseminating the warning.

Three times as many respondents (21 vs. 7) mentioned evacuation with 50 seconds of warning than with 10 seconds. Almost as many respondents, 20, mentioned turning off gas with 50 seconds of warning and 25 said they would shut down computers. With 50 seconds of warning organizations also started mentioning alerting the general community and/or other specific organizations. For example, one city emergency services department mentioned using a siren to alert the community and two fire departments and a transportation organization mentioned broadcasting the warning to the general public. Additionally, several organizations mentioned contacting local police and fire departments if they received a 50-second warning.

Table 4.6 Percent of Organizations Indicating How They Would Respond with 10 and with 50 Seconds of Warning (n=192)		
Organizational response(s) would be:	**With 10 Seconds of Warning** (as compared to no warning)	**With 50 Seconds of Warning** (as compared to 10 seconds of warning)
The same	17.7%	5.2%
The same, but sooner	59.9%	32.8%
The same, but with new/additional response(s)	19.3%	52.1%
New or different	3.1%	9.9%

Who should receive the warning signal?

When asked who should receive the warning signal at the organization, 11.5% of respondents indicated, "only one decision maker" (n=182)[3]. Almost half of these respondents, 48.9%, said that the warning should go to "selected workers with specific kinds of responsibilities." An additional 8.8% said the warning should go to "all workers, but not others, at the facility." And 30.8% thought the warning should go to everyone at the facility, regardless of whether people worked there or not. Variations across institutional sectors regarding who should receive the warning were statistically significant (see Table 4.7), but given the number of the sectors (4) and the number of response categories (4), it is difficult to determine which differences are the significant ones. In general, respondents in the healthcare sector were least likely to say that the warning should be disseminated to everyone at the facility, including non-employees. Only 14.3% of respondents in the healthcare sector, as compared to 27.7% in

[3] Nine respondents were skipped out of this question after indicating they were "not at all likely" to implement an earthquake early warning system and one respondent answered "don't know" to this question.

education, 35.8% in utilities and transportation and 46.8% in emergency services said that the warning signal should go to everyone.

Table 4.7 Percent of organizations indicating who at facility should receive earthquake early warning

Who should receive warning	**Education** (n=47)	**Emergency Services** (n=47)	**Healthcare** (n=49)	**Utilities and Transport.** (n=39)	**Total**[1] (n=182)
Only one decision maker	12.8	14.9	12.2	5.1	11.5
Selected workers with specific responsibilities	53.2	31.9	59.2	51.3	48.9
All workers, but not others	6.4	6.4	14.3	7.7	8.8
Everyone at the facility	27.7	46.8	14.3	35.8	30.8

* Pearson χ^2=.047
Nine respondents were skipped out of this question after indicating they were "not at all likely" to implement an earthquake early warning system and one respondent answered "don't know" to this question.

Should warnings go to people or equipment?

When asked whether their organization would be most likely to implement a warning system that 1) warns workers to take protective actions, 2) automatically shuts down or starts up equipment, or 3) does both, 57.3% of respondents said "both." Thirty-three percent said "warns workers" only. Three percent chose automating equipment by itself. Six percent of cases were missing data on this variable.[4] Differences between the study sectors were not statistically significant.

[4] Nine respondents were skipped out of this question after indicating they were "not at all likely" to implement an earthquake early warning system and one respondent answered "don't know" to this question. One respondent answered, "don't know." Two cases were missing data.

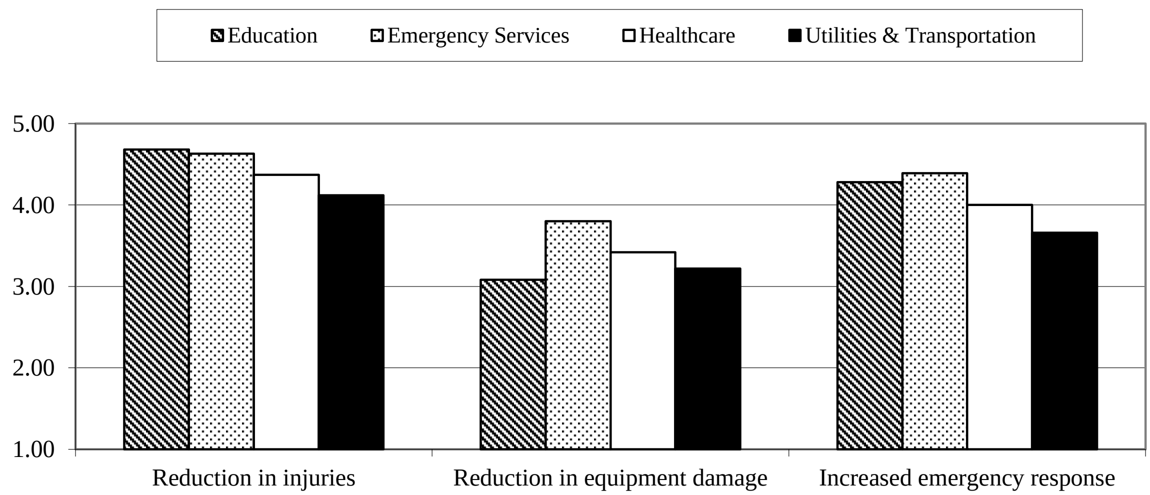
What benefits are important to get from a warning system?

Another way to look at how organizations might use an earthquake early warning system, albeit indirectly, is to explore what benefits the organization would want to realize from having the system. In the telephone survey, respondents were asked to rate on a scale from one to five, with one indicating "not at all important" and five indicating "extremely important," specific benefits their organization might realize if an earthquake early warning system were implemented. The potential benefits they were asked to rate included:

- Reduction in injuries caused by the earthquake
- Reduction in damage to equipment
- Prevention of loss of data
- Prevention of injuries or damage from secondary hazards such as toxic spills
- Increased effectiveness of emergency response activities.

In general, a reduction in injuries caused by the earthquake was rated the most important potential benefit of the system, with a mean rating of 4.46 on the 1-5 scale (n=192). Increased effectiveness of emergency response activities was second at 4.1 (n=192). Prevention of injuries or damage from secondary hazards was third at 3.97 (n=191), followed by preventing loss of data at 3.41 (n=192) and then reduction in damage to equipment at 3.39 (n=192).

However, mean ratings of importance of potential benefit varied significantly across institutional sectors for reduction in injuries, reduction in equipment damage, and increased effectiveness of emergency response (see Figure 4.5). Post-hoc statistical testing using LSD (least significance difference) indicates that the mean ratings for reduction in injuries differed significantly between education and utilities and transportation (4.68 vs. 4.12) and also between emergency services and utilities and transportation (4.63 vs. 4.12) at an alpha level of 0.05. The mean rating of importance of reduction in equipment damage differed significantly between emergency services and education (3.8 vs. 3.08) as well as between emergency services and utilities and transportation (3.8 vs. 3.22). Finally, the importance of increasing the effectiveness of emergency response also differed between education and utilities and transportation (4.28 vs. 3.66) and between emergency services and utilities and transportation (4.39 vs. 3.66). Overall, respondents in the Utilities & Transportation sector rated the importance of each of these potential benefits lower on average than respondents in the other groups.



(n=192, p=.021)* (n=192, p=.059)* (n=192, p=.011)*

*Pearson χ^2

Figure 4.5 Average rating of importance of potential benefit of earthquake early warning system by institutional sector on 1-5 scale with 1 representing "not at all important" and 5 representing "extremely important"

4.5 Predictors of Likelihood of EEWS Implementation

This section describes the results of analyses conducted to determine what variables are the best predictors of an organization's perceived likelihood of implementing an earthquake early warning system such as SCAN. Presented first is a brief review of the second set of research questions set forth in Chapter 3. A description of the dependent variable, perceived likelihood of implementation, and the subsample used for the analyses follows the research questions. Next, variables used in the simple logistic regression analyses are described and the results of these analyses are presented. Finally, the methods and results for the multinomial logistic regression modeling are presented.

Review of the research question set

The second set of research questions for this study was developed to determine what variables are predictive of the perceived likelihood of implementing an earthquake early warning system. The variables of interest, which were determined by theory, previous research, and some preliminary analysis of the survey data, fall into five primary domains. These domains include:

1) Organizational function – what does the organization do?
2) Organizational structure – size and number of sites
3) Earthquake experience– how have earthquakes affected the organization in the past?
4) Cognitive factors – what are the respondent's perceptions, beliefs, and knowledge about earthquake risk and earthquake early warning?
5) Practical or implementation-related factors – What resources are available for implementing earthquake early warning? How would an EEW system be used?

Definitions and distributions of the specific predictor variables found within each of these domains are described in more detail after a discussion of the dependent variable.

The dependent variable – perceived likelihood of EEWS implementation

In the telephone interview, respondents were asked to rate the likelihood of implementing an earthquake early warning system at their organization using a five point scale wherein: 0 = not at all likely, 1 = not very likely, 2 = somewhat likely, 3 = very likely, and 4 = extremely likely. Nine of 192 respondents, 4.7%, said that their organization would not be at all likely to implement the system and because of the skip pattern in the interview guide, were not asked questions about:

1) who at the organization should receive warnings,
2) what type of warning system might be implemented at their organization,
3) barriers to implementation, and
4) false alerts.

Because these respondents were missing data on variables that were of potential significance in the logistic regression analyses, a subset of cases omitting these respondents was created with which to conduct the simple and multiple logistic regression analyses. However, prior to deletion, analyses were conducted to determine if the cases to be deleted because of missing data differed discernibly from the remaining cases. Only after no significant differences or patterns were detected were these cases deleted from the dataset. One additional respondent who answered “Don’t know” to the question on likelihood of implementation was also deleted. Thus, the analyses described in this section are based on a dataset of only 182 cases.

Next, the response categories of the dependent variable were collapsed from the original four described above to three by combining the “very likely” and “extremely likely” categories. This decision was based on frequency distribution across the response categories, the similarity in meaning of the category designation, and to facilitate interpretation of the results. Frequency distributions for both forms of the dependent variable are presented in Table 4.8.

Table 4.8 Frequency distribution of the dependent variable: Perceived likelihood of earthquake early warning system implementation (n=182)[1]

Original response categories	Frequency	Percent	Collapsed response categories	Frequency	Percent
Not very likely	32	17.6	Low likelihood of implementation	32	17.6
Somewhat likely	76	41.8	Moderate likelihood of implementation	76	41.8
Very likely	45	24.7	High likelihood of implementation	74	40.7
Extremely likely	29	15.9			
Total	182	100.0	Total	182	100.0

Nine cases were not included in these analyses because they were skipped out of questions of interest after indicating they were "not at all likely" to implement an earthquake early warning system. One respondent answered "don't know" to the question on likelihood of implementation and was also omitted from the analyses.

The predictor variables

Potential predictor variables were selected from each of the domains of interest and frequency distributions were examined for variability and missing data. When needed and as appropriate, new variables were computed to be used in the regression analyses. The following sections describe the variables selected from each domain, their frequency distributions, and, if applicable, how the variables were modified to be used in the logistic regression analyses. Response categories and frequency distributions for each of the potential predictor variables can be found in Table 4.9.

Organizational function variables

Predictor variables in the organizational function domain were looked at first. This domain included the institutional *sector* variable (education, emergency services, healthcare, and utilities and transportation) and whether or not the organization *provides education to the public on earthquake preparedness*. In the subsample of 182 cases, distribution of cases across the across education, emergency services, healthcare, and utilities and transportation was fairly equal, 26.4%, 25.8%, 26.4%, and 21.4% respectively. Sixty-one percent of the organizations provide public education on earthquake preparedness. Neither of these variables was modified for the regression analyses.

<u>Organizational structure variables</u>

Variables describing organizational structure were examined next. These included *number of employees*, *number of sites* and *ownership* of buildings or facilities. The number of employees and number of worksites were left as continuous variables for these analyses. The number of employees in Southern California ranged from 3 – 25,000, with a median of 155 employees. The number of worksites in Southern California ranged from 1- 221 with a median of 8.6 worksites.

Ownership of buildings was originally included three nominal responses (owns all, rents some, rents all) and was dichotomized into “owns all buildings” and “rents some or all buildings.” For the regression analyses subsample, 68.1% of the organizations own all buildings versus 28.6% that rent all or some of their buildings.

<u>Organizational earthquake experience</u>

Variables describing organizational earthquake experience were selected based on the possibility that the particular aspect of their experience would be most likely be mitigated with an earthquake early warning system in place. These aspects included *injuries, damage to equipment and building contents*, and *operational interruptions*.

Only 3.8% of respondents in the subsample, seven organizations, reported that people at their organization had experienced injuries in any earthquakes since 1985. Because the number was so small, this variable was not included in any of the regression analyses. However, 44.5% of organizations reported damage to equipment of building contents in previous earthquakes and 48.9% reported operational interruptions.

Organizational resources

The three organizational resource variables used for these analyses included: 1) current *use of computers to disseminate warnings*, 2) *existing technology* available in the organization to use for an earthquake early warning system, and perceived level of *financial barriers* to setting up and having a warning system. Of the three variables, current use of *computers to disseminate warnings* variable is the most straightforward. Fifty-seven percent of organizations reported currently using computers to disseminate warnings.

The *existing technology* variable was collapsed from a three-category variable to a dichotomized variable. In the survey, respondents were asked if the organization would use current technology, add to current technology, or need to install new technology for an earthquake early warning system such as the one described to them. Only 18% indicated the organization would install new technology, so this category was combined with the "add technology" category. Thus, for the multivariate analyses, a dichotomized variable was used in which 30.2% of organizations would use current technology for an earthquake early warning system and 69.2% would need to add to or install new technological resources for the system.

A *financial barriers* scale variable was computed and used in the multinomial regression analyses. The three variables specifically about financial barriers to implementing an earthquake early warning system – initial investment, maintenance costs, and monthly subscription costs were included in the scale. The scale ranged from 1 – not at all a barrier to 5 – a major barrier. The Cronbach's alpha was .86. The mean and median for the scale was 3.7.

Potential use for earthquake early warning system

The potential use for the earthquake early warning system was defined as whether or not the organization would use the system to just warn workers or whether the system would both warn workers and automate the start up or shut down of equipment. Forty-three percent of organizations would warn workers and automate equipment versus 35.2% that would only warn workers.

Cognitive factors

The three cognitive factors included in the regression analyses were: 1) exposure to earthquake early warning information in the media or from other sources, 2) belief that a 10-second warning would affect the number of injuries caused by an earthquake, and 3) perception of earthquake risk. Less than one quarter of the respondents, 21.4%, reported being exposed previously to information in the media or from another source on earthquake early warning systems. Half of the respondents, 50%, believed that the number of earthquake-related injuries would be less with a 10-second warning. And, 45.6% believed that there was a high likelihood of a major earthquake seriously impacting their organization in the future.

Table 4.9 Frequency distribution of the independent variables used in the simple logistic regression analyses (n=182)				
DOMAIN	**VARIABLE**	**RESPONSE CATEGORIES**		
Organizational purpose			#	%
	Sector	Education	48	26.4
		Emergency services	47	25.8
		Healthcare	48	26.4
		Utilities & transportation	39	21.4
			#	%
	Public education in earthquake preparedness	Yes	111	61.0
		No	68	37.4
		Missing	3	1.6
Organizational structure	Size – number of employees	Number of employees	**Range**: 3 - 25000 **Mean:** 1069 **Median:** 155 **Missing:** 6	
	Size & centralization – number of sites/facilities	Number of sites	**Range**: 1 - 221 **Mean:** 8.6 **Median:** 1 **Missing:** 3	
			#	%
	Ownership of facilities	Owns all	124	68.1
		Rents some or all	52	28.6
		Missing	6	3.3
Organizational earthquake experience			#	%
	Damage to equipment or building contents	Yes	81	44.5
		No	91	50.5
		Missing	10	5.5
			#	%
	Injuries	Yes	7	3.8
		No	159	87.4
		Missing	16	8.8
			#	%
	Interruption of operations	Yes	89	48.9
		No	84	46.2
		Missing	9	4.9
Organizational resources	Financial barriers	1- finances not at all a barrier 5 – finances a major barrier	**Range**: 1 - 5 **Mean:** 3.7 **Median:** 3.7 **Missing:** 3	
			#	%
	Technical resources – computer warnings	Yes	104	57.1
		No	78	42.9
		Missing	0	
			#	%
	Technical resources – use current or add to current/need new technology	Use current technology	55	30.2
		Add to/install technology	126	69.2
		Missing	1	.5

Potential use for EEW system	Use EEW system to warn workers or to automate equipment	Warn workers & automate equip Warn workers Missing	# 109 64 9	% 42.9 35.2 4.9
Bivariate Cognitive factors	Perception of earthquake risk	High perceived likelihood Low/med perceived likelihood Missing	# 83 97 2	% 45.6 53.3 1.1
	Exposure to EEW information in media or other source	Yes No Missing	# 39 137 6	% 21.4 75.3 3.3
	Belief that 10-second warning would affect number of injuries	Injuries would be less No change in # of injuries Missing	# 91 88 3	% 50.0 48.4 1.6

Overview of the predictive model development

Due to the exploratory nature of this study, the analysis was conducted in steps to develop a parsimonious predictive model. The first step in the analysis was to identify variables individually using simple multinomial logistic regression to assess which variable were predictive of likelihood that an organization would adopt and implement an earthquake early warning system. In the second step, variables that were significant in the individual analyses were analyzed using multivariate multinomial logistic regression. The third step was to test the final model using only the variables found to be significant in the first multivariate multinomial logistic regression.

Simple multinomial logistic regression analyses

The first step in developing the predictive model was to analyze each of the predictor variables separately using simple multinomial regression analysis with low likelihood of implementation as the referent category of the dependent variable. Of the thirteen independent variables examined, only two were significant for both comparisons of high and moderate perceived likelihood of EEWS implementation versus low perceived likelihood of implementation. An additional five variables were significant predictors of perceived likelihood of implementing an earthquake early warning system when comparing high perceived likelihood of implementation versus low perceived likelihood. Specific variables that were found to be significant are discussed below and presented in Table 4.10.

Organizations that provide public education on earthquake preparedness were three times more likely to report a high perceived likelihood of implementation of earthquake early warning system (OR=3.039, p=.011) and two times more likely to report a moderate perceived likelihood of implementation (OR=2.006, p=.091) than to report a low perceived likelihood of implementation. Organizations that perceived financial barriers to implementing and maintaining an earthquake early warning system as low, were four times more likely to report high versus low perceived likelihood of implementation (OR=4.216, p=.005) and two and one-half times more likely to report moderate versus low likelihood of implementation (OR=3.489, p=.076).

Organizations that would use current technology to implement an earthquake early warning system and those that would use the system to both warn workers and automate equipment were significantly more likely to report a high perceived likelihood versus a low perceived likelihood of EEWS implementation (OR=.444, p=.068 and OR=2.515, p=.05, respectively). Individually significant predictors of high versus low likelihood of EEWS implementation also included perception of earthquake risk, exposure to information on EEWS, and belief that a 10-second warning could impact the number of injuries in an earthquake. Organizations that perceive their risk from a future earthquake to be high were more than three times more likely to be in the category of high likelihood of implementation than low likelihood (OR=3.39, p=.008). Organizations with prior exposure to earthquake early warning system information were seven times more likely to be in the high versus low category of implementation likelihood (OR=7.102, p=.011) and those that believe a 10-second warning would reduce the number of earthquake injuries were 2.7 times more likely to be in the high versus low category (OR=2.679, p=.023).

Table 4.10 Simple multinomial logistic regressions: Predictors of likelihood of EEWS implementation with referent category for outcome variable – low likelihood[1]

INDEPENDENT VARIABLE	DEPENDENT VARIABLE: PERCEIVED LIKELIHOOD OF IMPLEMENTING EEWS (vs. low likelihood)	ODDS RATIO	SIG	95% CONFIDENCE INTERVAL
Provides public education on EQ preparedness	High perceived likelihood of implementation	3.039	**.011**	1.288 – 7.168
	Moderate perceived likelihood of implementation	2.066	**.091**	.890 – 4.80
Number of employees	High perceived likelihood of implementation	1.00	.795	1.00 – 1.00
	Moderate perceived likelihood of implementation	1.00	.816	1.00 – 1.00
Number of sites in Southern California	High perceived likelihood of implementation	1.055	.134	.984 – 1.132
	Moderate perceived likelihood of implementation	1.038	.303	.967 – 1.114
Owns all facilities	High perceived likelihood of implementation	.629	.331	.247 – 1.604
	Moderate perceived likelihood of implementation	1.043	.931	.397 – 2.740
Experienced equipment damage / building contents in previous earthquakes	High perceived likelihood of implementation	1.385	.453	.592 – 3.239
	Moderate perceived likelihood of implementation	1.198	.680	.509 – 2.819
Experienced operational interruptions in previous earthquakes	High perceived likelihood of implementation	1.503	.346	.644 – 3.512
	Moderate perceived likelihood of implementation	1.697	.226	.721 – 3.998
Low perceived financial barriers to EEWS	High perceived likelihood of implementation	4.216	**.005**	1.552 – 11.452
	Moderate perceived likelihood of implementation	2.489	**.076**	.910 – 6.807
Currently use computer for disseminating warnings	High perceived likelihood of implementation	1.572	.288	.683 – 3.619
	Moderate perceived likelihood of implementation	1.738	.193	.756 – 3.999
Would use current technology	High perceived likelihood of implementation	.444	**.068**	.186 – 1.062
	Moderate perceived likelihood of implementation	.534	.151	.226 – 1.258
Would use EEW to warn workers & automate equipment	High perceived likelihood of implementation	2.515	**.050**	.998 – 6.345
	Moderate perceived likelihood of implementation	.771	.560	.320 – 1.86
Perception of earthquake risk high	High perceived likelihood of implementation	3.39	**.008**	1.38 – 8.36
	Moderate perceived likelihood of implementation	1.72	.239	.699 – 4.24

Exposed to EEW information	High perceived likelihood of implementation	7.102	**.011**	1.56 – 32.27
	Moderate perceived likelihood of implementation	3.195	.143	.676 – 15.08
Believes that 10-second warning would reduce injuries	High perceived likelihood of implementation	2.679	**.023**	1.14 – 6.28
	Moderate perceived likelihood of implementation	.755	.514	.324 – 1.76
[1]Note: N for analyses ranged from 172 – 182.				

Multinomial logistic regression results

Variables found to be significant in the simple logistic regression analyses were then simultaneously entered into a multivariate multinomial logistic regression model to test for main effects. In this analysis, three variables contributed significantly to the model – perceived financial barriers, perception of earthquake risk, and belief that a 10-second warning would impact the number of earthquake-related injuries. These results are presented in Table 4.11.

The variables found to be significant in the previous analysis were then used to create the final model also using multinomial logistic regression techniques. In the final model, organizations that perceive financial barriers to EEWS implementation and maintenance be low were five times more likely to be in the high perceived likelihood of EEWS implementation category versus the low likelihood category (OR=5.191, p=.002). Organizations perceiving their future earthquake risk to be high were three and one-half times more likely to be in the high likelihood of implementation category versus the low likelihood category (OR=3.443, p=.01). And, organizations believing that a 10-second warning would reduce injuries were almost three times more likely to be in the high likelihood of EEWS implementation category versus the low likelihood category (OR=2.864, p=.025).

Table 4.11 Multivariate multinomial logistic regression analyses: Predictors of likelihood of EEWS implementation (Referent category – low likelihood) Model I (n=157)

INDEPENDENT VARIABLE	DEPENDENT VARIABLE: PERCEIVED LIKELIHOOD OF IMPLEMENTING EEWS (vs. low likelihood)	ODDS RATIO	SIG	95% CONFIDENCE INTERVAL
Provides public education on EQ preparedness	High perceived likelihood of implementation	2.326	.126	.790 – 6.852
	Moderate perceived likelihood of implementation	1.830	.251	.652 – 5.134
Low perceived financial barriers to EEWS	High perceived likelihood of implementation	7.476	**.002**	2.104 – 26.566
	Moderate perceived likelihood of implementation	2.758	.109	.797 -9.547
Would use current technology	High perceived likelihood of implementation	1.589	.418	.518 – 4.877
	Moderate perceived likelihood of implementation	.748	.602	.252 – 2.224
Would use EEW to warn workers & automate equipment	High perceived likelihood of implementation	2.043	.192	.698 – 5.977
	Moderate perceived likelihood of implementation	.705	.497	.257 – 1.935
Perception of earthquake risk high	High perceived likelihood of implementation	2.661	**.068**	.928 – 7.629
	Moderate perceived likelihood of implementation	1.624	.356	.580 – 4.550
Exposed to EEW information	High perceived likelihood of implementation	3.424	.147	.650 – 18.028
	Moderate perceived likelihood of implementation	1.777	.508	.324 – 9.745
Believes that 10-second warning would reduce injuries	High perceived likelihood of implementation	2.828	**.054**	.983 – 8.135
	Moderate perceived likelihood of implementation	.670	.443	.241 – 1.863

Table 4.12 Multinomial multiple logistic regression analyses: Predictors of likelihood of EEWS implementation (Referent category – low likelihood) Model II (n=174)

INDEPENDENT VARIABLE	DEPENDENT VARIABLE: PERCEIVED LIKELIHOOD OF IMPLEMENTING EEWS (vs. low likelihood)	ODDS RATIO	SIG	95% CONFIDENCE INTERVAL
Low perceived financial barriers to EEWS	High perceived likelihood of implementation	5.191	**.002**	1.809 – 14.896
	Moderate perceived likelihood of implementation	2.345	.105	.837 – 6.573
Perception of earthquake risk high	High perceived likelihood of implementation	3.443	**.010**	1.341 – 8.845
	Moderate perceived likelihood of implementation	1.844	.193	.735 – 4.626
Believes that 10-second warning would reduce injuries	High perceived likelihood of implementation	2.864	**.025**	1.140 – 7.195
	Moderate perceived likelihood of implementation	.817	.650	.340 -1.959

In summary, organizations that perceived the financial barriers of earthquake early warning system implementation and maintenance to be low (practical or implementation-related factor), their earthquake risk to high (cognitive factor), and believed that even a 10-second warning could reduce the number of injuries in an earthquake (cognitive factor) were the organizations most likely to have a high perceived likelihood of implementing an earthquake early warning system as compared to those organizations that have a low perceive likelihood of implementation. However, all other factors we posited in Research Question Set #2 might be associated with higher likelihood of implementation, were not. These included all factors related to organizational purpose (institutional type, providing earthquake-related education activities to the public), structural factors (organizational size, number of sites, ownership of facility buildings), and historical factors (experiencing damage in previous earthquakes, having persons at the organization experience injuries in previous earthquakes, experience a disruption of services in previous earthquakes) as well as one of the three cognitive factors (exposure to information about earthquake early warning) and three of the four practical or implementation-related factors (having technical resources for implementation, current use of an earthquake warning system, types of anticipated uses).

CHAPTER 5: RESULTS FROM THE KEY INFORMANT INTERVIEWS

The primary objective of the key informant interviews was to further explore the study's first set of research questions about how an earthquake early warning system might be used by specific types of organizations. However, to put these potential uses into context, the organizations participating in the key informant interviews are first described in detail, including the organization's basic characteristics (purpose, size, scope of services, etc.); current disaster preparedness and response activities, including warning systems; and if applicable, the organization's role in community response to disasters. These findings are described in the first section of this chapter.

In the second section of the chapter, potential uses and possible implementation strategies for an earthquake early warning system are described for each organization. These findings are compared both across organizations within an institutional sector and across then the sectors (education, emergency services, healthcare, and utilities and transportation).

The third section of the chapter explores which organizations appear to be more and less likely to implement an earthquake early warning system and the factors that either support or hinder the likelihood of implementation. Key concepts in this framework include perceived benefits of the system, organizational resources available and/or needed for implementation (primarily technological, financial, and educational), and specific barriers to system implementation.

The final section of the chapter summarizes and integrates the findings from the first three sections. The findings are compared across and with institutional sectors and across individual organizations to provide the detailed picture contained within the key informant interview data.

5.1 Description of Key Informant Organizations

Key informants from three organizations in each sector were interviewed for this component of the study. All operated with Los Angeles County. In the Education sector, we interviewed emergency management representatives from a medium-sized school district with approximately 85 K-12 schools, a large school district that included over 600 K-12 schools, and a university with two main campuses sites, satellite sites located throughout the county, and approximately 40 student housing facilities. From the Emergency Services sector we interviewed the emergency manager from a large city, the emergency services specialist from a small city, and the Battalion Chief of a fire department overseeing approximately 150 fire stations. Organizations and key informants from the Health Care sector included executive and administrative staff familiar with the organization's emergency management policies and procedures from a large health maintenance organization, a public health program and a convalescent/nursing home facility. Finally, we interviewed emergency personnel from two utility companies, one water company and one water and power company, as well from a large airport.

5.2 Potential Uses and Implement Approaches for Earthquake Early Warning

Potential uses of an earthquake early warning system as described by the key informants interviewed are presented here. Also, key informants described how an earthquake early warning system might be set up in their organization – for example, would the system be automatic or mediated by human intervention and how would warnings be disseminated.

Potential uses for earthquake early warning

Potential uses for earthquake early warning varied across the respondent organizations, but generally fell into three main categories: 1) personal safety, 2) operations, and 3) increased awareness of earthquake preparedness and response issues. While almost all organizations contacted for this study described personal safety uses for earthquake early warning, the two utility companies and the airport described major operational uses, also. Several organizations talked about the warning systems potential uses with respect to rapid notification, information dissemination, and increasing earthquake safety awareness both within and outside the organization.

Life safety responses to early warning

According to the key informants, potential life safety actions taken in response to an earthquake warning would be similar to those taken now when movement from an earthquake is first felt as well as those reported in the telephone survey.

> "I think with a minute warning, if we trained employees, a minute might be enough to have people react. I know when I first thought about this it was like there's no way I could do anything with this but if it's an alarm that triggers a minute [warning], people can get under their desk but after that? They don't want to shut down unless they know the power's going off and the generator kind of takes care of that. So I don't think we would do anything to automatically shut down anything, but a minute might be enough to have people under their desk at least." (Key informant, small city)

Examples of the safety actions mentioned included:

- dropping to the floor and/or taking cover
- protecting patients – i.e., stabilizing IVs, stopping surgery and other invasive procedures
- notifying people working underground or in other physically dangerous situations
- evacuating
- getting flashlights and other earthquake safety supplies
- having workers move away from hazardous materials situations – e.g., in labs, near chlorine tanks, etc.

Operational use for an early warning system

Key informants also described several ways in which facility operations could be made safer in response to warnings. Examples of these measures included the following:

- de-energizing power lines before ground motion causes them to the lines to slap together
- data capture – customer billing information, water system performance data, payroll data, etc.
- re-routing of planes (suggested by airport, but actually an FAA function)
- opening of fire house garage doors (suggested for fire stations serving LAX, not for Los Angeles County in general)
- stopping elevators or sending elevators to first floor
- possibly shut down boilers
- starting the paging process to emergency responders before the paging system is overloaded or shutdown

The two organizations identifying the most actions that could potentially be taken in response to early earthquake warning, including measures such data capture, were the two utility companies.

Organizations <u>not</u> particularly interested in the operationally-related uses stated 1) that they already have automated procedures in place that are triggered by ground motion or power outages (e.g., automatic gas shutoff valves); 2) that there would not be enough time to shut down operations before the ground shaking began; and/or 3) that shutting down operations is too costly an endeavor to consider unless there is a proven guarantee that it would save money or lives. One of the utility companies stated:

> "Our systems though are labor intensive. I don't know that we could do it in the time that you are talking about" and gave the example, "When we're loading chlorine out of a tanker into our filtration plant up there, the amount of time that you're talking about would not be enough time to stop the operations."

The key informant from the convalescent facility expressed that most of the operational functions that might be affected by a large earthquake already had mechanisms in place to address problems and so a warning would probably not be all that helpful. He said:

> "The emergency generator system would go on by itself. If there's that much damage, chances are it's not going to go on anyway because it's going to wreck the machine. The water shut offs and the gas shut offs really don't need to be shut off until there's some sort of determination that there's damage that warrants them to be shut off. We have people here that are on heating pumps that are on a battery, so they will run for awhile. We have certain people that are on pressure reduction mattresses that are like blow up balloons that require power. They may just have to go out for a short period and you know the staff gets regular training in disasters and know what to do."

Earthquake preparedness and response awareness and information sharing

Four organizations participating in the key informant interviews specifically mentioned uses or benefits of earthquake early warning related to 1) increasing earthquake awareness both within the organization and in the larger community; 2) increased opportunities to network with other organizations and agencies on earthquake preparedness and response; and/or 3) "real time" dissemination of earthquake information. For example, staff training on earthquake early warning would increase general earthquake awareness and might lead to better general preparedness and response. Several organizations including one of the utility companies, the large city, and the public health agency discussed how implementing EEW would provide opportunities for networking with other agencies and businesses that are engaged in similar preparedness activities, as well as with the general public.

The airport and the water and power utility company representatives talked about using EEW to disseminate information about an event, not necessarily before ground motion occurs at a site, but as or shortly after ground motion begins. These organizations felt a system such as the one described for the interview could provide important information to key staff quicker than technologies currently being used.

For example, key informants from the airport thought it would be helpful to have immediate information about earthquakes that occur at other airport sites for which the organization is responsible, not just the main airport site. Having immediate information following the event would allow airport to determine what type of assistance might be needed at these distant sites and to begin preparing to send resources. Warnings would also make it possible for the airport to provide information on its website regarding the impact of the event on air travel, terminal schedules, and other airport operations. In another example, water company representatives suggested that personnel who currently conduct field checks after an earthquake could be contacted as soon as an earthquake occurs. They could be given pertinent information so field checks could be started earlier and response efforts could be focused on areas most likely to have suffered damage in the earthquake.

How a warning system might be implemented: Automation vs. human decision making

Five organizations (two in emergency services, one each in education, healthcare, and utilities and transportation) indicated that to be useful the warning system would have to be fully automated. This meant that once the system hardware had been set up and thresholds set, messages, alerts (flashing lights, audible sounds such as bells or sirens), and facility or operational procedures would need to be electronically triggered. Key informants from these five organizations believed that if human beings were needed to make the decision on whether and how to respond to the earthquake, no action would be taken within the short warning timeframe.

Four organizations (two education, one utility, and one health care facility) indicated a preference for a mixed system in which part of the system would be automated, but part of the system would require human intervention to activate a response. For example, one health care facility described a situation in which the message would arrive at the nursing station, and then the person receiving the message would make a coded announcement over the hospital's public address system. While the threshold level for making an announcement would be predetermined, thus eliminating any need for decision-making at the time of the event, the actual announcement would be made by a staff person. This is like what is done now to alert hospital staff when there is an urgent situation such as a fire, infant abduction, or medical emergency within the facility.

Key informants representing the two school districts also expressed a preference for similar mixed systems in which warnings would be sent to the school sites and individuals at each site would activate an alert based on predetermined threshold levels. Both school districts also wanted the warning sent to the central emergency management office for the district. Additionally, the water and power company indicated that it preferred a "dual use" system consisting of an automated public address warning message for employees and, on the operational side, a series of informational messages sent to a key decision-maker, who would decide on the necessary operational response(s).

Only one organization, a healthcare agency, stated it would prefer a mediated system in which the warning message would come to a key person or persons within the organization, who would then determine if and to whom the warning would be disseminated. Two organizations, the airport and the fire department, were unclear about the type of system that might be best to implement at their facilities. Neither of these organizations seemed likely to implement an earthquake early warning system, and therefore it was difficult to get them to discuss possible system designs. The county fire department, however, stated that the organization "might use [it] as a mediated system."

Types of messages to be disseminated

Message simplicity was key to almost all the organizations. Ten of the twelve key informant organizations said that messages disseminated to employees would have to be quite simple. Many conceived of warning messages in terms of non-verbal auditory messages (i.e., bells, tones) and/or visual cues (i.e., flashing lights). It was generally agreed that verbal messages must be simple and concise – consisting, for example of a recording plainly stating, "Earthquake alert." As one key informant from a large university described the type of message that might be both useful and effective:

> "I think it could be either one [audible or text]. I think for people out there if it is just a written message, I think it would have to pop up on your screen automatically. It couldn't be something [like an email]. I personally don't think anybody else in their right mind would stop to read the message. If it's an earthquake alert and the one thing I see is "duck and cover" or "get out of the laboratory or the corridor," little things like that and I could see where that might actually be potentially useful. …I think it would need to be [an audible alert] if it could be. The problem is I don't think the idea of an audible alert would work. Most computers at universities, many, many, many of them don't even have a sound card. …Those who are kind of computer literate have made an effort to make their sound system work because they like to get the cool internet sounds when they play games or something."

All informants indicated that threshold levels for disseminating these alerts would be determined prior to the event and either programmed into the warning system software or incorporated into emergency policies and procedures and taught in employee training programs. In a slight variation, one organization went further and said that while generally disseminated warnings needed to be simple, some messages for key personnel would need to be much more detailed.

One organization, the water and power company, wanted to have a detailed informational message go to only one key decision-maker. They described this continually updated message as including information on expected level ground motion along with a progression of associated probabilities and confidence intervals. This information would be used to make decisions pertaining to critical operations (e.g., shutting down a power grid).

5.3 Likelihood of Implementation: Supporting and Prohibitive Factors

As the key informant interview transcripts were coded, three domains related to likelihood of implementation emerged. Perceived benefits of having a warning system made up the first domain. The second domain consisted of resources the organization perceived it would need to implement and maintain a warning system and whether these resources were available or could be obtained. The third domain was comprised of perceived barriers or factors within the organization that would work against or preclude implementation.

Potential benefits of implementing an earthquake early warning system

Potential benefits as described by the key informants were varied, but across the board life safety was seen a primary benefit of implementing an earthquake early warning system.

Another significant benefit described by organizations was avoiding service disruption and decreasing "down time." Because many of the organizations participating in this study are involved in community level emergency responses in addition to internal responses, decreasing the time of service disruption was seen as an important benefit to almost half of the organizations – two of the three organizations in the utilities and transportation sector, one of the health care organizations, and two of the three emergency services agencies. Educational entities appeared to be less concerned about avoiding or decreasing service disruption time. On the other hand, the county fire department thought that having an early warning system, if it was a publicly disseminated warning, would actually contribute to increased service disruption by tying up the 911 phone lines with unnecessary, non-emergency calls.

The water and power utility company also stated that many of its industrial customers (i.e., oil refineries) would probably benefit from and be interested in a warning system. The emergency manager for the large city also indicated that he believed that businesses would probably be interested in an earthquake early warning system for benefits such as data capture.

<u>Technical resources</u>

Most of the organizations contacted for the study do have various kinds of technical resources, but the level of technical expertise varies greatly across the organizations and even within the larger organizations. For example, while all the organizations use personal computers to some extent, not all these computers are connected to the Internet or networked to one another. As one key informant from the Education sector described the capacity of their systems to be used for earthquake warning:

> "We have a number of them [networked communication systems] but they're mainly computer systems. They're used for accessing district information as well as inputting data requested. The problem with it is the system is not readily available. It's not something that's on all the time."

He went on to describe several other radio systems in place use for a variety of purposes, but then went on to say:

> "…there's nothing that I know of right now, there are some potential things but nothing that I can think of right now that we could instantaneously use to say in ninety or sixty seconds there's going to be a quake of 4.5."

The comprehensiveness and level of integration of other types of communication networks (i.e., radios, pagers, etc.) also varied both within and across organizations. Regardless of their level of in-house technical resources and expertise, all the organizations interviewed thought that some outside consultation and support would probably be needed to integrate the new warning system into their current systems. Except for one organization, all the organizations also noted that warnings messages would probably need to be sent to multiple sites, possibly relayed to these sites after receipt and/or review at a central location or by key personnel.

Utilities & Transportation

The most technologically sophisticated organizations contacted for this study are those in the utilities and transportation sector – particularly the utility companies. Both have extensive centralized information systems, in-house technical expertise, and the hardware necessary to implement an early warning system such as the one described in the interview. Integrating warning messages into public address systems currently used for safety-related announcements did not appear to be problematic for either of these organizations. However, integrating warnings into operational systems would be more complicated and would probably require some assistance/expertise from outside the organization. Two specific technical issues raised in key informant interviews with utility companies included concern about network firewalls that could impede the delivery of messages and concern about how to link warning system software to existing systems. Both utility companies indicated that they would consider it beneficial to partner with other similar companies to further develop system uses and implementation strategies, and possibly to share development costs.

The airport did not have a centralized information system and was not really interested in implementing an earthquake early warning system. They expressed concerns about how people might respond to a warning and how it could affect airport operations. As one airport key informant put it:

> "If we panic them like Bob said, if they went out onto the airfield. That's where a majority of our exits go, emergency exits and if it was a false alarm, then we've breached security and basically you have to shut the whole airport down for hours and hours as you try to round up all the folks back in there again. So it may not be form an operational standpoint. I agree I don't think that's something we'd want to do."

And another said:

> "Most of the exits are around glass doors. So the worst thing you do is tell them to run to the exits because if you had a bad earthquake, that's where all the glass is going to be flying."

They did suggest that the FAA, which controls communications with air traffic, and the individual airlines, which control communications within the terminals, might have uses for a warning system and also have the means by which to communicate warnings to appropriate targets. The airport was potentially interested in how warning system data might be used to provide "real time" information regarding airport conditions and operations to or from distant sites or to the public via their website.

Education

The three educational institutions interviewed also vary widely in their technological sophistication and access to technology resources and expertise. As an organization, the large university had the most in terms of technological resources, but this varied greatly across departments within the university. The computer and communications systems are decentralized, making it difficult to envision consistent or comprehensive dissemination of warnings across the different parts of the university. It was suggested that a system might be piloted in one or two departments before even considering wider dissemination of warnings. The information technology group from the university would need to be consulted before any decisions could be made about which departments and how the departments might be involved in an initial testing of an early warning system.

The large school district reported having limited technological resources and would need to complete a district-wide technological assessment before proceeding with any implementation discussions. Disseminating a warning to the district emergency services office would probably not be difficult, but getting the warning out to all schools, particularly in a timely manner, would be problematic. According to the key informant, once the warning reached the schools, getting it into the classrooms was not difficult. However, while all school sites have bell systems in place, the public address systems in schools are only about "20% effective." Thus, while it was feasible to have a tonal (bell) warning disseminated into the classrooms, it was not possible at this time to widely disseminate verbal warning announcements through the schools' public address systems that would reinforce those warning signals. It was suggested that TriNet technological representatives would need to meet with information technology personnel from the district before proceeding with any plans for testing or implementation of a warning system.

The medium-sized school district to have a more sophisticated and comprehensive communications system than the larger one. This district had about 110-115 sites that have computers operating on the same software programs. The district also had access to a radio station that could broadcast messages as well as video capabilities in some school administrative offices. However, according to the key informant, the public address systems in the schools were "untrustworthy." Even though the district had a communication systems department, it did not have programmers and would require tutorials and/or technical assistance to set up a warning system.

Health Care

The smallest of the health care facilities interviewed for this study, a convalescent home, had extremely limited technological resources. The facility had a computer at the main nursing station, but it was not Internet-connected, nor did a staff person monitor it on a continual basis. The facility did have a centralized electronic fire alarm system, but if an early warning program were to be incorporated into this system, the convalescent home would need a "professional" to install it.

Conversely, within the large healthcare system, all hospitals and 40% of the staff were linked through a computer system. Computers were on and connected and hospitals staffed 24 hours a day, seven days a week. The organization also had inter- and intra- hospital radio communication, as well as public and private telephone lines. The organization had a technology information systems department to provide support and expertise for implementing an early warning system. However, they also indicated that it would probably also require additional technical support to integrate earthquake warnings into its current communications systems.

The public health department also had numerous communication systems, several specifically for emergencies or health incidents. Further assessment would have to be conducted to determine how another warning system might be linked into one or more of these systems. The public health department had technical support available in-house but would probably also need some help from outside sources to set up and integrate a new system in with current systems.

Emergency Services

The fire department had a centralized communication system but was not interested in "infusing an unknown" into its "critical dispatch system." If the department were to implement a warning system in any capacity, the agency would probably have to hire a consultant to assist with this process. From a different perspective, the fire department expressed concern that if warnings are disseminated to the general public, it would likely cause technical problems in the current 911 emergency call system. Calls from the "concerned" public about an "impending" earthquake could overload the system and prevent real emergency calls from getting through.

The small city had computers connected to the Internet and an in-house emergency communication system (i.e., bell and flashing light alarms). The city would implement a new warning system using in-house expertise if software is "user friendly," but they also had a consultant available if the installation and integration were more complicated than they could handle. The emergency services office would also probably want to link the warning system with local fire and police communication systems. This would probably require some outside technical support to set up.

The key informant from the large city said that they would have the earthquake early warning system interface with current communications systems that included the Internet, radio, television, and satellite connections. However, he also said that "city government is highly complex and bureaucratic, and all technical systems within the overall system are not necessarily linked or compatible." The city would also want to work with local businesses and others in the community to expand the system's uses and dissemination of warnings. Implementing this type of network would necessitate conducting widespread technological assessments and meeting technological needs on many different levels.

Education and training resources

For almost all organizations participating in the key informant interviews, education and training was described as having to take place on at least two, possibly three, separate but equally important levels. In this case, "education and training" denotes activities that not only address how to elicit appropriate response behaviors from warning recipients, but also activities that 1) increase organizational decision makers awareness and knowledge of earthquake early warning systems and 2) provide the organizations' technological personnel with necessary information and resources to integrate a new warning system into current communication systems.

First, and perhaps most critical, to introduce a new warning system into the organization and to obtain "buy-in" by organizational management, executive level personnel would have to be "educated" as to what real time earthquake warning is and what it is not (earthquake prediction); how it works; the reliability of the TriNet system in providing earthquake warnings; and the potential benefits of implementing an early warning system in the organization. This type of information would need to be presented by credible sources involved in the development of TriNet and the warning system such as scientists and representatives from Caltech, CDMG, and USGS. Many of the organizations interviewed also believe that endorsement by OES would be particularly important to obtaining management "buy-in" for implementing the system and/or participating in the pilot study.

Once management "buy-in" was obtained, in most cases, the developers of the warning system as well as experts in related fields (e.g., engineering) would need to work with the organizations' information technology and facilities personnel to determine 1) how the warning system could be integrated into or added onto current technological systems and 2) at what thresholds the system should be set to disseminate warnings and/or trigger automated responses.

While a few organizations we spoke with appeared to have the technological expertise to make these decisions (e.g., the utility companies), most did not. Thus, for many agencies, technical education or training resource would be an integral part of implementing a warning system.

Almost all organizations interviewed believed that training personnel to appropriately respond to earthquake warnings could be easily incorporated into current emergency response and personal safety education efforts. All these organizations have policies and procedures in place for responding to emergency situations, and all conduct safety/emergency response drills or exercises on a regular basis. Some of these exercises consist of internal meetings or small-scale drills involving a limited number of sites and personnel, while others are widespread large-scale exercises involving numerous organizations and multiple sites.

However, there were also concerns expressed regarding training individual responders. These concerns included the cost of developing trainings and training materials, getting non-staff people who are on-site to respond appropriately to warnings, resistance by staff to take on another responsibility or activity, especially if it requires time or resources needed for completing daily tasks or providing basic services, and difficulty keeping people trained due to rarity of real events and/or staff turnover.

Potential funding mechanisms and resources

Key informant interview data indicated that funding issues for potential user organizations vary with the cost of the system. In general, if the system costs the organization less than approximately $5,000 to $10,000 to implement, funding would probably be handled internally, within the department responsible for the organization's emergency response and safety activities. This amount refers to a one-time implementation cost and does not include funding for maintenance or resources that would need to be devoted to the education and training needs associated with adoption of the system. Almost all of the organizations contacted for key informant interviews have funds specifically allocated for general emergency response and safety activities. A few key informants also had ideas on where additional funding might be sought – both within and outside of their organizations.

Organizational informants indicated that if the cost of implementation is more than approximately $10,000, funding will probably need to come from outside the organizational department handling emergency/safety services. This will involve obtaining funds from the overall organizational budget, applying to external funding sources, or forming cost-sharing partnerships with other organizations. The utility companies and the large city indicated an interest in partnering with other businesses and agencies to share potential implementation and maintenance costs. Obtaining funding through external sources would require a longer and probably detailed and persuasive information on the proposed system than funding the system through a departmental budget would entail. If funding had to be obtained or approval gotten from outside a department, having comprehensive and credible information about the system becomes even more crucial to the funding process – whether this process involves applying for grant or loan money or seeking "buy-in" from the financial decision makers in the organization.

Barriers to implementation

Several areas of concern arose around barriers to implementation. These included organizational complexity and decentralization, weighing potential benefits against potential harms, organizational decision-making processes, and the short amount of time between the warning and the earthquake.

During the interviews it became clear that in many organizations participating in the key informant interviews, warning dissemination could be problematic due to organizational complexity and decentralization. Not only do different departments within an organization have different warning needs, but some larger, more complex organizations such as the university, the airport, and the large school district do not have a single communication system that can instantaneously and simultaneously send warnings to multiple sites or multiple locations within one site. As the key informant from the university put it:

> "It's a very de-centralized organization. Our university is more like a city than it is like a corporation. Corporations are more centralized. They probably have centralized control of everything in their building whereas we have 300 buildings, each which have different situations and not centralized control."

Once the cost of the system is known, the issue then becomes one of weighing the relative costs and benefits of different safety and hazard mitigation activities and approaches within the context of available resources. At least one organization contacted as part of the key informant study had already mentally completed this type of assessment and concluded that the organization's time and monies would be better spent on safety education or non-structural mitigation. Others, such as one of the health care organizations, indicated that state and federal regulations dictate both explicitly and implicitly how money is spent in this area, leaving them with no money and hence no interest in investing in an earthquake early warning system.

Although the airport did discuss disseminating warnings to employees so they could take personal safety actions, this was not a compelling enough reason for the organization to want to implement an earthquake early warning system. The airport managers interviewed for this study indicated that since their employees are trained to take self-protective actions when ground shaking begins, an additional 10-90 second warning would not add a significant benefit to the practice. As stated before, they also thought disseminating warnings to people in the airline terminals would not only cause panic but could conceivably result in more and bigger problems for the airport, for example by causing more injuries and disrupting airport operations. It was pointed out in these interviews that many of the outer walls of the terminals are glass. Airport officials expressed concern that if people in the terminals heard an earthquake warning over the public address system, they would run toward the exit---and toward glass that could break and cause severe injury. Key informants from the airport also noted that if people were to run out onto the airfield, it would constitute a major breach of airport security and the entire airport would have to be shutdown regardless of whether the earthquake caused any damage.

The fire department was another organization that expressed concerns about warnings causing more harm than good. If personnel were actively engaged in response activities when shaking began (i.e., getting equipment together, moving fire trucks), it was felt that the potential for personal injury might increase. It was also noted that there are fire stations located in some parts of Los Angeles County where opening the fire station doors and leaving them open, especially late at night or very early in the morning, might lead to negative consequences for either fire department personnel or equipment.

Organizational decision-making processes

When discussing the organizational decision-making processes regarding warning system implementation, respondents generally referred to two key factors that would influence how the decision would be made: cost to the organization of implementing and maintaining the warning system and extent or type of warning system implementation proposed for the organization. Not surprisingly, the more costly and extensive the warning system being proposed, the more people would have to be involved in the decision-making process. In some cases, approval for implementing a warning system would be the responsibility of one key decision maker, while in others it will require approval by an executive management committee or an advisory board.

For example, for the small city, where the most likely use of the warning system would be to trigger an audible alarm alerting people to take personal safety actions such "drop and cover," if the cost of implementation is under $10,000, the decision to implement would most likely be made by a single key person such as the emergency services manager. On the other hand, at a large utility company where power grids might be shutdown based on information received through the warning system, a task force would be assembled to evaluate and make recommendations about implementation. This task force would include representatives from several areas in the organization such as customer service, field personnel and system operations. If the task force decides to recommend implementation, the decision would then have to be "sold" to the executive management team.

Another factor thought to potentially influence the organizational decision-making process was the stage of implementation being considered. The decision to implement a warning system on a limited basis for pilot testing might be made by a single person, perhaps with some input from other key personnel, but widespread implementation would require a more involved decision-making process. Executive decision makers could use or might want information obtained from participation in the pilot study to determine if more extensive implementation of the system is warranted.

For some organizations, implementing or not implementing an earthquake early warning system also may have positive or negative social and political implications. In these cases, the agency may need to obtain "community" input prior to making decisions about implementation. This is a particularly salient issue in organizations that provide public services and are supported primarily by public monies (i.e., city emergency services and schools). However, if the costs of implementing and maintaining the warning system fall within budget amounts already allocated for organizational safety activities, public support is generally less of an issue.

Regardless of the variety of decision-making processes engaged in by different organizations, all organizations interviewed for the study would require more information from the group developing or running the system before making any decisions about implementation. This additional information would include technical details about how the system works and the reliability of the system and the data as well as practical ideas and assistance on how the early warning system technology could be integrated into existing organizational technological systems.

5.4 Comparing and Contrasting Key Informant Organizations

In general, the data in these areas were mixed. Most organizations believed an earthquake early warning system could provide them with some potential benefits. However, many also expressed reservations about the usefulness of short warning times, as well as concerns about system reliability and potential costs of implementation and maintenance. Overall, there were four organizations that appear to be "likely" warning system users (the two utility companies, the large city, and one health care organization); four that could be described as "possible" users (two school districts, the small city, and the university); and four that are "unlikely" users (two health care facilities, the airport, and the fire department).

It should be noted that two of the unlikely users, the airport and the fire department, both indicated that other related organizations (e.g., the FAA or individual airline companies) or individual units within the organization (e.g., a specific fire station) might be interested in implementing an earthquake early warning system. Based on information obtained in the key informant interviews, further investigation of these possibilities appears to be warranted, but is beyond the scope of this study.

5.5 Comparing Quantitative and Qualitative Findings

Findings were from the quantitative and qualitative components of the study were triangulated across three separate domains: 1) who should receive the warning, 2) ways to implement the system, 3) potential benefits of the system. Survey findings indicated that most organizations in the sample, 48.9%, would have warnings go selected workers with specific responsibilities and about one-third of the organizations would have the warning go to everyone. Most of the key informants discussed having warnings that would go to workers who had specific responsibilities and then having this person or persons disseminate the warning to a wider group and/or use the warning to initiate or shut down some type of operation. Several discussed that they would like to have the warning go to everyone, for example in the schools, but did not feel that their technological resources at the time would support wide-spread dissemination.   About 57% of the respondents in the telephone survey reported that warnings should both go to people to warn them to take protective action and to machines or systems to start or stop operations. Key informants generally talked about both uses also, but also about how there were limits to the technology available to them to be able to do this.

In the telephone survey, respondents were asked to rate the importance of obtaining specific benefits from an earthquake warning system. In general, a reduction in injuries was rated most important, then increased effectiveness of emergency response activities, followed by prevention of injuries and damage from secondary hazards, preventing loss of data and finally reduction in damage to equipment. Further analyses indicated importance of potential benefit varied significantly across institutional sectors for reduction in injuries, reduction in equipment damage, and increased effectiveness of emergency response. And overall, respondents in the utilities and rransportation sector rated the importance of each of these potential benefits lower on average than respondents in the other groups. In examining findings from the key informant interviews, the desired or expected benefits of a warning system described were varied, but across the board respondents were interested in the potential for increasing individual safety of their workers and constituents. This is consistent with the survey results. At the same time, key informants often expressed doubt that warning times of a minute or so would allow for actions that would significantly improve on what is already done either by individuals or the organization.

CHAPTER 6: DISCUSSION & IMPLICATIONS

6.1 Discussion of Main Findings

Summary of main findings from telephone survey

Based on survey results with representatives four different sectors, most organizations had experience with earthquakes, however few had experienced major damage or injuries. A large majority of respondents, approximately 80%, reported some type of damage, most of it minor, to their organizations from earthquakes occurring since 1985, but only eight respondents (4.2%) reported that any of the organization's employees had suffered injuries from an earthquake while at work. Slightly half of the organizations reported interruptions to operations from earthquakes. Of those reporting interruptions, about one-quarter reported interruptions as lasting 12 hours or less, one-quarter reported interruptions for about 24 hours, and about half reported interruptions lasting for more than a day.

Almost all organizations reported undertaking life-safety responses when earthquakes occurred, however far fewer reported operational responses such as shutting down equipment, and very few, only 9.4%, reported taking action to protect computer systems and data. Even though the vast majority of organizations undertook life-safety responses, this varied by sector with education at 100%, healthcare at 98.1%, utilities and transportation 97.6%, and emergency services significantly less at 89.8%.

Use of alerts for facility operations also varied by organizational sector. Operation and facility responses were most often mentioned by organizations in the utilities and transportation sector. Utility companies most often described equipment or operations such as fuel pumps, boilers, and heating and cooling systems being shut down in an emergency. Respondents in the utilities and transportation group also volunteered that their organizations may close pipelines, turn off gas to customers, and stop trains and trucks. Healthcare organizations reported turning off medical equipment such as dialysis machines and oxygen tanks. In general, generators and sprinkler systems were the most frequently described systems triggered by an alert. About half of respondents volunteered that their organization used backup generators or some other source of power in an emergency. Whether these operations were automatic, manual, or a combination of both varied, but respondents in the education sector were least likely to volunteer that their shutdown or startup procedures are automatic and also least like to volunteer that they have backup power sources (e.g., generators).

In general, most organizations used some type of alert system, but types of systems and how alerts were disseminated varied by organizational sector. Almost all organizations reported having fire alert systems and one-third had some type of earthquake alert system. Educational organizations were more likely to already have some type of earthquake alert system, a bomb threat warning system, and systems for locking down campuses due to intruders, threats of violence at the facility or in the surrounding community. Significantly more organizations in healthcare than the other sectors reported alert systems for hazardous spills. Overall, audible non-verbal alerts were used most. Healthcare organizations were more likely to report using verbal messages disseminated through public address systems and all education organizations reported using non-verbal audible alerts on public address systems. Least common form of dissemination was through computers with only 56.3% of organizations reporting using these methods.

Most often warning times available in earthquake early warning were thought to be too short to do anything other than what was already being done, just seconds sooner. Most respondents indicated that with only 10 seconds of warning they would not change their earthquake responses other than undertaking them sooner. Only 3.1 % of respondents said that their organization would do something new or different with this amount of warning. With at least 50 seconds of warning, about half of organizations reported that they would undertake additional or different responses.

All potential benefits of an earthquake early warning system were rated as fairly important: reductions in injuries, reduction in damage to equipment, prevention of data loss, prevention of injury and damage from secondary hazards, and more effective emergency response. The potential benefit rated highest in importance was reduction in injuries. However, educational organizations rated this benefit more important than did those from utilities and transportation. Overall, respondents in the utilities and transportation sector rated the importance of all potential benefits to be lower than those from the other sectors.

Simple multinomial logistic regression analysis identified seven significant predictors of high perceived likelihood of implementing earthquake early warning. These included 1) providing public education on earthquake preparedness, 2) low perceived financial barriers to implementing earthquake warning, 3) technology in organization, 4) dual use of warnings (alert people and automate equipment), 5) high perceived risk of earthquake impacts, 6) prior exposure to earthquake early warning information, and 7) belief that a 10-second warning would reduce injuries.

In the final mutinomial multiple logistic regression analysis, the variables most predictive of the likelihood of implementing an early earthquake early warning system included low perceived financial barriers, high perception of earthquake risk, and the belief that as little as 10 seconds of warning would reduce injuries.

Summary of main findings from key informant interviews

Findings from key informant interviews were consistent with findings from the telephone survey and expanded on issues that the organizations thought were potentially problematic. Potential uses for earthquake early warning varied across organizations, but generally fell into three main categories: 1) personal safety, 2) operations, and 3) increased awareness of earthquake preparedness and response issues. In general, potential life safety actions in response to an earthquake warning would be like those taken now when shaking is felt, just sooner. The utility companies identified the most operational uses for earthquake early warning describing how operations or equipment might be shut down. Descriptions of potential ways to implement a system and disseminate warnings varied across organizations depending in large part on what the warning would be used for as well as what technical resources were available to the organization. Many organizations discussed ways that earthquake warning might be integrated with systems already in use.

New areas of potential benefits that came up in the key informant interviews included partnering with similar companies to develop uses and implementation strategies, using earthquake early warning for increasing earthquake awareness both within the organization and in the larger community, having increased opportunities to network with other organizations and agencies on earthquake preparedness and potentially being able to have a more consistent and integrated response across organizations.

Potential barriers to implementing an earthquake warning system were discussed in detail, including issues with disseminating warnings throughout large, decentralized organizations with multiple sites; not having the technology and technological expertise inhouse to receive and disseminate warnings; concerns about short warning times, particularly for shutting down equipment and operational processes, costs, and buy in from organizational management and decision makers.

<u>Research questions and findings</u>

The study's first set of research questions were descriptive, asking how organizations might use earthquake early warning and if use would vary by institutional sector. It was hypothesized that potential uses would fall into three primary domains – life safety, property protection, and operational continuity. These questions were answered through both the quantitative and qualitative components of the study. Using earthquake early warning for life safety was of interest to all organizations as illustrated by findings in both the telephone survey and the key informant interviews. The two other domains of use, property protection and operational continuity, were not clearly delineated from each other in the findings. However, there was interest in using earthquake warnings for starting and stopping operational processes. These types of uses were of most interest to organizations in the utilities and transportation sector as shown by findings in both the quantitative and qualitative components of the study.

The second set of research questions focused on what organizational characteristic were associated with the perceived likelihood of an organization implementing earthquake early warning. Characteristics were grouped into five categories: 1) organizational purpose (institutional type, providing earthquake education for the public), 2) structural factors (organizational size, number of sites, ownership of facility buildings), 3) historical factors (experienced damages, staff injuries, disruption of services in previous earthquakes), 4) cognitive factors (perceived risk, belief that earthquake early warning would reduce injuries, previous exposure to information about earthquake early warning, and 5) practical or implementation-related factors (financial barriers, availability of technical resources, current use of an earthquake warning system, anticipated types of uses). These questions were examined through analysis of the telephone survey data. Simple multinomial logistic regression analysis identified seven of these characteristics as significant predictors of high perceived likelihood of implementing earthquake early warning. In the final multinomial logistic regression analysis, only three of the characteristics remained significant – low perceived financial barriers to implementation, perception of earthquake risk high, and belief that having a 10-second warning would reduce injuries.

Conceptual frameworks, prior studies and results

While a specific conceptual framework was not used to design this study, relevant frameworks (i.e., adoption of innovation), theoretical concepts (i.e., perception of risk) and the limited research on organizational disaster preparedness and behavioral responses to earthquakes were employed to guide the development of the questions used for data collection and the analytical plan. Not all the ideas derived from these sources were borne out in the results, but in general they provided a good starting point for this research which was exploratory and descriptive rather than causal and explanatory in purpose and design.

6.2 Significance

Although rare occurrences, major earthquakes in Southern California can have serious and even devastating impacts and so are well worth preparing for and mitigating against. The probability of a major earthquake occurring in the Southern California area in the next 30 years is high. It is expected that the impacts from such an earthquake will be catastrophic, resulting in a great many deaths, innumerable injuries, widespread damage, and massive financial costs. An earthquake early warning system has the potential to help ready us for such an event through increased knowledge and awareness about earthquake preparedness and response, and then to respond in ways that will reduce deaths, injuries, and damage when the event occurs. However, implementation of an earthquake early warning system for Southern California is a huge and expensive undertaking. Ultimately, to be effective, careful thought and planning needs to be put into all aspects of the system, including the technology, reliability, length of the warning time, use of human mediation, channels used to issue warnings, settings, goals and objectives. This study was an important part of the beginning of the earthquake early warning development process and even though the research was conducted 20 years ago some of the findings are even more significant now that the technology has advanced to the point wherein warnings can be easily disseminated to individuals wherever they are. Moreover, it should be noted that despite the risk of a major earthquake California has yet committed the resources needed to fully build out the system.

Findings from the study indicated that the proposed method of disseminating warnings through internet-connected computers would not be feasible in many organizations at the time the study was implemented. Luckily, the almost ubiquitous use of smartphones and other electronic devices has provided a channel for widespread dissemination of warnings to individuals. This means that individuals, no matter where they are, can now be warned to take protective actions like “drop, cover, and hold” or to move away from hazardous situations (e.g., in labs with toxic chemicals) prior to the arrival of ground shaking at their location. Less clear is whether, even with improved technology, the short warning times likely to be provided are sufficient to allow for complex actions such as equipment or operational shutdowns. Study findings indicated that uses like this vary across organizations and how earthquake warnings might be implemented within an organization for these purposes may need to be individualized.

Overall, there was both interest in and concerns about using an earthquake early warning system. In addition to the life-safety aspects of early warning, organizations were interested in earthquake early warning for its potential for stimulating networking and collaborative work across organizations around earthquake preparedness and response. This interest could be built upon and used to help promote the use of earthquake early warning by organizations even now. Concerns of financial barriers, technological resources needed, and buy-in from management and organizational decision makers are still very salient. To realize widespread adoption of earthquake early warning in organizations, these issues continue to be relevant and still need to be addressed.

6.3 Strengths and Limitations

Overall, the study was well developed, and the mixed methods design provided both breadth and depth. Involvement of system designers and other disaster practitioners in the development of study questions helped insure that the information gained would be salient and practicable This was primarily an exploratory study and as such we wanted to elicit a broad range of views about the potential uses for and benefits of earthquake early warning. Thus, the interview questions tended to be general and cover a variety of topics. Additionally, the telephone survey and key informant interview samples were designed to include a number of sub-samples within the four main institutional sectors of education, emergency services, health care, utilities and transportation. This broadness of topic areas covered, and the heterogeneity of the sample were strengths in that they provided a breadth of knowledge in an area that up to this point little was known.

While these design elements did support the study's exploratory aims and provide insight into a topic that has thus far not been systematically examined, they, along with the small sample sizes, also limited the analytical approaches that could be used and the conclusions that could be drawn from the study results. The most striking example of how the study design may have "muddied" the study results is illustrated by the lack of statistically significant differences between institutional sectors on key questions as was originally hypothesized. Within each sector size and subtypes of organizations varied greatly. It may be that heterogeneity within institutional sectors made comparisons across sectors inappropriate.   However, comparisons of sub-groups within or across sectors were not possible due to very small size of the sub-groups. How these limitations could be addressed in future research is discussed in the next section. Additionally, I believe including businesses the study of organization adoption of earthquake early warning would provide valuable insights and information not gained from this study.

It must be noted here that data for this study were collected about 20 years ago. However, the questions and issues addressed in this study and most of the results are still relevant. This study is perhaps even more relevant now than before as the State of California moves forward with its plan for a statewide earthquake early warning system. The seismic monitoring system throughout California has been expanded over the years, but the basic concept of how the warning system would work remains the same. The biggest change since this study was conducted has been in the advancement of communication technologies, particularly in our ability to transmit information very quickly to a vast number of individuals. As discussed in various parts of this dissertation, and following, this does not negate the findings of the study and actually addresses some of the concerns brought up by respondents about the then proposed way of disseminating warnings through personal computers.

The model scenario used in this study was developed at a time when there were far fewer ground motion monitors throughout Southern California, though the means of transmitting information from these monitors to CalTech facilities were in place. What was still to be worked out was how that information could very quickly be processed and transmitted out to end users such as the organizations that took part in the study. Additionally, having organizations or individuals receive the warning information was predicated on having a computer powered up and connected to the Internet 24 hours a day, seven days a week. At the time, this imposed limitations on which organizations might be able to implement a warning system based on their level of technological resources. It also potentially limited further dissemination of the information to individuals within the organization once the information was initially received. With the far-reaching developments in wireless and mobile communications over the past decade, this component of the warning system prototype has changed considerably and warrants further study. This issue is discussed in more detail in the next section.

6.4 Implications

Implications for research

Earthquake early warning involves sending out alerts for a low-probability high-consequence event within a very short time before the event occurs, from seconds to possibly a minute and a half. Research on how people respond to real time warnings such as these is limited. To increase the likelihood that earthquake early warning is implemented more widely in a manner that supports successful outcomes, further research is needed. In a study by Kim, et. al on influences on taking protective action upon receiving Wireless Emergency Alert (WEA) messages, only one in five people took immediate protective action. The study also showed that individual characteristics (language spoken at home, prior exposure, and desensitization to emergency alert messages), the messages themselves, and other situational factors all influence what protection actions were taken (Kim, 2019). While most people living in Southern California have been exposed to an earthquake or two, far fewer have been exposed to earthquakes causing significant injuries and damage and almost none to an earthquake the magnitude of what is predicted for the area. Most people are not aware of or know little about earthquake early warning. On the other hand, with the increase in California wildfires each year, the current pandemic, and the increased use of technology to disseminate warnings, warnings are more and more prevalent.

In the article, Communicating Actionable Risk for Terrorism and Other Hazards, M. Wood and colleagues propose shifting the emphasis in risk communications from the risk itself to what should be done or what protective actions should be taken (Wood, 2012). While their study focused on household disaster preparedness, the approach seems applicable to earthquake early warning and should be examined further to determine what types of messages would be most effective in promoting self-protective behavior when an earthquake warning is received. Other research has shown that for low-probability high-consequence events, risk communications need to be available across different channels, should be consistent, and as stated above, people need to know what to do. As earthquake early warning becomes more accessible to more people, evaluative research should be conducted to ensure that these aspects of the warnings and the warning systems addressed.

Additional research is needed on the adoption of earthquake early warning by organizations and businesses. The research presented in this dissertation indicates that uses and implementation of earthquake alerts will vary across organizations depending on many factors including what alerts will be used for, resources needed and available for initial set up and maintenance, and management views on the utility of the system. Businesses and organizations that are already using earthquake early warning can provide valuable insights into benefits and barriers and areas of improvement for earthquake early warning for similar service providers and industries. Also, more research is needed on how earthquake early warning can be integrated into existing systems with an organization and used to automate processes when appropriate.

Even though some research has been done on the use of new technologies for disseminating warnings, communication technologies are evolving at a fast pace and additional research is needed how these can best be used for earthquake early warning. When this study was conducted, the proposed method of disseminating alerts was through personal computers. Now, much of the focus is on smart phone applications. Other channels of communication need to be examined so that the most effective warnings can be received by the most people, but also to learn how warnings can be best communicated to larger groups such as organizations, business, and communities.

And finally, I believe it is important to examine cost-benefit or cost-effectiveness aspects of earthquake early warning. Developing and implementing a comprehensive and effective earthquake early warning system for Southern California is a financially expensive and time intensive endeavor requiring the concerted efforts of many. There are many competing priorities for resources in our society, and it is unclear to me if and why earthquake early warning should be one of them. Balancing the costs of implementing a system for an event that occurs rarely, although potentially catastrophic in its impact, against the day-to-day needs and problems in our communities is an important undertaking. More information is needed to make this kind of assessment.

Implications for practice

As just mentioned, there are many competing needs and limited resources for an intervention with narrow uses, especially for a low probability event. In this environment, it is important to note that numerous warning and messaging systems are already in use. Rather than looking at earthquake early warning as a unique system even though it has unique characteristics, we should look closely how it can be integrated into public systems already available. California has guidelines for issuing alerts and warnings set forth in the State of California Alert & Warning Guidelines issued by Governor Gavin Newsom. There is a national internet-based system for providing alerts in local areas to the public operated by the Federal Emergency Management Agency (FEMA). The Integrated Public Alert & Warning System (*IPAWS*) public disseminates emergency messages through mobile phones using Wireless Emergency Alerts (WEA), to radio and television via the Emergency Alert System (EAS) and through National Oceanic and Atmospheric Administration (NOAA) weather radio. WEA specifically delivers text-based alerts and warning messages to the public prompting them to take protective action. Working with government agencies (federal, state, and local) and integrating earthquake early warning with established warning systems is vital to implementing a public and effective system. It can also help with maximizing existing resources, expanding available methods for disseminating messages, and reducing warning fatigue experienced when too many messages are coming from too many sources.

To promote the use of earthquake early warning by organizations, we need to build capacity within organizations that supports the warning system implementation and use. This support may be in the form of guidelines or toolkits for creating systems tailored to different types of organizations or businesses and different uses (life safety vs. operational). Because integrating warnings into operational procedures may be complex and take significant resources, more technical and financial support may be needed by organizations wanting to employ earthquake early warning in this way. It might be beneficial or easier to focus on simple life safety applications to start. Since funding was a significant concern for organizations in this study, further consideration of financial support for implementing and maintaining an earthquake early warning system is needed. Potential sources of financial support might include public-private partnerships, small grants or loans, and incentives.

Demonstration projects, normalizing earthquake early warning as a best practice, and establishing the system as a "opt out" like Amber Alerts would all help encourage the use of earthquake early warning by both individuals and organizations. Awareness can be increased through education, social marketing, and branding and much of this could be incorporated into other earthquake preparedness and response education efforts. Identifying early adopters and using them in these efforts would also be helpful.

Conclusion

Earthquake early warning has come a long way since 1989 when CDMG completed their survey with potential users. And with improvements in communications technology and seismic monitoring systems it has come even further since this study was conducted. Organizations in this study were interested in using earthquake early warning, but also identified barriers to its use and expressed concerns about many aspects of it. Some of those barriers and concerns have been addressed over time, but many still exist and need to be addressed if widespread implementation of earthquake early warning in organizations is to be realized. Much of the advancement in earthquake early warning and other warning systems has been focused on alerts and warnings aimed at individuals rather than organizations. If earthquake early warning is to be useful and feasible for organizations and businesses, there is still much to be done in terms of research, evaluation, policy, and implementation.

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