California Governor's Office of Emergency Services

California Seismic Safety Commission

Pacific Earthquake Engineering Research Center

California Earthquake Early Warning System Benefit Study

Prepared by:

PEER – Pacific Earthquake Engineering Research Center

Laurie A. Johnson, Sharyl Rabinovici, Grace S. Kang, and Stephen A. Mahin

For:

CALIFORNIA GOVERNOR'S OFFICE OF EMERGENCY SERVICES
3650 Schriever Avenue
Mather, California 95655
www.caloes.ca.gov

and

CALIFORNIA SEISMIC SAFETY COMMISSION
1755 Creekside Oaks Drive, Suite 100
Sacramento, California 95833
www.seismic.ca.gov

CSSC Publication 16-04
PEER Report No. 2016/06
July 29, 2016

California Governor's Office of Emergency Services

Mark Ghilarducci, *Director*

Christina Curry, *Deputy Director*	Ryan Arba, *Branch Chief*
Planning, Preparedness & Prevention	*Earthquake & Tsunami Program*

California Seismic Safety Commission

Michael Gardner	City/County
Sheriff Ian Parkinson	City/County
Anthony Cannella (Salinas)	Senate Appointment
Chester "Chet" Widom	State Architect
Mia Marvelli	Building Standards Commission
Mark Ghilarducci	State Office of Emergency Services
Kit Miyamoto	Structural Engineer
David Rabbit	Local Government
Assistant: Andrea Kraut	
Mark Wheetley	Local Government
Tim Strack, *Chairman*	Fire Protection
Helen Knudson	Social Services
Greg Beroza	Geologist
Randy Goodwin	Architecture & Planning
Fuad Sweiss	Mechanical Engineer
Ken Cooley	Assembly Member
Margaret (Peggy) Hellweg	Seismologist
Tracy Johnson, *Vice-Chair*	Public Utility

California Seismic Safety Commission Staff

Richard J. McCarthy, *Executive Director*

Robert Anderson
Lena Daniel
Fred Turner
Henry Reyes
Salina Valencia

PEER – Pacific Earthquake Engineering Research Center

Khalid Mosalam, *Director*

Laurie A. Johnson
Visiting Project Scientist
University of California, Berkeley
Study Author

Sharyl Rabinovici
Visiting Project Scientist
University of California, Berkeley
Study Author

Grace S. Kang
Communications Director
Study Coordinator

Stephen A. Mahin
Byron L. and Elvira E. Nishkian Professor of Structural Engineering,
University of California, Berkeley
Principal Investigator of Record

CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEFINITIONS AND ABBREVIATIONS

ATIS	Alliance for Telecommunications Industry Solutions
ATC	Automatic Traction Control
Cal OES	California Governor's Office of Emergency Services
CISN	California Integrated Seismic Network
CodeRED	A licensable emergency notification system that pushes information out via smart phones or other technology applications
DCHO	"Drop, Cover, and Hold On" personal safety action
EEWS	Earthquake Early Warning System
ENS	U.S. Geological Survey Earthquake Notification Service
EOC	Emergency Operations Center
GETS	Government Emergency Telecommunications Service
ICS	Incident Command System
IPAWS	Integrated Public Alert and Warning System
Latency	Lag time
MMI	Modified Mercalli Intensity (earthquake shaking impact scale)
NIMS	National Incident Management System
OSHA	Occupational Safety and Health Administration (federal)
PEER	Pacific Earthquake Engineering Research Center
Reliability	The ability of an apparatus, machine, or system to consistently perform its intended or required function or mission
SCADA	Supervisory control and data acquisition monitoring and distribution control systems, commonly used by the utility sectors
SEMS	Standardized Emergency Management System
ShakeAlert	Demonstration earthquake early warning system for the West Coast of the U.S. from the U.S. Geological Survey and its partners
ShakeCast	U.S. Geological Survey application for automating ShakeMap delivery to critical users and for facilitating notification of shaking levels at user-selected facilities
ShakeMap	U.S. Geological Survey product of near-real-time maps of ground motion and shaking intensity following significant earthquakes
SMS	Short Message Service
SSC	Alfred E. Alquist Seismic Safety Commission
UCD	User Centered Design
USGS	U.S. Geological Survey
WEA	Wireless Emergency Alert

EXECUTIVE SUMMARY

The California Governor's Office of Emergency Services (Cal OES) in partnership with the Alfred E. Alquist Seismic Safety Commission (SSC) engaged the Pacific Earthquake Engineering Research Center (PEER) to independently explore the anticipated value of a statewide earthquake early warning system (EEWS) to the state's economy and infrastructure. As detailed in Section 1 of the report, since 2013, Cal OES has been leading a public-private partnership to develop a statewide EEWS. The capital cost to construct and launch a statewide EEWS is estimated at $28 million, and the personnel and operating expenses are estimated at $17 million annually.[1]

In a six-month investigation, researchers conducted 18 semi-structured interviews with 24 organizations representing 14 important sectors of the state's infrastructure and economy. The interviews focused on the perceived value of a statewide EEWS for each organization as well as specific types and settings for EEWS use that could benefit public and employee safety, business resiliency, and the protection of critical operations and assets that serve local communities and the economy. Information from the interviews was then consolidated and interpreted into this summary, which is primarily aimed at informing future study needed to quantitatively assess the costs and benefits of a statewide EEWS. More information about the organizations participating in the study and the study approach is provided in Section 2, as well as the appendices of the report.

The outcomes of the study include:

- A list of 14 high potential application types for EEWS (Section 4);
- Discussion of application potential for human-controlled versus automated implementation (Section 4);
- An assessment of which applications are most relevant to which key sectors of the state's infrastructure and economy (Section 4);
- An assessment of which applications are most ripe for development and use (Section 4);
- A brief scan of relevant current emergency response planning features of the organizations interviewed into which EEWS must fit (Section 5);
- Detailed discussion of potential barriers to the implementation and use of a statewide EEWS (Section 6), and

[1] California Earthquake Early Warning Working Group, "California Earthquake Early Warning System: Project Implementation Framework," May 2016. The capital costs include new and upgraded seismic stations, GPS equipment, telemetry, microwave nodes, overhead, and public education and outreach. Annual costs include personnel and operating costs, and initial and ongoing training and education. The costs for warning distribution systems and receiver units for external essential facilities are not included in the estimate.

- Suggestions of knowledge needs and next steps towards a comprehensive cost-benefit study of a statewide EEWS (Section 7).

As reported in Section 3, organizations unanimously perceived the overall societal benefits from having a statewide EEWS as very high. A few seconds to tens of seconds of advance warning time could help thousands to possibly millions of people to take precautionary actions and Drop, Cover, and Hold On (DCHO) before strong shaking begins. However, given the limited warning response time that most California earthquake scenarios will provide, most interview participants tended to describe a simple EEWS broadcast notification that is widely disseminated (i.e., via cell phones) in order for the full societal benefit of life safety to be realized. Some also reasoned that implementing EEWS may have other major benefits by raising the level of personal and organizational awareness and preparedness for earthquakes, and reducing anxiety given the sudden onset of earthquakes.

There was also strong consensus that overall societal value can result from different sectors of the state's economy and infrastructure having access to and making concrete use of a statewide EEWS. Section 4 reports on the many possible avenues for organizational use of an EEWS; however, to date, these uses are mostly hypothetical. Fourteen high-potential application types for EEWS were identified. On a fundamental level, they represent the potential uses of an early earthquake warning to change the movement of people, vehicles, machinery, and materials that are in motion. They are:

- Notification for Occupational Safety
- Broadcast Notification for General Public Safety
- Large-Scale Utility Control
- High-Speed Mass Vehicle Control
- Independent Vehicle Control
- Industrial Chemical Control
- Large-Scale Access Control
- Notification for Public Safety in a Particular Facility
- Activation of Emergency Response Plans and Situational Assessment
- On-Site (Facility) Utility Control
- Low-Speed Mass Vehicle Control
- Industrial Equipment, Asset, and Process Control
- Commercial Equipment, Asset, and Process Control
- On-Site Access Control

The sectors unanimously perceived that the benefit value, both to society and individual organizations, comes first and foremost from those potential applications that provide for occupational safety, public safety in a particular facility, and general public safety. Most commonly, interviewees described the potential organization applications as human-controlled actions taken upon receipt of an earthquake early warning. A key group of beneficiaries would be employees in hazardous situations. Such applications have the potential to reduce injuries as well as the time required by organizations to address post-earthquake life-safety issues and complete life-safety assessments. A series of cascading benefits could help organizations to be more effective and efficient in post-earthquake situational assessment and response, which in turn may reduce organizational downtime, disruption, and economic interruptions.

As first noted in Section 3 and then further elaborated in Section 6, the interviews provided rich information on crucial conditions and constraints that will need to be addressed in order for these benefits to be fully realized. They include:

- **Until the system performance standards are better understood, organizations cannot fully evaluate their willingness to use a statewide EEWS, invest in applications, contribute in-kind work, or provide funding for the system.** A plan for how potential users will have transparency, documentation, and active communication and engagement in the entire system design (i.e., from "send to end"), as well as the system performance objectives around resiliency, redundancy, and scalability, is needed now and their engagement must be sustained.
- **The development, management, and operations of a statewide EEWS need to be treated as a major public safety infrastructure project with a deeply and broadly collaborative planning and implementation model, starting with a core group representing five key areas: scientific/technical/engineering teams, leading emergency management organizations, the Telecommunications and Information Technology sectors, the Electric Utility sector, and experts in occupational behavior, public health, psychology, and community engagement.** Clarification and confidence in the governance structure for the development, management, and operations of a statewide EEWS is an important consideration in organizational willingness to invest in system use and applications.
- **The issue of liability protection for system partners and users should be a factor in determining the appropriate governance structure for the management and operations of a statewide EEWS.** Organizations want more information on sovereign immunity and how that might apply to them if the system is managed and operated by a state or federal agency.
- **A statewide EEWS is viewed as a social entitlement with responsibility for such a system residing with government and its social contract with the public, and with access being free and open to the public including public and private organizations.** There was not strong support for a subscriber model among interview participants. However, some organizations are already making, or will need to make, significant investments in similar technology; more investigation is needed to better ascertain how these current and future investments might be aligned with the funding needs for a statewide EEWS.
- **A secure and consistent funding source is a factor in an organization's views about the overall system reliability and thus their willingness to invest in the development, deployment, and training necessary to use an EEWS.** Developing and communicating the funding model and assuring organizations that the effort will be adequately funded and resourced for long-term needs to happen sooner rather than later. Funding plans must

address both the system development as well as the on-going costs to maintain and upgrade the core system and the applications technology and equipment, and to address the sizable education and training needs. If a public-private funding model is adopted, organizations want to know the terms of the arrangement, their expected contribution, and the timing of that contribution. They also want organizational costs and their in-kind contributions for becoming involved and transitioning their practices to incorporate an EEWS to be recognized in the system funding/costing analyses.

- **With life safety viewed as the primary benefit of a statewide EEWS, issues of equitable access to both organizations and society as a whole need to be carefully considered.** Implementation plans that differentiate and sequence access to organizations and then the general public are in conflict with the tremendous societal-serving life-safety benefit that the system could provide. Some interview participants caution, however, that they could face significant liabilities and challenges in dealing with public warnings, and they want more direct control over the timing and delivery mode of warning information to people within their realm of responsibility. These issues should be faced sooner rather than later in the planning for a statewide EEWS.
- **The implementation timeframe for a statewide EEWS needs to realistically account for the timing of contributions from critical partners in the system development as well as the system requirements of its potential users.** The organizational timeframes to develop, deploy, and train users on potential applications is quite varied, and adoption timeframes are influenced by organizational confidence in the reliability of a statewide EEWS. The implementation timeframe needs to account for the system and regulatory requirements of users and development timeframes of critical partners, e.g., the telecommunications industry.
- **Study the range of situationally-specific human activities and the set of practical delivery modes and appropriate warning responses in each.** A range of appropriate warning responses (e.g., more than DCHO) is needed given the variety of situationally-specific human activities that people may be engaged in when an earthquake occurs. These investigations need to cover an array of socio-demographic, organizational, temporal, and functional situations, and will require a baseline study of population reactions to EEWS notifications that consider the potential and perceived risks of panic, complacency, and other human responses. Results of such studies need to inform the design and budgeting for a comprehensive and nuanced education and outreach program for EEWS implementation.
- **Ensuring adequate understanding and training in use of a statewide EEW is a fundamental prerequisite to life-safety benefit realization.** People with very sophisticated and practical understanding of warnings for human interactions, risk communication, and public awareness campaigns (e.g., experts in occupational behavior, public health, psychology, and community engagement) have to join with traditional emergency management in the program design and implementation. All education and training products must consider an array of cultural communities, multiple languages, and

persons with access or functional needs and provide a range of training models at multiple levels—for people, organizations, and communities.

Section 7 of the report elaborates on the recommended next steps for expanding a cost-benefit study. They are to:

- **Develop a robust set of use scenarios for each potential application type and elaborate on user-specific cases for the most promising applications.** This study provides a more comprehensive set of example applications than available previously, but there is still much work to be done to generate lists within each application type and of specific use scenarios. Adequate details are needed about precisely who is doing what and how (tasks) as well as where and when (environment). Deep and sustained engagement with a strategically selected and much larger than currently involved group of likely EEWS users will be necessary to do this.
- **Collect quantitative evidence about the likelihoods and magnitudes of different application-use scenarios and their benefits.** With a more fully developed set of use cases, quantitative benefit estimation becomes possible. One essential data input is occurrence, count, and rate data for gauging the frequency and likelihood of each scenario taking place. Benefit estimation needs to look at the secondary and cascading elements and less tangible benefits such as psychological benefits, and also consider the phasing in over time of benefit attainment.
- **Consider potential benefits in sectors not included in this study, as well as sources of variation in benefits within all sectors.** This study was not designed to investigate every possible sector of relevance, and there are additional sectors and sector representatives that could have valuable applications. A systematic (possibly random sample) survey within sectors of importance would be one way to develop an understanding of the full range of activities, benefits, and implementation issues that EEWS could have in different sizes and variations of organizations.

In closing, many of the insights gathered in this study underscore and strengthen the objectives for a statewide EEWS as specified in the 2013 State legislation, as well as the California Earthquake Early Warning System Implementation Steering Committee and the U.S. Geological Survey's implementation plans. However, in some instances, these insights challenge and necessitate a second look at some of the fundamental objectives and plans for system performance standards and protocols, development timeframes, governance and funding structures, education and training, and implementation timeframes, costs, and feasibility.

This study provides an important step forward in understanding the main types and avenues of benefits for a statewide EEWS and issues that need to be confronted for them to be realized. One of the most important next steps is to foster more systematic, varied, and deeper involvement with organizations that will be at the front lines of EEWS use. Collaborative study of system uses will in fact help create, shape, and bring both the applications and benefits of a statewide EEWS into reality.

1. INTRODUCTION

California is one of the most seismically active states, second only to Alaska. Dozens of disastrous earthquakes have resulted in loss of life, injury, property damage, and economic losses across the state; and it is almost guaranteed that there will be a major damaging earthquake somewhere in California within the next 30 years.[2] In 2013, the State Legislature called upon the California Governor's Office of Emergency Services (Cal OES) to form a public-private partnership to develop a statewide earthquake early warning system (EEWS). [3]

The EEWS bundles together seismometers and other sensing and telecommunications technology so that advance signals and warnings of strong ground shaking can be broadcast to people, information systems, and equipment—just as radar and satellites are used to provide advance warnings of tornadoes and hurricanes. However, unlike weather warnings, which are often broadcasted days in advance, earthquake early warnings can only be provided within seconds—from the time the first signal of an earthquake is detected to the time strong ground motions arrive at a particular location. Since most of California's 39 million residents reside within close proximity to the state's most active faults, the advance warnings for larger and potentially more damaging earthquakes are likely to range from a few to tens of seconds.

Since 2013, the California Earthquake Early Warning System Implementation Steering Committee[4] has been working to develop a comprehensive statewide EEWS that meets the objectives set forth in the 2013 State legislation. They specifically include: (1) use of a public/private partnership model for planning and implementation; (2) development of an organizational structure for the system's management and operations; (3) identification of funding sources excluding the State's General Fund; and (4) production of a comprehensive plan for education and training. Plans for the California system build upon the existing seismic sensor array of the California Integrated Seismic Network (CISN) and the ShakeAlert demonstration system developed by the U.S. Geological Survey (USGS) and a consortium of partners.[5] In 2014, ShakeAlert successfully alerted California test users with warnings ahead of both a magnitude 6.0 earthquake that struck in southern Napa County and a magnitude 5.1 earthquake that struck near the city of La Habra.

Under current plans, Cal OES, the USGS, and other partners will jointly develop and operate the California EEWS and notifications. The capital cost to construct and launch a California system is estimated to be $28 million, and the personnel and operating expenses are estimated at $17

[2] Edward H. Field et al., "Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3)—The Time-Independent Model," USGS Open-File Report, (2013), http://pubs.usgs.gov/of/2013/1165/.
[3] Senate Bill 135 is codified as California Government Code Section 8587.8.
[4] The California Earthquake Early Warning System Implementation Steering Committee is chaired by Cal OES and includes the SSC, California Geological Survey, University of California, California Institute of Technology, USGS, and other stakeholders.
[5] See www.shakealert.org.

million annually.[6] [7] In addition to the primary system, technology is also needed to distribute and receive the signal, such as access to Emergency Alert System messages or smart phone applications. Organizational users may also need to invest in technology and equipment to monitor, receive, and control critical operations.

[6] California Earthquake Early Warning Working Group, "California Earthquake Early Warning System: Project Implementation Framework," May 2016.

[7] The capital costs include new and upgraded seismic stations, GPS equipment, telemetry, microwave nodes, overhead and public education, and outreach. Annual costs include personnel and operating costs, and initial and ongoing training and education. The costs for warning distribution systems and receiver units for external essential facilities are not included in the estimate.

2. STUDY AIMS AND APPROACH

Given the importance of the statewide EEWS initiative and the sizeable investment that is needed for a fully operational system, Cal OES in partnership with the Alfred E. Alquist Seismic Safety Commission (SSC) engaged the Pacific Earthquake Engineering Research Center (PEER) to independently explore the anticipated value of a statewide EEWS to the state's economy and infrastructure. This relatively brief, six-month investigation is best characterized as a scoping study with two primary objectives:

- To qualitatively assess the value of a statewide EEWS to key sectors of the state's infrastructure and business community for public and employee safety, business resiliency, and the protection of critical operations and assets that serve local communities and the economy.
- To provide information on the potential value of a state EEWS in such a format that it can then be used subsequently to develop a preliminary cost-benefit analysis and to develop a more comprehensive benefit-cost analysis that will likely be conducted over time as the system is developed.

PEER was tasked with designing and conducting a series of semi-structured interviews with at least 10 organizations representing 14 sectors of the state's infrastructure and economy. Table 1 lists the included sectors along with the number of organizations that were interviewed within each sector and their approximate geography of relevance.

PEER worked with Cal OES and the SSC to identify and prioritize key organizations within each sector across the state based on selection criteria that included:

- Organizational size and sophistication in terms of their ability to use an earthquake early warning system, including some current experience with pilot EEWS efforts;
- Organizational importance to the resiliency of the state's infrastructure and economy, as well as to a particular region or sector; and
- Societal and life-safety value of the organization's potential earthquake warning decisions and actions.

In all, 18 interviews were conducted with 69 individual representatives of 24 different organizations. In most of the interviews, there were individual representatives from both the executive management and technical operations of their respective organization. Additional details on the study protocols and interview procedures are available in Appendix A. An example interview invitational letter sent by Cal OES, the Interview Brief, and the Interview Guide, are available in Appendices B, C, and D, respectively.

Table 1 Statewide Distribution of Organizations (by Sector) Participating in the Study.

Represented Sector	Northern California	Southern California	Statewide	Total
Electric Utility	+	+	1	**1**
Telecommunications			2	**2**
Mass Transit	1		1	**2**
Transportation			1	**1**
Gas Utility	1+			**1**
Water Utility		1		**1**
Public Safety			1	**1**
Hospital and Emergency Medical Services			1	**1**
Education		1		**1**
Business		1		**1**
Commercial/Industrial	+	2	1	**3**
Insurance			1	**1**
Financial			1	**1**
Information Technology	1			**1**
Grand Total	**3**	**5**	**10**	**18**

Note: (+) indicates when the work of the organization fits in additional sectors.

PEER developed an outline for the final report that was reviewed and approved by Cal OES and the SSC. Data gathered in the interviews (conducted May 1 through and June 16, 2016) was then integrated into this summary of results. The findings are organized by first looking at interviewee perspectives on the broader societal value for a statewide EEWS (Section 3); the perceived potential uses and benefits of a statewide EEWS in key sectors (Section 4); baseline sector-specific findings about the current organizational earthquake preparedness activities and uses of monitoring and warning systems as well as near-real-time earthquake information (Section 5); potential implementation issues related to developing a statewide EEWS (Section 6); and insights and recommended next steps, in particular for a future, more quantitative, cost-benefit study of a statewide EEWS (Section 7).

The focus of this study is the potential benefits of a statewide EEWS as a whole, not the particular activities or perspectives of participating organizations. The conclusions drawn from interacting with this broad but small sample of organizations should be regarded as indicative, not representative, of the realities or points of view that similar organizations might have. Measures have been taken to ensure the privacy of individuals and proprietary aspects of each organization in the summarization of results. All participating organizations have been given an opportunity to review the draft report for clarification purposes and to ensure reporting accuracy. Cal OES and the SSC will work with organizations on a coordinated release of the final report.

3. BROADER SOCIETAL VALUE FOR A CALIFORNIA STATEWIDE EEWS

The study sought input from 14 important sectors of the state's economy and infrastructure on two aspects of the broader societal value for a statewide EEWS: (1) the overall societal benefits of a statewide system (i.e., society having access to the system); and (2) the added societal value resulting from sector uses of an EEWS.

To the first point, **the sectors unanimously perceived the overall societal benefits of having a statewide EEWS as very high**. Given the high likelihood of a large magnitude earthquake occurring within the next 30 years and the close proximity of California's population centers to major active faults, sector representatives agreed that even a few seconds to tens of seconds of advance warning time could help thousands and possibly millions of people to take precautionary actions and Drop, Cover, and Hold On (DCHO) before strong ground shaking begins. Many also believe that the effort of providing societal access to an EEWS may have a major educational benefit in and of itself. For instance, it could raise the general level of awareness and preparedness on both a personal and organization level, just as the annual Great ShakeOut drills have done over the last decade. Furthermore, many also speculate that there are socio-psychological benefits to be gained from society's access to an advance warning, which could help people to be more psychologically prepared for the earthquake occurrence, thus reducing anxiety given the sudden onset of earthquakes.

To the second point, **there was strong consensus among interviewees that overall societal value can result from different sectors of the state's economy and infrastructure having access to and making concrete use of a statewide EEWS in different ways**. In particular, there is strong agreement across the sectors that use of an EEWS can help to enhance employee safety. The primary avenue for this is the potential to reduce the number of injuries and organizational time needed to address life-safety issues and complete life-safety assessments by directly informing people so they can take preventative actions.

The warning can also serve as an early source of technical data for organizational use in situational assessment and response planning, ahead of other existing data and products like the USGS Earthquake Notification Service (ENS), ShakeMap, and ShakeCast, as well as organization-specific sensors and impact modeling systems. Interviewees saw these potential time-savings as helping to facilitate faster organizational movement through the stages of response and to implement more targeted response efforts. This, in turn, can reduce organizational downtime and disruption as well as economic interruptions, which can then benefit customers and communities by providing essential services related to safety, loss avoidance, and resumption of normal life. Figure 1 illustrates how organizations might progress through the stages of organizational response with and without access to an EEW. An EEW may provide very immediate real-time response benefits to organizations by reducing injuries, serving as an early source of technical data for use in situational assessment and response planning, and enabling them to implement more targeted response efforts.

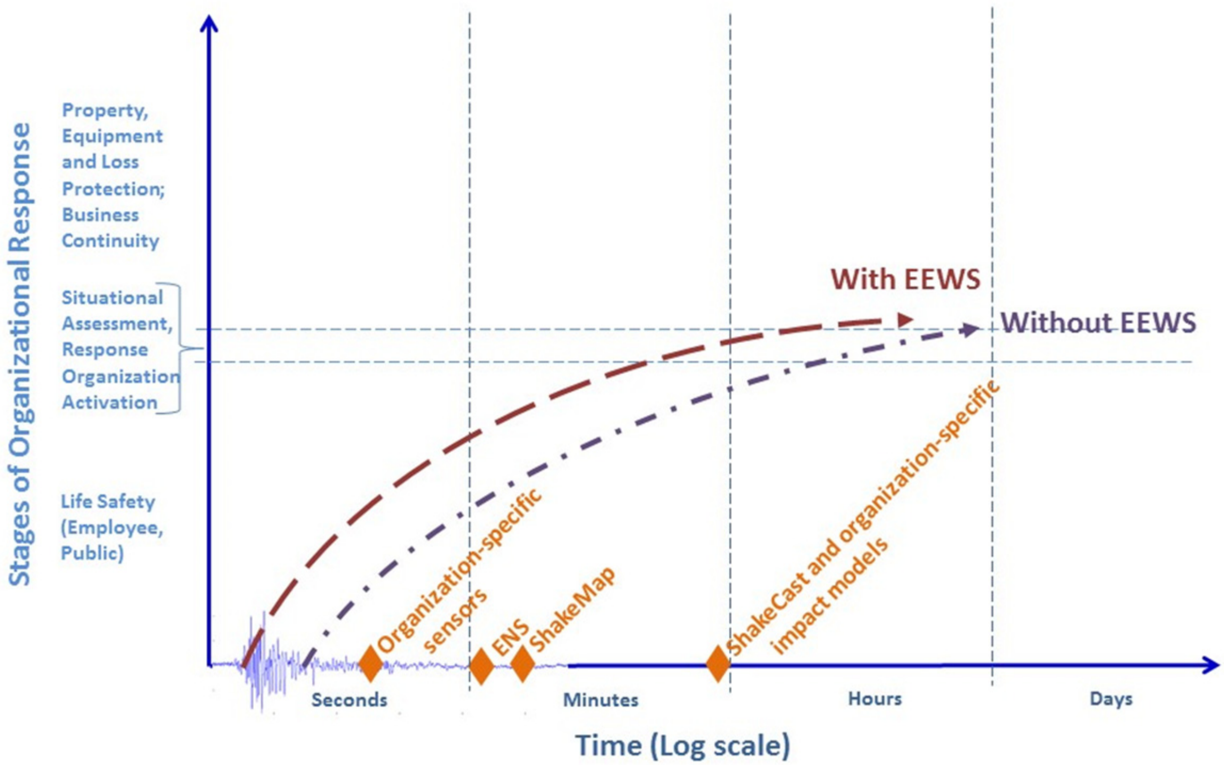

Figure 1 **Conceptual Illustration of How EEWS Could Facilitate Faster Organizational Response.**

It is crucial to note, however, that the pathways for achieving these benefits have conditions and constraints. These will have to be addressed in order for those benefits to be fully realized. Thus, in seeking input on the issue of broader societal value of EEWS, the following overarching insights emerged and are presented now as central tenets for the study results and the content of this report:

- **The foremost life-safety benefits, both to society and organizations, require a highly reliable and scalable EEWS that can provide a large-scale broadcast notification to people who can execute a range of situationally-specific human-controlled applications of EEWS.** It can only be achieved if people have equitable access to technology and are properly educated and trained, so that in the event of an earthquake they are prepared to physically protect themselves or to manually initiate preemptive protocols (via equipment or software) to re-position objects that could harm others. In a few but very important contexts, automated applications of an EEWS have the potential to prevent injuries and protect lives.

- **In order to maximize the potential life-safety benefits, detailed study is needed of the range of situationally-specific human activities and the set of practical delivery modes and appropriate warning responses tailored to each activity.** A range of appropriate warning responses (e.g., more than DCHO) is needed given the variety of situationally-specific human activities that people may be engaged in when an earthquake occurs. These investigations need to cover an array of socio-demographic, organizational, temporal, and functional situations, including for example, hazardous industrial and occupational scenarios, what individuals of different backgrounds and abilities might do in various private or public settings, and human-object interactions and the different warning response times ranging from only a few to many seconds. This will require involving a wider set of experts in the warning protocols and notification design process, e.g., from occupational behavior and public health disciplines. Results of such studies should also inform the design and budgeting for a comprehensive and nuanced education and outreach component of a statewide EEWS implementation program. Ensuring adequate understanding and training in appropriate warning responses is a fundamental prerequisite to life-safety benefit realization, and that educational process will not be simple or "one size fits all."
- **A high-level of system reliability and scalability must be assured in order for sectors to make full use of a statewide EEWS and thus maximize the potential societal benefits of such a system.** This applies to the entire system from the sensors and point of wave detection, to the signal communication and processing, and through to the warning transmission pathways and receivers. Physical scientists, technologists, and engineers who are building the underlying technologies of the EEWS are responsible for documentation and transparency of improvements to this important system attribute. Doing so is important for the handful of most promising but mostly yet not realized automated applications. However, reliability is not just a statistical concept with measurable properties, but also an unscientific impression of whether people can depend on the system, trust its creators, and count on it to be accurate and helpful. Improvement and establishment of a baseline standard of system reliability is also pivotal to the development of a more quantitative cost-benefit assessment. Organizational investments in training, technology, and equipment necessary to apply and expand the applications of an EEWS are dependent upon the reliability and performance expectations that different organizations and sectors have for a statewide EEWS.
- **The pathways for achieving societal benefits for a statewide EEWS are diverse and not equal in importance or complexity across organizations and the different sectors that they represent.** In particular, the Telecommunications, Electric Utility, and Information Technology (IT) sectors are central to the operational feasibility and performance of EEWS and thus to all the sectors and their potential uses of a statewide EEWS and all the organizational and societal benefits stemming from these applications. Collaborative engagement with the Telecommunications, Electric Utility, and Information Technology sectors in the system development and implementation planning of a statewide EEWS is essential for the societal benefits to be realized.

- **The close linkage of EEWS to life safety has political, financial, and equity implications that should be faced early and head on.** Many sector representatives view a statewide EEWS as a social entitlement with responsibility for such a system residing with government and its social contract with the public. Concerns about liability protections, access, and ensuring a stable governance structure and sustained funding source for a statewide system are also embedded within this viewpoint. Many organizations want liability protections for decisions and actions taken based upon a warning, especially false warnings. Potential errors of commission were perceived by many sector representatives to be more negative than errors of omission or just allowing the natural flow of events to occur. Issues of social and organizational equity also quickly arise when discussing (1) warning notification formats; (2) accessibility to technology applications; (3) differential timing of system accessibility for various sectors and the general public; and (4) potential funding models that might limit universal access to a statewide EEWS.

In some cases, these insights underscore and strengthen the objectives for a statewide EEWS as specified in the 2013 State legislation, as well as the California Earthquake Early Warning System Implementation Steering Committee and the USGS implementation plans. However, in some instances, these insights necessitate a second look at or challenge some of fundamental objectives and plans for system performance standards and protocols, development timeframes, governance and funding structures, education and training, and implementation timeframes, costs, and feasibility. A contribution of this study is to illuminate priority areas needing further attention.

4. POTENTIAL USES AND BENEFITS OF A STATEWIDE EEWS

A central element of the study was the structured exploration of the potential uses or applications of a statewide EEWS. Interview participants were asked to identify and distinguish both the potential applications that involved human-controlled decisions and actions, and those that could be automated if the technology exists or could be developed. Participants were also asked to identify the potential benefits that apply to each potential application and to discuss the different pathways and potential challenges that they would face organizationally with regards to key system sensitivities that might affect the potential uses and benefits.

Recall that this section documents and interprets the information gained during a limited set of interviews conducted over a relatively short period of time. The study team integrated the data into several formats deemed helpful for advancing the state of knowledge about EEWS benefits. Note: the data is not necessarily exhaustive and should not be considered representative of typical opinions or the full range of perspectives for any given sector. A broader and more systematic study of organizations, sector by sector, is recommended, and potential next steps for that are presented later in Section 7. It is hoped that the framework presented herein can be a starting point for more a systematic study of the potential uses and their respective potential benefits, that will provide guidance to the start-up, transition, and maintenance costs that organizations might incur implementing an EEWS.

Potential Uses of a Statewide EEWS

Most of the interviewed organizations perceive many potential uses of a statewide EEWS; but to date, these are primarily hypothetical. Given the need to protect privacy and proprietary aspects of various organizations participating in the study, a generic typology of potential uses of EEWS was developed. Fourteen categories or distinct application types were identified. They are:

- Notification for Occupational Safety
- Notification for Public Safety in a Particular Facility
- Broadcast Notification for General Public Safety
- Activation of Emergency Response Plans and Situational Assessment
- Large-Scale Utility Control
- On-Site (Facility) Utility Control
- High-Speed Mass Vehicle Control
- Low-Speed Mass Vehicle Control
- Independent Vehicle Control
- Industrial Equipment, Asset, and Process Control
- Industrial Chemical Control
- Commercial Equipment, Asset, and Process Control
- Large-Scale Access Control
- On-Site Access Control

On a fundamental level, this list represents potential use of an EEW to change the movement of people, vehicles, machinery, and materials that are in motion. For illustrative purposes, the use typology provides a framework to think more generically about potential applications that can help with future data collection on potential applications. It can also help to expand the list of applications as well as the potential user base of sectors and organizations. Table 2 gives specific examples of each use type mentioned by interview participants. Previous reports on the uses or potential uses of EEWS tend to provide only these kinds of more specific, anecdotal examples.

Table 3 maps the organizations that mentioned a potential use type to the primary sector that they represent. Note that citing of a particular use type by an organization does not necessarily imply ability and willingness for a particular use type. In most instances, the interviewees were mentioning potential applications that their organizations might consider, but there are cases where there were noted difficulties in the potential ability or willingness for a particular use type by the organization or the primary sector that it represented. Aspects of ability and willingness are explored further in a following section.

Table 2 A Typology of Potential Uses of EEWS with Specific Examples Offered by Interview Participants.

Typology of Potential Uses of EEWS	Examples Offered by Interview Participants
Notification for Occupational Safety	Employees can DCHO or take other appropriate personal safety actions. Specific examples were offered for all sectors. Many require situationally-specific safety guidance, particularly those in non-traditional office settings. They include: machinery and special equipment operators, system and equipment maintenance providers, and workers in vulnerable locations (e.g., confined spaces such as vehicle repair bays, tunnels, and trenches, and in unsecured or elevated places such as holding live wires or on ladders). The potential use was viewed as less viable or more difficult to implement for complex or high-hazard operations such as surgery, crane operations, and amusement park ride operations. There may also be value for warnings of aftershocks, for instance while personnel are performing inspections of facilities pursuant to allowing reentry.
Notification for Public Safety in a Particular Facility	Members of the public can DCHO or take other appropriate personal safety actions in particular facilities, such as schools and both indoor and outdoor assembly areas.
Broadcast Notification for General Public Safety	All people have access to an EEWS notification through a variety of transmission mechanisms including wireless broadcasts, internet applications, audible systems, and visual signals. Systematic study is needed and develop a more robust set of situationally-specific human responses (e.g., while driving, outdoors, when lacking a safe haven, for people with access and functional needs, and understanding potential panic conditions for both individuals and within groups). There may also be added value for warnings of aftershocks.
Activation of Emergency Response Plans and Situational Assessment	The notification is an input into organization's monitoring systems and impact assessment modeling software used for situational assessment. Some systems are proprietary or internally-built and others are licensed or externally acquired (e.g., SCADA and ShakeCast). Elements of an organization's response plans are activated upon receipt of the EEWS notification, such as engagement of an automated call system to incident management team, other key personnel (e.g., security, safety assessment and inspection teams), or key vendors (e.g., base camp providers for repair teams or suppliers of special equipment needed for response). There may also be added situational awareness value for warnings of aftershocks.
Large-Scale Utility Control	Maintain reliability and flow control within utility systems such as electricity, water, wastewater, natural gas, and liquid fuel. Specific applications might involve any or all system components including transmission, distribution, generation, and sources in order to prevent widespread system outages or severe damage to assets and equipment, and/or protect the loss of commodity in the system. The application can be situated within a system control center and/or system components (e.g., valves to shutoff flow, and switches to deactivate a particular piece of system equipment or part of the system). The potential use is less viable across the larger electrical grid and the telecommunications network where paths are redundant, and the protocols themselves are resilient and can find alternate paths if blocked. However, there are more potential localized applications within electric utility systems.
On-Site (Facility) Utility Control	Flow control of on-site utilities such as electricity, water, wastewater, natural gas, and liquid fuel. Specific examples include shut-off valves and switches, pump switches, activation of intermediate/gap power supplies as well as back-up generators, and controlled deactivation of vulnerable power lines and sprinkler systems.

Typology of Potential Uses of EEWS	Examples Offered by Interview Participants
High-Speed Mass Vehicle Control	Control the deceleration and stop of high-speed mass vehicles such as trains or amusement park rides with the primary purpose of preventing derailment. In limited instances, vehicles might need to speed up to avoid a potential hazardous condition (e.g., exit a tunnel to avoid potential damage from adjoining structures/equipment). The application can be situated within the system control center, the vehicular controls (e.g., traction control system,) and/or the on-board operator controls (e.g., mounted GPS-based notification).
Low-Speed Mass Vehicle Control	Control the deceleration and stop of low-speed mass vehicles such as public and private passenger and cargo trains and light-rail systems, as well as on site transport systems such as conveyors or monorails for both people and goods. The primary purpose is to prevent derailment. In limited instances, vehicles might need to speed up to avoid a potential hazardous condition. The application can be situated within the system control center, the vehicular controls, and/or the on-board operator controls.
Independent Vehicle Control	Notification to both human and robotic drivers of vehicles to prevent accidents. Examples offered were for organizational vehicles, such as maintenance fleets, public and private buses, shuttles, and airplanes.
Industrial Equipment, Asset, and Process Control	Protect key assets and control the functioning of industrial and manufacturing equipment and processes that can apply to many sectors, including those with sensitive or high-valued production lines with automated material handling, including high-tech (e.g., semi-conductor) and pharmaceutical production. A lot of manufacturing equipment already has emergency shutoffs systems that could be adapted to move to safe idle, slowdown, or shutoff. The potential use was viewed as less viable for high-temperature and volatile manufacturing and industrial processes. Large equipment for construction, goods transport, and dredging operations were also noted, as was notification to temporarily stabilize or shore up an asset or property.
Industrial Chemical Control	Control the flow of flammable and ignitable liquids and gases, other hazardous materials, and chemicals used in industrial and manufacturing processes to prevent asset and equipment damage as well as to protect life safety and reduce the risk of environmental contamination. Maintaining power to alarms for leak detection was also identified.
Commercial Equipment, Asset, and Process Control	Control the function of commercial equipment, assets, or processes to prevent asset and equipment damage and protect life safety. Examples offered included computer server farms, escalators and elevators (slowed, turned off, go to bottom, or return to nearest floor), sprinkler systems, and sump pumps.
Large-Scale Access Control	Control access onto freeways or bridges (e.g., signal or barrier engagement), and secure or ensure egress from high-congestion areas or places of known hazards
On-Site Access Control	Open garage doors (e.g., fire stations, maintenance facilities, heliports, and airports) and control security doors and gates to secure a facility or site (e.g., fire doors, IT rooms, security rooms, school sites, and law enforcement security doors and gates). Several specific examples involved government and critical facilities (e.g., fire stations and ambulance garages) and high-occupancy facilities (e.g., hotels, theaters, parking structures, and entertainment facilities).

Table 3 Organizations (by Sector) that Discussed each Type of Potential Use of EEWS.

	Electric Utility	Telecommunications	Mass Transit	Transportation	Gas Utility	Water Utility	Public safety	Hospital/EMS	Education	Financial	Insurance	Business	Commercial/Industrial	Information Technology
Notification for Occupational Safety	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Notification for Public Safety for a Particular Facility		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
Broadcast Notification for General Public Safety	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		✓
Activation of Emergency Response Plans and Situational Assessment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Large-Scale Utility Control	✓			✓	✓	✓								
On-Site (Facility) Utility Control	✓			✓	✓		✓	✓	✓		✓	✓	✓	✓
High-Speed Mass Vehicle Control			✓	✓								✓		
Low-Speed Mass Vehicle Control		✓		✓								✓		
Independent Vehicle Control	✓			✓			✓		✓			✓		
Industrial Equipment, Assets, and Process Control	✓			✓		✓					✓		✓	✓
Industrial Chemical Control				✓		✓					✓		✓	✓
Commercial Equipment, Assets and Process Control	✓			✓		✓				✓	✓	✓	✓	✓
Large-Scale Access Control		✓		✓			✓							
On-Site Access Control	✓	✓	✓	✓		✓	✓		✓			✓	✓	✓

Potential Benefits from Uses of a Statewide EEWS

Interview participants were also asked to identify the potential benefits that apply to each potential application that they identified. The categories of potential benefit are consistent with the following organizational objectives of emergency response plans and procedures:

- Public Safety
- Employee Safety
- Property and Asset Protection
- Equipment and Operations Protection
- Business Resumption and Continuity
- Business Income and Loss Protection

Table 4 presents a consensus view derived from across all the sectors and all the interviews of the primary and secondary benefits potentially realized with each type of use. The primary benefits are shown with a (P) and in a shaded box. The secondary benefits are shown with an (S). While the primary benefits were more specific for each type of use, there was some level of secondary benefit across all the benefit categories for all use types. There are also cascading and time-sequential aspects to the benefit accrual. For most use types, life safety and the protection of property, assets, equipment, and operations are the primary and crucial benefit that the organization must first achieve, which can then open pathways for the organization to realize the benefits of business resumption, continuity, and income and loss protection.

In terms of benefit value, there was unanimous perception across the sectors that the overall life-safety benefits to employees and the public could be very high. Sector representatives agreed that even a few seconds to tens of seconds of advance warning time could help people to take precautionary actions and DCHO—Drop, Cover, and Hold On, before the onset of strong ground shaking. Direct benefits could come primarily through the potential to reduce the number of injuries and the organizational time needed to address life-safety issues and complete life-safety assessments. Many also noted that there could be less tangible psychological benefits as well, with employees being more mentally prepared. The time savings could also help to facilitate faster organizational movement through the stages of response, thus implementing more targeted response efforts sooner, which, in turn, can help organizations to be more self-sufficient and reduce organizational downtime and disruption, as well as economic interruptions which then benefits society and societal resilience as a whole. There are also downstream benefits to other sectors because of the potential reduction in human injuries or reduced downtime. This is particularly true for the Hospital/Emergency Medical Service sector that would benefit from the reduction in health-related emergencies and threats.

However, organizations condition the realization of benefits on their ability to design a range of appropriate warning responses for employees to undertake (e.g., more than just DCHO), given the variety of situationally-specific, work-related activities that they may be engaged in when an earthquake occurs. In other words, access to EEWS by itself is not sufficient for most organizations or society to realize benefits. Access must be accompanied by a considerable organizational investment to audit employee work-related activities and design an appropriate array of safe responses beyond DCHO. Similarly, considerable investment will be needed by organizations to make use of the EEWS to protect equipment and other business functions in advance of the onset of strong ground shaking.

Many also believe that the effort of providing societal access to an EEWS may have a major educational benefit that grows exponentially by helping to raise the general level of awareness for being prepared for earthquakes on a personal, family, and organizational level. Furthermore, there are socio-psychological benefits to be gained from society's access to an advance warning, which could help people to be more psychologically prepared for the earthquake occurrence, and reducing anxiety given the sudden onset of earthquakes.

Table 4 Primary (P) and Secondary (S) Benefits Identified for Each Type of Potential Use of EEWS.

	Public Safety	Employee Safety	Property and Asset Protection	Equipment and Operations Protection	Business Resumption and Continuity	Business Income and Loss Protection
Notification for Occupational Safety	S	P	S	S	S	S
Notification for Public Safety in a Particular Facility	P	P	S	S	S	S
Broadcast Notification for General Public Safety	P	S	S	S	S	S
Activation of Emergency Response Plans and Situational Assessment	S	P	P	P	S	S
Large-Scale Utility Control	S	S	P	P	S	S
On-Site (Facility) Utility Control	S	S	P	P	S	S
High-Speed Mass Vehicle Control	P	P	P	P	S	S
Low-Speed Mass Vehicle Control	P	P	P	P	S	S
Independent Vehicle Control	P	P	P	S	S	S
Industrial Equipment, Assets, and Process Control	S	P	P	P	P	P
Industrial Chemical Control	S	P	P	P	P	P
Commercial Equipment, Assets, and Process Control	S	P	P	P	P	P
Large-Scale Access Control	P	P	S	S	S	S
On-Site Access Control	P	P	S	S	S	S

As with the use typology, it is hoped that these benefit categories provide a framework to think more holistically about potential benefits that can help with future data collection and benefit assessment work.

Potential Ability and Willingness for Human Controlled vs. Automated Applications

Interview participants were asked to identify and distinguish both the potential applications that involved human-controlled decisions and actions, and those that could be automated if the technology exists or could be developed. Table 5 identifies the consensus view (among the interviewees in so far as it was identifiable) as to the ability and willingness for human-controlled or automated types of applications of EEWS. Categories of "Strong," "Weak," and "Mixed" indicate the current feasibility and willingness for human-controlled or automated types of applications. Feasibility relates primarily to technical abilities to implement a particular type of application, and willingness relates more to organizational abilities and policy matters regarding implementation of a particular application.

It is challenging to discern trends or conclusions from this data, and requires further study. However, there are some evident patterns, particularly the strong willingness to have at least human-controlled approaches to most of the use types. It is also important to distinguish between automated *delivery* and automated *use*. This table considers the automation of uses or applications. The underlying assumption is that if most of these applications are to be effective, then the warning delivery must be automated as well. For example, with the broadcast notification for general safety, there was concern that a large-scale broadcast needs to simultaneously reach millions of users in most urban areas of the state, requiring an automated delivery in order to be effective.

The strong and mixed willingness to automate many other use types also stems from the concerns about latency or lag time—both in the EEWS transmission and in the human reaction process. With the relatively short amounts of warning times expected for most major California earthquakes, interviewees felt that automated delivery was essential and that the only way to reduce latency and help to ensure that a particular application really worked was to automate the application as well, even if the technology for a particular automated application is hypothetical.

Conversely, strong views often existed from within the same organization that the liability of taking an automated wrong action is too high, and that certain use types and potential applications need to remain in human control. Attitudes are asymmetrical and more negative about errors of *commission* compared to errors of *omission*. In these instances, maintaining the status quo is better than making the wrong decision or a decision that impacts the natural flow of events. Some Utility sector organizations caveated their willingness to use EEWS for large-scale utility system control, perceiving the redundancy within their own system as adequate. They expressed concerns that there needed to be sufficient redundancy so that utility services could still be provided if something went wrong and they needed a way to switch back quickly.

Table 5 Consensus View (Among Interview Participants) as to the Current Feasibility and Willingness for Human-controlled and Automated Types of Uses of EEWS.

	Feasibility for Human Controlled Application of EEWS	Willingness for Human Controlled Application of EEWS	Feasibility to Automate Application of EEWS	Willingness to Automate Application of EEWS
Notification for Occupational Safety	Strong	Strong	Mixed	Mixed
Notification for Public Safety in a Particular Facility	Strong	Strong	Mixed	Mixed
Broadcast Notification for General Public Safety	Weak	Weak	Mixed	Strong
Activation of Emergency Response Plans and Situational Assessment	Strong	Strong	Mixed	Mixed
Large-Scale Utility Control	Strong	Weak	Weak	Weak
On-Site (Facility) Utility Control	Mixed	Strong	Mixed	Mixed
High-Speed Mass Vehicle Control	Strong	Strong	Strong	Strong
Low-Speed Mass Vehicle Control	Strong	Strong	Mixed	Mixed
Independent Vehicle Control	Mixed	Strong	Weak	Weak
Industrial Equipment, Assets, and Process Control	Weak	Strong	Mixed	Mixed
Industrial Chemical Control	Weak	Strong	Mixed	Mixed
Commercial Equipment, Assets, and Process Control	Weak	Strong	Mixed	Mixed
Large-Scale Access Control	Weak	Strong	Weak	Weak
On-Site Access Control	Mixed	Strong	Mixed	Mixed

As to the feasibility question, strong feasibility often meant that the organization already had some procedures or technologies in place that could be leveraged in using an EEWS. Issues of current technology limitations and costs were frequently identified as reasons for a weak feasibility ranking. Many organizations also tied feasibility to system reliability, stating that there was a preference to implement human-controlled applications first, especially those allowing employees to take actions to protect themselves and equipment, and to build confidence and trust in the EEWS before making a more significant investment in automating a particular application.

Key System Sensitivities and Organization Issues Affecting the Potential Ability and Willingness for Use of EEWS

Overall, the potential for different organizations to make the necessary operational changes for either human-controlled or automated applications of EEWS increases if system sensitivities and potential organizational barriers are overcome.

System Sensitivities

Some of the key concerns expressed by organizations about the design and performance of a statewide EEWS and sensitivities of the system are as follows:

- **System reliability and trust**. For some organizations, using EEWS would be a paradigm shift: understanding and trusting the system reliability is fundamental to organizational willingness to make that shift. The potential for missed warnings and false warnings could be costly or even dangerous for some organizations and their operations; this was most strongly voiced by the Gas Utility sector interviewees. It can also have cascading effects on reputation and market competitiveness. In addition, some organizations do not want to have to build reliability or uncertainty factors into application activation criteria or software that they may have to develop for different applications.
- **Notification thresholds.** Organizations also tied ability and willingness to use an EEWS to the potential activation criteria and notification thresholds for an EEWS. Among societal-serving sectors, there was some preference for having a statewide EEWS issue a warning for all earthquakes that are likely to be "felt." Because major earthquakes occur infrequently in California, some interviewees think that a "felt" threshold helps to build an association between an earthquake early warning and taking safety and preparedness actions, thus providing an opportunity to test preparations and plans for larger earthquakes. Alternatively, there was also some preference, especially among representatives of the Utility, Mass Transit, and Industrial sectors, to have flexibility in the activation thresholds to ensure that the triggering threshold was high enough so that the risk of unnecessary operational interruptions caused by smaller earthquakes and false warnings would potentially be reduced. In this case, the EEWS locates where they are and only notifies them of earthquakes that are likely to impact their facilities or system. Some sectors also have regulatory reporting thresholds—such as industries that handle hazardous chemicals and materials— that may also influence their preferences and needs for certain notification thresholds.
- **Length of time for the advanced warning.** For most organizations, the potential benefits and value of investing in the use of EEWS increases as the length of warning time increases. A warning that is too short for a person to think and act upon safely is by definition not useful for many of the potential applications. It also presents some significant organizational challenges in training personnel for occupational safety. The interviews also revealed that the time needed to control many organizational operations is highly variable, company by company, industry by industry, system by system, etc. A gas shutoff can be enacted quickly, but for more complex applications, safe control of a system or process can take much longer than the expected warning times given for some of the major urban earthquake scenarios; e.g., a magnitude 7.8 on the southern San Andreas in the Los Angeles region or a magnitude 7 on the Hayward Fault in the San Francisco Bay Area. A few interview participants also noted concerns that there can be "too much warning time" making it difficult for people to maintain DCHO or other appropriate safety responses.

Without more definitive information on the anticipated reliability, notification thresholds, and expected warning times for a wider range of scenarios than what was presented during the interviews, many organizations had difficulty answering questions about their potential ability and willingness to use an EEWS.

Organizational Barriers, Complexities, and Implementation Issues

Organizations also face some significant internal issues that are likely to affect both the potential ability and willingness of different organizations and the sectors that they represent to use an EEWS. While not an exhaustive list, some of the key issues raised during the interviews are as follows:

- **Design and development of the appropriate delivery mechanisms and equipment to use an EEWS is not trivial.** One utility operator commented that a simple equipment design project within their organization takes at least a year. The steps involved in creating the appropriate equipment for a particular EEWS application would require them to develop the manufacturing specifications, secure funding, contract for the design and manufacturing, and then install the equipment. Interview participants from an Industrial sector organization also described their current limitations with on-site communications. Personnel are not allowed to carry smart phones while on-site, and so special radio signals or other audible and visual signals would need to be developed. Special training and testing would also have to be designed and implemented so that personnel would be ready to carry out different recommended behaviors depending what the person was doing at the time.
- **Organizations have IT security, firewall, and software issues that have to be addressed in order to use an EEWS.** In order to achieve benefits of an earthquake early warning, users have to confront difficult issues of IT and security (e.g., protecting their data as it moves through their firewall). Although a few organizations have considered this issue, most have not. Some interview participants reported facing these challenges in trying to use the ShakeAlert prototype system. There are also concerns about the potential incompatibilities between EEWS and different emergency management and operational system monitoring, and impact modeling software and applications. Telecommunication sector representatives caution that SMS-based (i.e., “point to point”) alerting systems do not make efficient use of the telecommunications networks and can fail, with the potential to cause the rest of the telecommunications network to fail in the event of a major earthquake.
- **Organizations face personnel constraints to develop and deploy applications, and the training necessary to realize the benefits of an EEWS.** Anticipatory planning for EEWS applications and integration seems clustered within a limited number of emergency management and operational staff of many organizations. Personnel constraints have already affected some organizations’ levels of involvement with the ShakeAlert beta testing. Organizational implementation of an EEWS will need to involve a far larger and more organizationally diverse group of personnel.

- **Issues of leadership, institutional support, interdepartmental coordination, and organizational resistance must be overcome for benefits of an EEWS to be realized.** These issues are more difficult in organizations facing significant budget challenges or those that lack a strong culture of preparedness. For some statewide organizations, potential resistance to bear some portion of the costs or to invest personnel time in training to use an EEWS may be higher in parts of the state where there is less risk. Some organizations that rely on unionized labor to perform key operational functions raised concerns about the potential willingness of union personnel to accept additional duties and to remain on-site once an EEW is issued. Conversely, other organizations identified their unionized personnel as possible allies in helping the organization to manage its disaster response mission responsibilities and look after the wellbeing of large groups of people following an earthquake. These uncertainties in institutional support must be addressed as part of the adoption process.
- **The internal training, education and communication investments needed to realize the full benefits of an EEWS will be significant.** All sectors recognized that there has to be systematic study and design of appropriate warning responses for situationally-specific work activities in order to realize the potential benefits of occupational safety. Ongoing information dissemination and training will also be needed. Some interviewees, especially within the social-serving and customer-facing lifeline and economic sectors, expressed a need to further study. They noted the likelihood of potential human confusion and panic that might occur when an earthquake early warning is disseminated and the need to develop appropriate information and training to manage these situations.
- **Organizations will face significant costs for organizational development, deployment, and training associated with potential applications of EEWS.** While organizations acknowledge that the potential benefits and value for life safety are high, many organizations stressed that the system reliability, seamlessness, and annual cost have to be weighed against the value added. They also want organizational costs to be part of the dialogue on funding, including costs for IT and security needs, and the development of equipment required for potential applications, training, and maintenance of the applications. Some organizations are already engaged in the development of the EEWS by installing seismic monitoring instrumentation and helping to build the telecommunications infrastructure for the system; they want these contributions to be valued in a cost-benefit assessment. Public-sector organizations question whether the costs can be funded through general obligation bonds or through state or local hazard mitigation grants. Other public-utility organizations question whether the costs might involve a rate increase filing, and how they would balance this investment with other resilience investments (e.g., hiring security officers and upgrading of infrastructure). They also noted that there may be long lead times for capital planning or funding that involves potential rate changes.
- **Some organizations may need to obtain regulatory changes in order to use an EEWS**. Some organizations, particularly within the Utility and Industrial sectors, are highly regulated and must adhere to operations standards and guidelines. In some

instances, these operational standards and guidelines specify that their first organizational response to an emergency incident is to "assess." Being proactive, rather than reactive, to an earthquake through the use of an EEWS may require regulatory changes. If the design and use of potential EEWS applications would need to be aligned to comply with regulatory obligations and compliance processes, there will be added costs and risks for the organization.

Sector Interdependencies in Potential Use of an EEWS

The interviews also explored the interdependencies among the 14 sectors to better understand the importance of one sector to another in making use of an EEWS. Table 6 shows a compilation of the interview discussions about sector interdependencies with respect to potential uses of an EEWS. The interdependency that a particular sector has on another sector is shown by reading across the rows. It is important to stress that this is a research interpretation of the interview data and not a systematic accounting of sector responses.

Top Tier (1) interdependencies are those that are crucial to a sector's ability to access and use an EEWS. The three most critical Tier 1 interdependencies exist with each sector's need to access electricity, telecommunications, and information technology as part of the potential application of EEWS. Even the human-controlled applications, such as notifications for employee or public safety, have dependencies on these three sectors.

Tier (2) interdependencies exist within a sector's dependency for real-time operations that may be disrupted by an earthquake and might be mitigated by use of EEWS. The Transportation, Gas Utility, Water Utility, Public Safety, and Financial sectors are critical to the real-time operations of many sectors. Many potential applications involve these sectors, such as: (1) needing real-time access to transportation networks to undertake safety assessments and restore services; (2) needing water and public safety for fire-fighting, security, and other property and asset protection efforts; and (3) maintaining financial security. Also, there are Tier 2 interdependencies within all sectors. This is a reflection of the integrated nature of most sectors, underscoring their interactions and interdependencies with many facilities and organizations within their sector in order to function.

Tier (3) interdependencies are mostly dependencies that include a sector responsible for restoring function. These include the Mass Transit, Hospital, Emergency Medical Service, Education, Insurance, Business, and Commercial and Industrial sectors. Most sectors do have a downstream dependency upon each of these sectors, but it is not as essential to real-time operations or the potential use of EEWS by different organizations within the other sectors.

Table 6 Degree of Interdependency among Sectors in Making Use of an EEWS*.

	Electric Utility	Telecommunications	Mass Transit	Transportation	Gas Utility	Water Utility	Public safety	Hospital/EMS	Education	Financial	Insurance	Business	Commercial/Industrial	Information Technology
Notification for Occupational Safety	1	1	3	2	2	2	3	3	3	2	3	3	3	1
Notification for Public Safety for a Particular Facility	1	1	3	2	2	2	3	3	3	2	3	3	3	1
Broadcast Notification for General Public Safety	1	1	2	2	2	2	2	3	3	2	3	3	3	1
Activation of Emergency Response Plans and Situational Assessment	1	1	2	2	2	2	2	3	3	2	3	3	3	1
Large-Scale Utility Control	1	1	3	2	2	2	2	3	3	2	3	3	3	1
On-Site (Facility) Utility Control	1	1	3	2	2	2	2	3	3	2	3	3	3	1
High-Speed Mass Vehicle Control	1	1	2	2	2	2	2	2	2	2	3	3	3	1
Low-Speed Mass Vehicle Control	1	1	3	3	2	2	2	2	3	3	3	3	3	1
Independent Vehicle Control	1	1	3	2	2	2	2	2	2	3	3	3	3	1
Industrial Equipment, Assets, and Process Control	1	1	3	3	2	2	3	3	3	2	3	3	3	1
Industrial Chemical Control	1	1	3	2	2	2	3	3	3	2	2	3	3	1
Commercial Equipment, Assets and Process Control	1	1	3	2	2	2	2	3	3	2	3	2	2	1
Large-Scale Access Control	1	1	3	2	2	2	2	3	3	2	3	2	2	1
On-Site Access Control	1	1	3	3	2	2	2	3	3	2	3	3	3	1

*The interdependency that a particular sector has on another sector is shown by reading across the rows. Top Tier (1) interdependencies are those that are crucial to a sector's ability to access and use an EEWS. The next tier (2) interdependencies exist within a sector's dependency for real-time operations that may be disrupted by an earthquake and might be mitigated with a potential use of EEWS. The third tier (3) interdependencies are largely dependencies that a sector has on restoring function.

While there are likely to be conflicting views about this data and the merits of some of the individual interdependency tier designations, the critical point that hopefully emerges from this analysis–which becomes a key outcome theme for the study—is as follows: **The viability of EEWS and the ability of organizations and society as a whole to access and use EEWS depend greatly on the integration and continuous functionality of telecommunications, electric utility, and information technology as part of the delivery of and ability to receive an early warning**.

Figure 2 provides an illustration of how the Telecommunications, Electric Utility, and Information Technology sectors are an integral part of the design and functionality of an EEWS and its ability to deliver notifications and thus provide for potential applications and benefits for all 14 sectors.

It is also noteworthy that several interview participants identified important interdependencies with two additional sectors that were not an explicit part of the study. They are government (primarily regulatory agencies) and the community-based/non-profit sectors. Future studies may want to include these two sectors and also consider if there are other sectors that should be added to future studies.

There are also some critical sub-sector divisions that should be considered for any future studies. For the purposes of this analysis, the interview participants' dependencies on gasoline and liquid fuel were included with the Gas Utility sector, which are in different cases transported by rail, boat, and truck. However, the actual refining and production of gasoline and industrial chemicals were included in the Commercial and Industrial sector. Further subdivisions and distinctions like these are needed in future studies.

The interviews also attempted to explore by sector the upstream, vendor, and supply-side dependencies as well as the downstream and user/customer dependencies. All organizations identified upstream dependencies on the Telecommunications, Electric Utility, and Information Technology sectors for them to access and use the EEWS, and also cited other lifelines critical to their real-time operations. A few organizations, primarily in the Commercial and Industrial sector, identified some key suppliers of materials, commodities, chemicals, and equipment essential to their manufacturing operations, especially those that are more engaged with "just in time" and global manufacturing processes. For instance, the Gas Utility sector group identified the need to be able to ship out spent acid on a timescale of every few days in order to continue operations. Another noteworthy set of downstream dependencies that many organizations have is on vendors that set-up and manage the daily needs of staff, such as food delivery, for base camp operations that will be used to service their repair crews, and for highly specialized equipment or materials that the organization would need to perform repairs and restore functioning.

The upstream and downstream dependencies of different organizations and sectors and how they relates to the identification of potential applications of EEWS merits further study in future cost-benefit analyses.

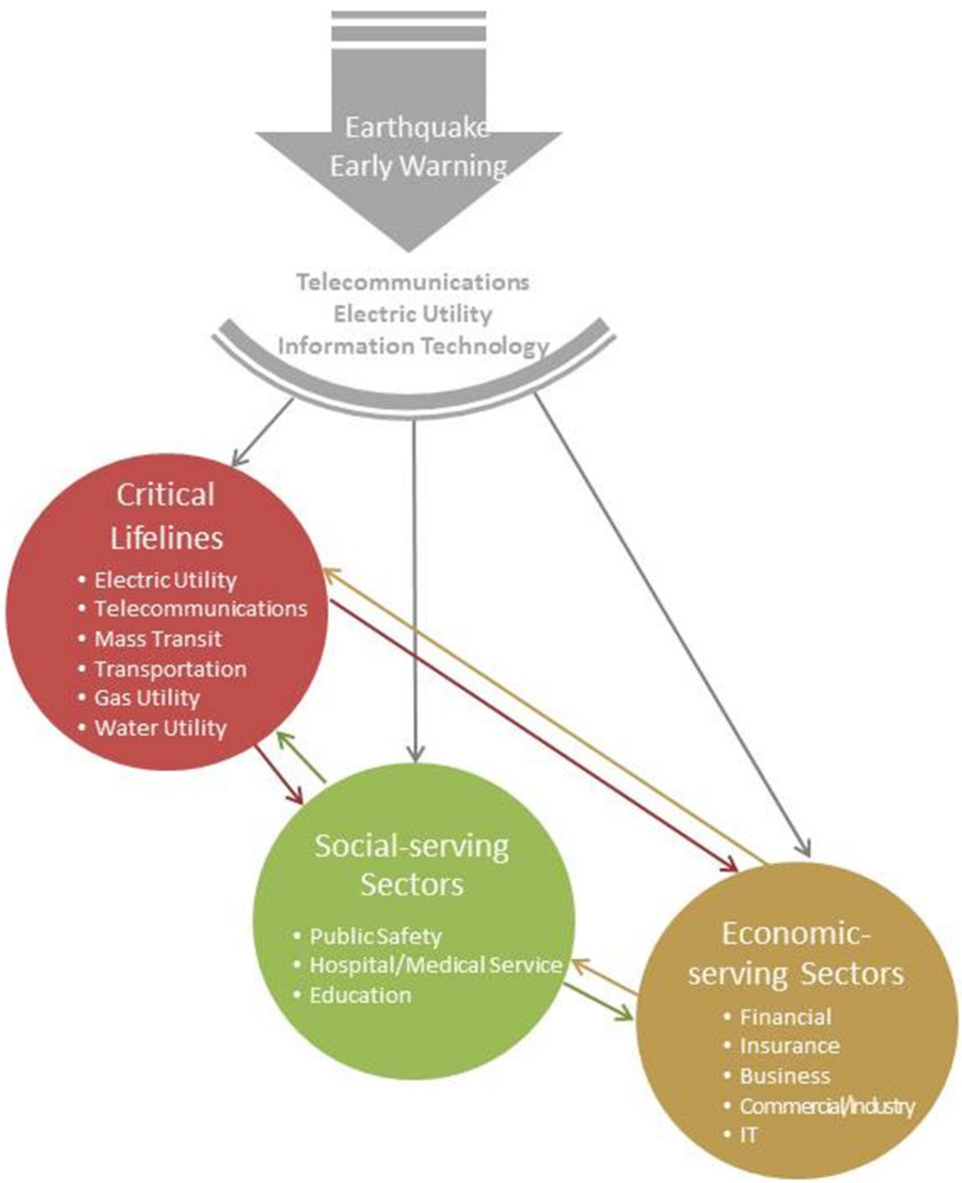

Figure 2 An Integrated View of the Telecommunications, Electric Utility, and Information Technology Sectors in the Functionality of an EEWS and its Service to Key Sectors and Society as a Whole.

5. OTHER SECTOR-SPECIFIC FINDINGS

Baseline Earthquake Preparedness and Response Planning

This study takes the stance that the benefits of EEWS are incremental based on the system's capacity to *improve* outcomes relative to what would have occurred under existing emergency response plans and preparedness activities. By definition, this difference is difficult to quantify, but the interview questionnaire asked participants from each sector to describe their baseline state of emergency preparedness and planning as part of conducting the most realistic benefits assessment possible.

This approach is important for several reasons. A statewide EEWS can contribute to the California populace and economy but only to the extent that it integrates well with and goes beyond efforts that are ongoing and constantly being refined. Response planning is furthermore constrained by internal organizational characteristics and capacity as well as each organization's external regulatory and sectoral environment. In some cases, safety and response methods and standards of practice are heavily prescribed from outside, e.g., in the Energy, Oil and Gas, and Health sectors as well as across the board by the Occupational Safety and Health Administration (OSHA) and telecommunication systems and information technology realities. Understanding these factors is important in identifying critical variations in information needs, cost-effective opportunities to integrate an EEWS within different types of organizational practices, and functional considerations for warning integration with existing efforts and external requirements.

The experiences and work that many organizations are already doing with EEWS and other near-real-time communications software and systems are also important. There are opportunities to learn from their current integration efforts and to find ways to leverage EEWS benefits and reduce delivery costs by aligning with existing approaches. For instance, most interviewees already work with Incident Command System (ICS), National Incident Management System (NIMS), or Standardized Emergency Management System (SEMS) protocols; EEWS must integrate with these other protocols and avoid conflict. Several sectors also work with existing emergency communication systems such as the Government Emergency Telecommunications Services (GETS) program[8] and Wireless Emergency Alerts (WEA)[9] (such as the Amber Alert program).

Response Planning Objectives and Priorities

Consideration of the key objectives reflected in response plans and procedures of the organizations interviewed for this study is essential. A statewide EEWS is unlikely to alter these priorities and will be expected to serve them.

[8] https://www.fcc.gov/general/government-emergency-telecommunications-service (Accessed July 11, 2016).
[9] https://www.fcc.gov/consumers/guides/wireless-emergency-alerts-wea (Accessed July 11, 2016).

Among the organizations in this study, a nearly uniform hierarchy of goals emerged. These organizations definitively put life safety first, including the health and wellbeing of their own employees, first responders, direct customers or members, and the general public. The next set of objectives related to preservation or restoration of operations and business continuity. The ability to continue to function and restore any impacted services was viewed as important to fulfilling their key organizational purposes or mission. In some cases, this is also vital to immediate incident response and speed of community recovery, not just for their own organizational survival. Note that these objectives for the most part mirror the perceived opportunities for potential EEWS benefits. These are the two main areas where organizations are most optimistic that an EEWS can be beneficial. The following paragraphs briefly discuss each of these priorities in more detail.

Given the limited EEWS lead time that most California earthquake scenarios will provide, for life-safety benefits to be fully realized, participants tended to describe an EEWS that is widely disseminated (i.e., via cell phone alerts). Participants coupled these remarks, however, with concern for the potentially heavy upfront costs that might be necessary for extensive training for a variety of different audiences and response scenarios and circumstances.

Interviewees emphasized that safety for different groups of people may best be addressed in different ways. From the perspective of any particular organization, the safety of the public may have multiple dimensions (i.e., on-site customers or users of infrastructure assets, or users of a service that are physically dispersed). Organizations in different sectors and of difference sizes face different scales of life-safety concerns. Larger entities have thousands of people (both employees and members of the public on their own vehicles or property), while others have hundreds who are mostly employees. The ratio of employees to public can also be different, which might be a factor to consider in developing EEWS use trainings or scenarios. All these parameters change depending on the time of day of the earthquake.

The interviewed organizations have, for the most part, extensive existing collaborations with local governments and first responder partners, often through joint planning efforts, protocols, and training exercises. How a statewide EEWS will work in practice will need to be thoroughly understood by all involved, and any resulting changes in expectations have to be worked out and communicated clearly. This is particularly important for the Electric, Gas, Telecommunications, Public Safety, Health, and Water sectors that are co-dependent and essential to effective immediate incident response.

After safety, all interviewed groups said they want to preserve and restore critical functions that provide the basis for maintaining a high level of service to customers and local communities, and avoiding economic disruptions. Those objectives are closely related to employees with the right training and knowledge, and who are healthy, available to work, and mentally focused, status of equipment that is undamaged and in key locations, and facilities that are safe, inhabitable, and functional.

Protection of assets, equipment, and facilities was primarily viewed as something that occurs through facility design, systems planning, and mitigation before an event. Most organizations were confident that they have done a good job of pursuing high structural performance in vital facilities through pre-event facilities hardening and preparations. In the Electric, Gas, and Mass Transit sectors, billions have been or will be spent on investing in improved structural performance. Several organizations said they design their facilities to withstand Maximum Considered Earthquake shaking. Another type of pre-event preparation is investment in redundant communications and information technology systems, such as parallel internets and remote duplicate data centers. One entity said they had a runner system as back up if all other communications systems fail.

Some response plans appeared to be more informed by vulnerability assessment than others. Entities in this study from the Mass Transit, Water, and Business sectors have, for example, assessed where tunnels or aqueducts cross faults, which pieces of their infrastructure are not yet retrofitted, or how each manufacturing or business process might be affected by shaking. The degree to which an organization has been able to assess its own internal earthquake risk exposure might matter for how ready an organization is to deploy EEWS to benefit restoration of damaged facilities. Clients of mutual commercial insurers would have already completed this risk assessment, but smaller commercial entities may not.

Other response concerns expressed but not previously discussed here include:

- The need to remain in communications within the organization and with first responders (mentioned by the Mass Transit, Transportation, and Public Safety sectors).
- Helping employees exchange communications with their loved ones elsewhere (per the Mass Transit and Transportation sectors).
- Protection of the environment (per the Mass Transit, Transportation, and Health sectors)
- Reputation and preservation of brand quality (per the Electric, Gas, Business, Health, and Commercial/Industrial sectors).
- Maintain security in their physical and cyber environments (per the Electric, Gas, Business, Financial, and Commercial/Industrial sectors).
- Businesses and private organizations that were interviewed tended to speak about continuity of operations in terms of their organizational "lines of business." Some lines of business might be more sensitive to earthquake disruption than others.

Overall Response Planning Sophistication and Organization Culture

In general, nearly every interviewed group had a high level of sophistication in terms of earthquake threat and impact awareness, with detailed plans in place for emergency response. This is due in part to the study selection criteria, but it is important to reiterate that EEWS will not be the driver or central feature of any organization's response plans; it must be integrated into existing, highly thought out, and complex infrastructure already in place.

Current response plans were aimed at multiple hazards rather than addressing earthquakes as a standalone phenomenon. Earthquake response is nested within and in some ways very similar to other response situations, and it is recognized that earthquakes can induce secondary hazards such as fire, tsunami, or chemical spill. Consequently, potential pathways to achieve ancillary benefits from use of EEWS that could benefit preparedness and response outcomes for other hazards should be considered.

In general, the interviewed groups also had relatively high levels of overall earthquake preparedness and espoused a culture of preparedness. Commitment to preparedness at the top was seen as important but varied, as was lower-level employee awareness and preparedness. This is likely due to variation in the centrality of emergency preparedness relative to organizational mission. Highest focus was found among organizations with primary emergency response responsibilities (Public Safety and Transportation sectors) basic utility (Electric, Gas), and health services delivery. As the Hospital sector group stated, "Health is our business." These entities know that their people, services, facilities and equipment will be subjected to multiple major earthquakes throughout their large service areas and long-term organizational existence. They feel deep responsibility to protect their employees and the public from ever-present threats. They also see themselves as at the center of society's ability to respond and recover; therefore, they aim to continue operations with as close to regular service capacity as possible.

One type of variation was the how the emergency management department or team were positioned with the organizational hierarchy and the extent of efforts related to emergency response. An organization might have more or less employees who lead emergency efforts, or who are trained regularly and rigorously in emergency management issues at all. For instance, "front line" employees such as teachers or bank tellers might receive far less training in issues related to risks and emergency management than field personnel for a regional electricity or urban rail service. Hospital staff receives more emergency-related training than staff at a bank or amusement park, even though they both work daily with numerous members of the public. However, it seems that across sectors employees receive trainings of some type relatively frequently. Consequently, there may be relatively direct opportunities to integrate training about use of EEWS into existing employee training processes.

Another phenomenon of note is differing degrees of "siloing" or separation between different departments who work on areas related to emergency management from different perspectives. Some sector participants have long-standing, intentional crosscutting collaborative processes in place (i.e., utilities and private corporations), whereas a few did not. Other organizations showed strong "silos" between emergency preparedness across organizational departments, perhaps due to organizational complexity and capacity, or far fewer departments involved. This could affect ease of integration of warnings into different areas of mission, operations, or functions. Progress seems to be slow and minimal, even in some of the beta testing organizations, in terms of thinking out how to coordinate internal response to the opportunities created by EEWS.

The standout in terms of lowest emphasis, scope of effort, and resources was the Education sector, where a single person held significant responsibility for managing an entire school district's earthquake preparedness efforts. This lack of resources is counterbalanced, however, by the apparent simplicity of the pathways through which EEWS might benefit this sector. Therefore, EEWS might be more difficult to implement (take more time, cost more, require more technical assistance) in sectors where emergency response is more peripheral to the core mission, such as Education, where staff and monetary resources are limited.

Response Activities in the Seconds, Minutes, and Hours after Shaking is Detected

In the first critical seconds or minutes of shaking, people instinctually try to assess what's occurring and may take action to protect themselves, in addition to helping others around them. They use all available senses and faculties to do this, even though those might be compromised by the dangers, shock, and distractions in the moment. Next, people expand their field for collecting information by assessing the situation relative to what is most important to them, which is usually people and living things, be that the other people present, employees elsewhere, their distant loved ones, or pets. Once safety is in check, attention can turn to other aspects of their organization for which they are responsible.

By nature, some organizations, e.g., power companies, gas processing, transportation networks, and hospitals, operate continuously throughout each day of every week, even if there are different volumes of need at various times (such as at commute hours, nights, or weekends). These sectors always have some staff at work or ready to go, usually on rotating duty. In the case of Utilities, real-time supervision or dispatchers are physically positioned in an operations facility all the time. Maintenance activities may be specifically targeted to off- or low- use hours.

In the Electric sector, Supervisory Control and Data Acquisition (SCADA) systems are used in monitoring and controlling the distribution system. Persons and equipment in a centralized control room at any given time observe and receive automated information from sensors throughout the system. In a Mass Transit operations center, methods can be used to remotely slow or stop a train by killing the power on site or through an Automatic Traction Control (ATC) system or having a train operator do so manually.

In the majority of cases, where reaction to ground shaking is not automated, personnel have to absorb information and decide the next course of action. Some organizations create "playbooks" for various scenarios that employees have been trained on and drilled. This study found that playbooks and predesigned expectations and procedures are mainly deployed in reactive ways, driven by human synthesis and interpretation rather than prescriptive formulas. Most organizations put the actual response decision making in the hands of a single individual supported by a small set of other lead personnel. Interestingly, in several cases specific divisions, sites, departments, or lines of business had significant responsibilities and roles in writing response plans that were customized to their particular setting, while central emergency management teams were responsible for goal setting, advising, and coordination. This might prove challenging to "impose" certain kinds of uses of EEWS from above.

Most interviewees did not describe their plans as having any prescriptive earthquake response activation thresholds or criteria. Response actions taken will be reactive based on assessment of perceived impacts. The most extreme example of the reactive stances seems to be in the Public Safety and Health sectors, where response actions are triaged based on calls received by dispatch or impacts that physically present themselves; first responders are primarily reactionary unless they witness an incident firsthand. This hints at potential benefits if EEWS is used to circumvent the need for citizens and businesses to call in to 911 or travel to a healthcare site. If localized deployment occurs sooner, it might help in some life safety or property damage (e.g., in the case of fire) situations.

If response is primarily reactive and based on human information collection and processing, the leadership structure, common understanding of roles and protocols, and preparation for response among all employees are of utmost importance. In Mass Transit, Mass Assembly, and some Public Safety circumstances, organizations depend on private citizens as part of primary response. For instance, Mass Transit sector interviewees said they depend on Good Samaritans; to some degree this would also be true for mass assembly sites such as amusement parks or sports stadiums. Many rural fire departments rely almost exclusively on volunteers.

Activation of Emergency Operations Centers (EOCs) and the ramping up time for their operations can vary from 30 minutes to a few hours. It can take several hours to deploy field teams for inspections, especially for entities with distributed infrastructure such as the Electric sector. All the while, EOC operations require constant updating through two-way information flow, taking in reports, and transmitting out instructions. Even though these activities take place well after an initial shock has been felt, if employees are deployed into areas of damage to assess and inspect, EEWS may have benefits for situational awareness even if the "warning" does not arrive in time. Receiving a heads up about aftershocks is one of the main benefits of the EEWS.

In the Utilities and Industrial/Commercial sector, some processes were mentioned where conveyor belts, pouring or mixing of chemicals, pressurization, electricity, water and gas flow, etc., are in motion, so that if slowed or stopped could reduce the likelihood or severity of damage or asset loss. Some organizations primarily face "ramp downs" or new challenges in delivery of service as a result of earthquake disruption, while others face clear thresholds at which service delivery can be abruptly halted; this is true to ports, which can be shut down by the coast guard if deemed unsafe or inoperable.

The response plans that did contain activation thresholds were in the Electric, Gas, Mass Transit, and Transportation sectors. These groups reported having activation criteria or gradational category systems that called for different responses, depending on the intensity of shaking (the Modified Mercalli Intensity (MMI) estimate) or recorded Richter magnitude associated with an earthquake in a relevant location. For example:

- One Energy sector organization notifies key response management level employees for a magnitude 3 event anywhere in the state, while senior officers are notified at a magnitude 5;
- A Mass Transit sector organization has three situational conditions levels tied to MMI;

- A Transportation sector automatically activates maintenance field crews at magnitude 4.0 and structural maintenance group at a magnitude 5.5; and
- Organizations signed up for ShakeCast receive an email at magnitude 4.0 or higher.

Current Use and Experiences with Warning Systems and other Near-Real-Time Information

Familiarity with current EEWS efforts varied, with several organizations showing relatively early stage understanding and involvement. This is partly due to the people selected to be interviewed and does not necessarily reflect awareness or knowledge in other parts of the organization, such as front line employees, other areas of management, or leadership. The study was not designed to assess systematically familiarity with EEWS.

A few interviewed organizations had access to and some employees were directly involved with ShakeAlert and ShakeCast systems. For direct users of the ShakeAlert system, a handful of mid-level technical personnel installed it on a laptop. This is intentional because currently the system is not broadly recommended for automated use or as a major factor in go/no go decisions. Some interviewees lamented how far it is from actually functioning like a "warning" and how slow the system development process is progressing.

There appeared to be modest experimentation and or proactive thinking by users of the ShakeAlert beta system or other proprietary systems as to potential applications. In most cases, the users have a few computer installations that observe system performance, and this information is used by operations/response staff to augment other data and inform their decisions/actions. The Utility, Mass Transit, Transportation, and Telecommunications sector interviewees were the most advanced sectors in actively exploring what would be required to implement its use. For instance, an electric utility might look at how it can get information to peoples' computers and/or phones, and to field crews involved in hazardous or critical functions. In at least three cases, sophisticated post-processing algorithms were or are being developed for translating the ShakeAlert information into actionable, organization-specific formats.

Overall, the level of progress in taking steps to implement greater integration seemed low. Anticipatory planning for EEWS integration seems clustered in mid-level technical staff. For instance, at one utility, a seismologist was the principal in charge of this task. In two other organizations, it was IT specialists. Use of ShakeCast or other modeling of systems due to ground shaking was the most sophisticated automated application seen.

Note that there are a few commercial providers of earthquake warning systems. The organizations in this study cited other technologies designed to disseminate information immediately and repeatedly throughout an incident. Interviewed groups mentioned several specific platforms, listed in Table 7. The list includes not only SCADA in the case of the Electric Utility and Telecommunications sectors, but also Everbridge, SendWordNow, CodeRED, other automated systems and functions. There is concern that communications system will be saturated with post-event activity and that these platforms may fail as a result.

There is a need for basic public information on how to use wireless/internet bandwidth post-event. This presents a real problem for companies that have invested in these expensive employee notification systems that will not function if using SMS and other systems. However, this reality makes EEWS even more valuable, because it might be organizations' first and last reliable source of event information.

Table 7 Examples of Rapid Information Collection and Dissemination Software or Systems Mentioned by Interviewees.

Types of Earthquake Sensing or Near-Real Time Information Used	Reference URL	Counts of Specific Mentions
SCADA, Open-Source or Commercial Solution Providers, or Customized system monitoring tools	Various Vendors	5
ShakeAlert	http://www.shakealert.org/	3
Equipment Malfunction Sensors, On Site Strong Motion Instrumentation	Various Vendors	3
ShakeCast	http://earthquake.usgs.gov/research/software/shakecast/	3
Earthquake Notification Service	https://sslearthquake.usgs.gov/ens/	2
Internal Organization-Specific Post Processing Applications	Various	2
ShakeMap	http://earthquake.usgs.gov/earthquakes/shakemap/	2
CodeRED	https://ecnetwork.com/state-local-government/ (Accessed July 1, 2016).	2
CitizenConnect	http://www2.deloitte.com/global/en/pages/technology/solutions/deloitte-citizen-connect.html	1
Everbridge	http://www.everbridge.com/	1
Reddinet	http://www.reddinet.com/	1
SendWordNow	http://sendwordnow.com/ (Accessed July 5, 2016).	1
AlertUS	http://alertus.com/	1

Other Organizations, Programs, and Associations of Importance

Many interviewees noted that because they are heavily regulated industries, safety planning must comply according to standards approved either by governmental entities and/or professional associations. Therefore, an EEWS cannot disrupt protocols currently required or approved and ideally should be compatible with them. In some cases, there might be constituent or regulator resistance to support price increases in addition to the perception that an EEWS is prone to false alarms.

The potential role of industry and professional associations is similar in terms of adoption of standards. For industry groups, "umbrella" organizations are both important stakeholders and potential allies in the development of an EEWS. Interviewees mentioned at least 30 regulatory and industry organizations that they viewed as important to their businesses in terms of setting standards of practice.

6. POTENTIAL IMPLEMENTATION ISSUES FOR A STATEWIDE EEWS

Although outside the scope of this study, the interview data provide some rich information on numerous topics under consideration by the California Earthquake Early Warning System Implementation Steering Committee. Some, but not all, interview participants made comments regarding system design and performance considerations, the organizational structure for system management and operations, system funding, and system deployment and rollout concerns. Some of the major concerns and recommendations emerging from the interviews on these topics are provided in the following sections. Also, interview participants included their own suggestions for how they would like to stay involved with the design, development, and deployment of a statewide EEWS. These are offered up as points of consideration for Cal OES and the California Earthquake Early Warning System Implementation Steering Committee, and the implementation framework for a statewide EEWS.

System Design and Performance Considerations

- **The planning and implementation model for a statewide EEWS should be deeply and broadly collaborative, starting with a core group representing five key areas: scientific/technical/engineering teams, leading emergency management organizations, the Telecommunications and Information Technology sectors, the Electric Utility sector, and experts in occupational behavior, public health, psychology, and community engagement.** These are the "design and delivery partners." Involvement of all of them is seen as critical for the system's success. Also for some interview participants involved with the ShakeAlert prototype development and beta testing, there is concern that ShakeAlert will not scale properly. This is only one approach rather than an agreed-upon approach. These perceptions and concerns are affecting organizational trust and willingness to support development and implementation of a statewide EEWS.
- **System resiliency, redundancy, and scalability are important considerations in organizational willingness to invest in applications and use a statewide EEWS.** More transparency and active communication and engagement with potential users about the entire system design are needed now and must be sustained. Interview participants expressed concerns about the current robustness of the sensor network and its ability to reliably predict the magnitude and geography of an earthquake. They are concerned about the telemetry communication, and they want assurances about the seismic resiliency of sensors so that earthquake aftershocks will also be available. They want assurances that the middle ware (e.g., central data processing unit) will be robust, resilient, and scalable to handle the level of traffic and demand that will occur on a spiking basis. They want to

better understand the accuracy and speed of the signal processing algorithms and how false warnings will be filtered.

They want multiple transmission pathways (e.g., wireless broadcast, text, TV, radios, emergency broadcast, IPAWS, sirens, internet email, and technology applications) that are reliable, scalable, and consistent with global standards so that all people, including out-of-state and foreign visitors and residents, will have equitable access to the warnings. They also want to be sure that incorporation of global standards also applies to more than just transmission devices. As one Industrial sector organization noted, they already have manufacturing equipment with Japanese EEWS-enabled technology embedded in it, and they want to use it with a California system as well. Organizations also want to be involved in deciding whether people and organizations can be allowed to "opt out" of warning notifications and how notifications might be tailored by organization and location, with specific directions for employees to take, especially given the relatively short timeframes for a warning response. They also want assurances about IT security both at the societal and organizational levels.

- **Until the performance standards for the system are better understood, organizations cannot fully evaluate their willingness to use an EEWS, invest in applications, contribute in-kind work, or provide funding for the system.** In order to build trust in the system, everyone needs to buy into how it will work. A plan for how potential users will have transparency, documentation, and active communication and engagement in the entire system design (i.e., from "send to end"), as well as the system performance objectives around reliability, redundancy, and scalability is needed now, and their engagement needs to be sustained. Statistical information about latency, false warnings, and other reliability issues is desired. Some interviewees recommended that benchmarking of the current system start now, and that it should be tracked over time as well as benchmarked against with other systems in the world. Many also advocated for community-based agreement on the performance standards as well as activation criteria and notification thresholds for warnings. Processes used by the engineering profession to develop agreement on building design and code provisions might be helpful in more collaboratively formulating the performance standards for a statewide EEWS.

System Governance and Management Structure

- **The development, management, and operations of a statewide EEWS needs to be treated as a major public safety infrastructure project given the size of the state and the area to be covered, the financing issues, and the complexity of engineering needs.** The coalition of largely government and academic institutions involved in system development efforts to date needs to be expanded into a 24/7 operation, with a broader myriad of organizations working to provide their expertise to achieve the vision. Clarification and confidence in the governance structure for the development, management, and operations is an important consideration in organizational willingness to invest in applications and use a statewide EEWS.

Some organizations suggested that foremost priority action should be to expand the California Earthquake Early Warning System Implementation Steering Committee chaired by Cal OES to be more inclusive of key stakeholders, notably members of the Electric Utility, Telecommunications, and Information Technology sectors that are central to automated delivery of broadcast notifications and performance of EEWS. Consideration should also be given to creating an additional tier of "partners" who can serve critical roles in garnering public support and understanding of the benefits of a statewide EEWS, as well as designing and executing policy advocacy and media and public outreach. These might include members of the Education, Hospital, and Emergency Medical Service sectors, large statewide personnel unions, and community-based organizations. Umbrella organizations and industry associations can also be effective partners in the development process, helping to engage their member organizations as partners and assist in advocacy and outreach efforts.

- **The issue of liability protection for system partners and users should be a factor in determining the appropriate governance structure for the management and operations of a statewide EEWS.** Organizations want more information on sovereign immunity and how that might apply to them if the system is managed and operated by a state or federal agency. Some suggested studying other warning systems (e.g., tornadoes, floods, volcanoes, tsunamis, and hurricanes) to learn how liability issues are handled. Telecommunication sector representatives noted that the Wireless Emergency Alert system (WEA) was rolled out on an entirely voluntary basis with full liability protection established by Congress. That liability protection was crucial to the rollout and the tremendous adoption by wireless carriers because it limited their legal liability in the event of erroneous messages.

System Funding

- **An earthquake early warning is a social entitlement with responsibility for such a system residing with government and its social contract with the public, and with access being open and free to the public including public and private organizations.** A subscriber model had limited support among interview participants. However, some organizations are already investing or will need to invest in similar technology, and it may be worthwhile to conduct a more in-depth investigation as to how these current and future investments might be aligned with the funding needs for a statewide EEWS. Such an investigation might start with State agencies as to their current investments and future plans and needs with the CISN and systems and technology related to EEWS. A couple of interview participants went so far as to suggest that the Governor should task key State agencies to prepare a plan for how they would use an EEWS and develop a pooled funding scheme. There were mixed views as to whether a State mandate requiring agencies to use the EEWS would help with adoption; some public agency organizations cautioned, however, that grant funding typically accompanies State mandates related to emergency management. There was also concern expressed about requiring agencies that provide a public safety service to pay for an EEWS.

- **A secure and consistent funding source is a factor in organizational views about the overall system reliability and thus their willingness to invest in the development, deployment, and training necessary to use an EEWS.** Development of a funding model and widespread communication of its structure to assure organizations that the effort will be adequately funded and resourced for the long-term needs to happen sooner than later. Funding plans must address both the system development as well as the on-going costs to maintain and upgrade both the core system and the applications technology and equipment. Estimated costs in the USGS ShakeAlert implementation plan seem low to some interview participants who are quite familiar with the implementation effort; they raised specific concerns about the estimates for on-going maintenance and the need for a sizable education and training component as part of implementation. If a public-private funding model is adopted, organizations want to know the terms of the arrangement, their expected contribution, and the timing of that contribution (e.g., in the development stage and on-going efforts).
- **Identify the potential ways and ancillary benefits for organizations to be engaged in the development and implementation of a statewide EEWS**. Many participants acknowledged their responsibility to fund development, deployment, and training for their potential applications of EEWS, and there is a high willingness to do so. However, they also want these organizational costs for becoming involved and transitioning their practices to incorporate EEWS, as well as their in-kind contributions, to be recognized in the system funding/costing analyses. During the course of the interviews, organizations have identified an array of assets (e.g., seismic sensors and dedicated radio networks) and system development contributions that they can offer or are already offering to help build the system and help reduce the costs. These assets and development contributions should be inventoried.

  Consideration of the statewide and industry benefits of having a more robust seismic infrastructure, telecommunications network infrastructure, and other key elements of the system in place needs to be expanded and valued. For example, hardening the CISN has so many benefits beyond EEWS, such as improving both the ShakeMap and ShakeCast, and that value needs to be defined and communicated as part of the partnership engagement, advocacy, and outreach efforts for the system.

  Consideration might also be given to working with organizations to develop monetary incentives for using an EEWS. One possibility would be to work with the insurance industry to develop an insurance rate reduction scheme for organizations' potential applications of EEWS. Insurance underwriters will need a level of assurance on the reliability and availability of both the statewide system and the applications. Some insurers may require a formal testing and certification process to approve an application product for rate reduction. Product certification involves development and execution of a product test protocol and auditing of the product manufacturer to ensure quality and consistency in the product manufacturing.

System Deployment and Rollout Plans

- **With life safety viewed as the primary benefit of a statewide EEWS, issues of equitable access by both organizations and society as a whole need to be carefully considered.** Implementation plans that differentiate and sequence access to organizations and the general public are in conflict with the tremendous societal-serving life-safety benefit that the system can provide. It conveys an environment of "haves" and "have nots" in terms of access. Interview participants recognized that the rollout has to start somewhere, and some recommended that an approach where the system is initiated to public safety providers and then released to organizations and the public is reasonable. In an effort to maximize the societal benefits of an EEWS, the classification of organizations as "public safety providers" might also be expanded beyond the traditional fire, law enforcement, and medical service providers to also include utility and transportation providers and others who provide vital services to society. Some interview participants, however, perceived the potential risks of public panic and chaos as high and are concerned that they face significant liabilities and challenges in dealing with the public who might be on their property when a warning is issued. They want more direct control over the timing and delivery mode of warning information to people within their realm of responsibility. These issues should be faced sooner rather than later in the development and implementation planning for a statewide EEWS.
- **The implementation timeframe for a statewide EEWS needs to realistically account for the timing of contributions from critical partners in the system development as well as the system requirements of its potential users.** The organizational timeframes to develop, deploy and train users on potential applications is quite varied. Some organizations see a fairly quick adoption and implementation process if the system is reliable. Others see adoption taking much longer. Concerns about the timing of applications would shift if the system reliability and organization's confidence were higher or lower. The implementation timeframe also needs to account for the system requirements of users and development for timeframes of bringing onboard critical partners, like the telecommunications industry. The 2015 study by the Alliance for Telecommunications Industry Solutions (ATIS)[10]—the North American technical standards organization for telecommunications technologies—estimated that it will take a minimum of 3–4 years to complete standards and fully deploy EEWS capabilities in wireless networks, and 5–7 years from the start of their implementation work to obtain meaningful saturation of a statewide EEWS deployed via wireless devices. Given the limited warning response time that most California earthquake scenarios will provide,

[10] ATIS, 2015, Feasibility Study for Earthquake Early Warning System, ATIS0700020, https://access.atis.org/apps/group_public/download.php/24638/Feasibility-study-for-earthquake-early-warning-system.pdf.

most interview participants tended to describe a simple EEWS notification that is widely disseminated (i.e., via cell phones) in order for the full benefits, especially for life safety, to be realized. It is imperative that the implementation timeframes for the statewide system work with partners and realistically account for such constraints.

- **Study the range of situationally-specific human activities and the set of practical delivery modes and appropriate warning responses in each.** A range of appropriate warning responses (e.g., beyond DCHO) is needed given the variety of situationally-specific human activities that people may be engaged in when an earthquake occurs. These investigations need to cover an array of socio-demographic, organizational, temporal, and functional situations, including, e.g., hazardous industrial and occupational scenarios, what individuals of different backgrounds and abilities might do in various private or public settings, and human-object interactions and different warning response times ranging from only a few to many seconds. For occupational scenarios, such a study has to be done holistically by one agency or the user organization has to be trained and supported with a data call and some systematic analysis and reporting back/design of hyper-DCHO for occupational safety. This will require occupational behavior and public health disciplines as well as a baseline study of population reactions to EEWS notifications that considers the potential and perceived risks of panic, complacency, and other human responses. Results of such studies need to inform the design and budgeting for a comprehensive and nuanced education and outreach component of a statewide EEWS implementation program.
- **Ensuring adequate understanding and training in use of a statewide EEW is a fundamental prerequisite to life-safety benefit realization.** The educational process will not be simple or "one size fits all," and it will need to involve experts in occupational behavior, public health, psychology, and community engagement in the production of a comprehensive education and training program. People with very sophisticated and practical understanding of warnings for human interactions and risk communication, and those with expertise in running sophisticated public awareness campaigns (e.g., Centers for Disease Control campaigns) have to join with traditional emergency management in the program design and implementation. A variety of cultural communities and persons with access or functional needs need to be engaged with the design and dissemination of all education and training products. Multiple language support is necessary for all products that are developed and education efforts have to consider the needs of organizations using the EEWS as well as resident and visitor populations. There should be time and resources allotted to study how Japan, Mexico and other regions with an EEWS have managed public education and the warning broadcast and communication.

  A range of training models at multiple levels—for people, organizations, and communities—needs to be developed. One organization recommended the Cal OES "train-the-trainer" model, which trains people to become certified education and outreach instructors who then go out into their communities to provide more education and training. Exercises of the statewide system should be held annually during the Great

Shakeout drill. Case studies, data, and reports about how other organizations in other countries (Japan, Mexico, and elsewhere) have used EEWS and the lessons gleaned from their experiences should also be developed.

Maintaining Sector Engagement

There is strong enthusiasm and support for development and implementation of a statewide EEWS across all the sectors participating in the study. The potential societal benefits, particularly with respect to life safety, are expected to be quite high. Participants referred to the potential launch of a statewide EEWS as a paradigm shift in emergency management and seismic safety in California.

There was also strong enthusiasm among the organizations to stay involved and to collaborate with the State and its partners on the development and implementation of the statewide system. When asked about how they might like to stay involved, some notable suggestions were:

- **Expand the ShakeAlert beta system user group and involve potential users of a statewide EEWS in brainstorming and helping with the overall system development process.** Being engaged helps to ensure that the system will be better utilized and help in educating and building support from potential users.
- **Establish a forum or platform for development partners and users to effectively communicate with each other, build collaboration, and increase the systems' utilization and benefits.** Encourage more interviews and interaction with other organizations in their respective sectors. Collaborate with participating organizations to develop scenarios of benefits of system use to their organization and their sector. Japan's Real-Time Earthquake Information Consortium is a potential model worth exploring.
- **Engage organizations to help in educating the public about EEWS**. They recognize that they have a significant role in disseminating the messaging and helping to disseminate that "realization of the life-safety benefit" is possible. Many organizations, especially those in the health and social-serving sectors, already provide training for the public, first responders, neighborhood response teams, and others. Some offered to disseminate education and training products through existing customer and patient notifications, employee orientations, and training briefings and practicing. Some organizations also regularly run ads about public safety issues.

  Work with organizations to incorporate earthquake early warnings into a wide range of organizational exercises and drills, and to develop playbooks for appropriate warning responses, education, and training for EEWS. Most organizations have robust emergency management exercise and training programs, and some also have "playbooks" for various scenarios that employees have been trained on and drilled. Most of these are reactive and put response decision making in the hands of a single individual supported by a small set of other lead personnel. Organizations invite more collaboration and engagement with the statewide EEWS implementation team in planning for and conducting exercises and drills and in reviewing these playbooks to ensure that a statewide EEWS is being properly integrated into their response protocols and procedures.

7. INSIGHTS AND RECOMMENDATIONS FOR NEXT STEPS IN ASSESSING BENEFITS OF A STATEWIDE EEWS

The purpose of this study was to document and qualitatively assess the value of a statewide EEWS through an interview process with organizations from 14 key sectors of importance to the state. Contacts were made with organizations believed to have relevant insights, and the interviewees discussed a range of uses and benefits related to public and employee safety, the protection of critical operations and assets essential to business resiliency, and the infrastructure that forms the fabric for community life and functioning of the economy.

All stakeholders would likely agree that one goal of a statewide EEWS is to provide public benefits that are as inclusive as possible over the long run but also commensurate with start-up, transitional, and maintenance costs. This study provides an important step forward in understanding the main types and avenues of benefits, how they can be studied in more detail, and issues that need to be confronted for them to be realized. Interviewees seemed grateful and excited about participating in the study and the opportunity to voice their advice and concerns. They agreed with the notion that empirical study on the subject of system uses and benefits is critical to advancing development of the system.

The central contribution of this study is a high-level typology of potential applications for a statewide EEWS. Rich information was gathered highlighting which applications are most relevant and attainable through either human-controlled or automated pathways in each of the sectors. Additionally, analysis was provided about critical settings where the realization of one application depends upon the realization of others, and where key challenges lie. These results advance the state of understanding about a significant endeavor with widespread implications for the health and wellbeing of California and its economy. Future major earthquakes are inevitable, and an EEWS is a valuable part of the state's overall preparedness for managing earthquake risks and minimizing the impacts and ripple effects of such events.

Study Limitations

As in all research, when a study moves from words on paper to field work, some objectives become more attainable than others. This study was successful in generating a clear and robust list of potential applications. However, the list of applications is admittedly more hypothetical than originally hoped. Only a few of the interviewed groups were able to share specific use scenarios they had generated or explain their business case and implementation thinking. This is likely attributable to the early stage nature of the system; without detailed information about its features, organizations are naturally limited in their ability to move very far with their own internal plans and evaluation of opportunities. EEWS is only one of many possible earthquake risk management activities, and earthquake risk management is only one of a myriad of business risk management issues with which all these organizations must contend. The ability to provide a detailed typology or mapping of benefit magnitude and sensitivities by application type was consequently constrained.

Other organizations not involved in the study may have done more or less to evaluate and prepare for implementation of a statewide EEWS. That is yet another reason to keep in mind the small sample size, recruitment criteria, and to refrain from over-generalizing from one or two organizations in a sector to the entire universe of entities operating in that sector. The data used here are also just one snapshot in time. Organizations in the Information Technology sector proved the most difficult to access. Consequently, the study underrepresented businesses that specialize in the architecture of the web and its potential use as a delivery mechanism and avenue for public education.

Regardless of the modest sample size, it is important to acknowledge the significant contribution in terms of valuable time and information that was shared by all 64 interview participants and their support staff who were vital to arranging the meetings.

Needs for Further Study and Quantification of EEWS Benefits

This study is the first step in preparing a more formal and comprehensive and quantitative study of the anticipated value of a statewide EEWS to the state's economy and infrastructure. It presents a benefit typology that can be used as a framework for more detailed study. This final section of the report highlights three fundamental areas requiring additional investigation and potential next steps.

1. **Develop a robust set of use scenarios for each application and elaborate on user-specific cases for the most promising applications.**

User centered design (UCD) has become standard practice in the field of product innovation and management, particularly for software development and human-system interactions. The process of UCD involves creation of concise descriptions of specific scenarios where an actor is engaging with a system to achieve a goal.

This report provides a more comprehensive set of example applications than available previously, but there is still much work to be done to generate lists within each application type and specific use scenarios. Adequate details are needed about precisely who is doing what and how (tasks), as well as where and when (environment). That information forms the basis from which requirements for the human-system interface can be written, actualized, evaluated, and refined. Different human-system interfaces will be needed for different scenarios of use.

Descriptions of existing emergency management protocols and systems uses, explored in Section 5 of this report, may be a useful starting point to identify potential use scenarios. Deep and sustained engagement with a strategically selected and much larger than currently involved group of likely EEWS users will also be required. Some potential users of an EEWS have the organizational sophistication to create user cases independently, but others, particularly in less-resourced sectors such as Education, might need more assistance. Development of a user case template could serve as an aid for those organizations and for standardization purposes for the overall effort.

Some types of applications are better understood than others, and the less understood ones that could have a significant impact should be prioritized for investigation. For instance, interviewees in this study mentioned the potential environmental benefits of avoiding industrial-material train derailments or hazardous material leaks. Which types of companies and chemicals are involved, in what quantities, and where?

Development of high-quality user case information also necessitates broader involvement by scientists and practitioners of the occupational and behavioral sciences, user-centered and ergonomic design, public health, and risk communication. Detailed occupational behavior studies are needed for each human-decision application. Although relevant studies have been done, notably a survey by Porter and Jones[11] on people's ability to DCHO if they receive an earthquake early warning, the depth of knowledge from analogous risk communication contexts has yet to be tapped. The EEWS currently operating in other countries are an important source of information, but cultural and economic differences should be considered; e.g., different attitudes towards authority. Conducting a landscape scan and literature review of analogous risk contexts and communication approaches is advised. Direct observation of actors in various use settings, and in some cases experiments, may be needed in order to fully understand what the EEWS delivery system can do and needs to do, to achieve the desired response and goal.

In order to maximize the potential life-safety benefits, detailed testing is needed of the set of practical delivery modes and appropriate warning responses. A range of appropriate warning responses (e.g., beyond DCHO) is needed, given the variety of situationally-specific human activities that people may be engaged in when an earthquake occurs. These investigations need to cover an array of socio-demographic, organizational, temporal, and functional situations, including, for example, what individuals of different backgrounds and abilities might do in various private or public settings, and human-object interactions and different warning response times ranging from only a few to many seconds.

Results of such studies should also inform the design and budgeting for a comprehensive and nuanced education and outreach component of a statewide EEWS implementation program. Ensuring adequate understanding and training in use of the system is a fundamental prerequisite to life-safety benefit realization, and that educational process will not be simple or "one size fits all."

[11] Porter, Keith and Jamie Jones (in publication), "How many more people can drop, cover, and hold on if they receive an earthquake early warning?" (developed as part of the USGS HayWired M7 Hayward fault earthquake scenario)

2. **Collect quantitative evidence about the likelihoods and magnitudes of different application-use scenarios and their benefits.**

With a more fully developed set of use cases, quantitative benefit estimation becomes possible. One essential data input is occurrence, count, and rate data for gauging the frequency and likelihoods of each scenario taking place. For instance, a Utility sector entity might be able to provide data on how many maintenance crew members it has in the field at various times of the day, week, or year who are engaged in precarious maneuvers, as well as how long a maneuver takes to complete and the minimum time frame crew members would require to perform safety protocols. Along with some assumptions about the size of the sector as a whole, this kind of information creates the ability to calculate an outcome, such as the potential number of injuries avoided for that particular application type and scenario.

Cost-benefit studies often seek not just benefit estimation but also monetary valuation. Extensive, though not uncontroversial, studies and standards exist for assigning dollar values to instances of avoided deaths or injuries of various types. A landscape scan and literature review of analogous benefit valuation and cost-benefit studies would be useful. Given the sector interdependencies identified in this study, benefit estimation also needs to look at secondary and cascading elements, such as estimates of business interruption losses avoided and reductions in recovery costs and timeframes. There may also be legal and not just practical challenges to collecting the type of organization- and sector-specific information that would be valuable, e.g., concerns for corporate privacy, proprietary systems, and cybersecurity.

Some types of outcomes are easier to quantify than others; for instance, psychological benefits, such as peace of mind, mental wellbeing, reduced stress or anxiety, or increased ability to focus, are important but notoriously difficult to study formally. These types of intangible benefits should be acknowledged and explored, however, even though they are difficult to document and estimate.

Additionally, it is important to understand the phasing in over time of benefit attainment. The timing of different types of benefits will depend on implementation plans, technical realities, organizational capacities, and other factors. In a full cost-benefit assessment, benefit timing matters greatly because of the time value of money (future benefits are worth less in present value terms).

3. **Consider potential benefits in sectors not included in this study, as well as sources of within-sector variation in benefits across all sectors.**

This study was not designed to investigate every possible sector of relevance. In addition to the Information Technology sector that proved difficult to engage, additional sectors and sector representatives that could have valuable applications include the military, government, construction, pharmaceutical, and aerospace technology sectors, as well as universities, private schools, automobile insurers, a major pipeline conveyor, heavy rail, and industrial production companies that use flammable and ignitable liquids and gas.

A systematic (possibly random sample) survey within sectors of importance would be one way to develop an understanding of the full range of activities, benefits, and implementation issues that EEWS could have in different sizes and variations of organizations. Such a survey should ask for quantitative information such as:

- Number of employees on site at different times of day/days of week
- Number of members of the general public on site at different times of day/days of week
- Fraction of employees engaged in hazardous maneuvers and fraction of time that each spends on those maneuvers in a typical work day
- Level of education of these employees
- Types and frequency of emergency-related training
- Internal communication systems in place
- Level of interest and willingness to use EEWS
- Ranking of possible impediments and concerns about use of EEWS

Even with the efforts described above, fundamental issues about how to estimate EEWS benefits will still need to be explored. Some significant remaining questions and uncertainties include:

- What is an appropriate scope of "ripple effects" that should be used in evaluating benefits?
- What are the factors that make any particular application more or less feasible and realistic, and what kind of assistance do various organizations need to overcome any barriers?
- Which applications do not make as much economic sense and should not be pursued?
- What is a realistic scale and cost for the education, training development and deployment, and public health campaign needs related to broad notification applications?
- What are the critical assumptions and intermediate steps to achieving any particular application's highest benefit? For instance, how effective does an education program have to be before the general public's DCHO behavior is significantly improved enough on average to prevent a significant number of injuries?
- What cascading and less tangible benefits merit investigation and quantification in a cost-benefit study? For instance, there are perceived educational and socio-psychological benefits that may be gained from society's access to an advance warning, but how feasible and important are they to measure?
- What might it cost for different organizations to engage in developing the system as a whole and then establishing the user capability internally?

As is often the case in scoping studies, more questions tend to be generated than answered. However, both the process of conducting this study and its subsequent findings have demonstrated that the most important next step is to foster more systematic, varied, and deeper involvement with organizations that will be at the front lines of EEWS system use. Applications and benefits of EEWS cannot just be studied from afar. Collaborative "study" of system uses will in fact help create, shape and bring them into reality.

APPENDIX A: STUDY PROTOCOLS AND INTERVIEW PROCEDURES

Study Protocols and Interview Procedures for the California EEWS Benefit Study

PEER worked with Cal OES and the SSC to identify an extensive list of potential organizations to interview in each of the 14 prescribed sectors of the project. The potential organizations within each sector were then ranked according to the following criteria:

- Sophistication and ability to use an earthquake early warning system
- Organizational value to the resiliency of the state's infrastructure and economy, as well as to a particular region or sector
- Societal and life-safety value of the organization's potential earthquake warning decisions and actions.

With all these conditions in mind, an organizational batching structure and key candidate organizations were identified. Alternates were also identified for each batch. In some cases, these alternates were from another sector but had similar characteristics or fit well within that batch. It was agreed that if contact wasn't made with the key candidate organization after two attempts, or if the candidate organization declined to be interviewed, then an alternate would be contacted. Only one of the key candidate organizations declined to be interviewed and an alternate then had to be contacted.

The order and timing of interviews were structured into three batches of six to eight organizations each. Each batch included a useful spread across each of the sectors with at least one organization from each of the 14 sectors interviewed within the first two batches. Consideration was also given to geography and other factors that would help to enable an assessment of the potential interdependencies and cascading effects of warning-related decisions and actions among organizations and sectors. In this way, the first batch emphasized large regional and statewide organizations located in the San Francisco Bay Area, thereby reducing travel-related logistical issues and enabling a swifter launch. The second batch emphasized large critical facility organizations and organizations located in Southern California. The third batch also emphasized large critical facility organizations as well as sector-related associations, state agencies and regulatory agencies.

Cal OES Director Mark Ghilarducci sent an invitational letter addressed to the primary contact at each of the candidate organizations; a sample copy of that letter is contained in Appendix B. PEER developed both an Interview Brief and an Interview Guide that were sent to each of the interview participants ahead of the interview. All these materials were reviewed and approved by Cal OES and the SSC; copies of each are available in Appendices C and D. The Interview Brief provided a general overview of earthquake early warning and its applications in at least nine other countries around the world, plans for a statewide system in California and details on the study interview format and content. The Interview Guide identified the questions that the PEER team asked during each of the semi-structured interviews, organized around the topics of:

- The organization's current earthquake/disaster response plans and procedures
- Potential uses, benefits and costs of a statewide earthquake early warning system within the organization.
- Consideration of the interdependent and cascading nature of an earthquake early warning and subsequent decisions and actions taken by various organizations and the public, and
- Broader societal benefits of a statewide earthquake early warning system.

In all, 18 interviews were conducted with 69 individual participants from a total of 24 organizations. In most cases, individuals represented both the executive management and technical operations of selected organizations. The interviews averaged about 90 minutes in length, with many participants willingly extending the time to continue the discussions. With permission, members of the PEER team took notes and audio recorded the discussions. The PEER team also followed up with participants if clarifications were needed after the interview.

After completing an initial round of interviews, PEER held an interim briefing with project leadership staff from Cal OES and the SSC. It was agreed at that time that the Interview Guide and Interview Brief were working effectively and the PEER team would complete the interview process as designed.

PEER developed an outline for the final report that was also reviewed and approved by Cal OES and the SSC. Data gathered in the interviews was then integrated into the summary of results. Measures have been taken to ensure the privacy of individuals and proprietary aspects of each organization in the summarization of results. All participating organizations have been given an opportunity to review the draft report. Cal OES and the SSC will work with organizations on a coordinated release of the final report.

APPENDIX B: INTERVIEW INVITATION LETTER

EDMUND G. BROWN JR.
GOVERNOR

MARK S. GHILARDUCCI
DIRECTOR

April 29, 2016

[redacted]

Subject: Participation Requested - California Earthquake Early Warning Benefit Study

Dear [redacted]

The California Governor's Office of Emergency Services (Cal OES) is requesting your assistance as we seek to identify the benefits associated with earthquake early warning. Earthquake early warning in some cases can provide seconds to minutes of advance warning before strong ground shaking begins, allowing people and industries to take actions to protect themselves and their equipment by ceasing critical processes.

In 2013, Senate Bill 135 passed and was signed by the Governor as California Government Code 8587.8 tasking Cal OES with the development of a system for California. Earthquake early warning beta systems are already operating in Southern California and the San Francisco Bay Area. These beta systems will ultimately become part of an expanded and integrated statewide system. However, to sustain needed support for this system now and into the future, it is critical that a more systematic understanding of the potential uses and benefits of earthquake early warning be pursued. In particular, we need to better understand how an early warning might be utilized and how it might affect key sectors of the state's economy and infrastructure, specifically lifeline utilities, telecommunications, mass transit, transportation, public safety, hospitals, education, finance, insurance, business, commercial industries, and information technology.

Cal OES, in partnership with the California Seismic Safety Commission, has engaged the Pacific Earthquake Engineering Research Center (PEER) to perform this study. You, your organization and particular sector are vital to our state and we would like to learn more about your views on a statewide earthquake early warning system. We request that you take the time to participate in an interview to be conducted by PEER. Grace Kang from PEER will contact you in the next week with additional information.

The interviews will focus on organizational-level views about the potential applications and benefits of a state earthquake early warning system. Data gathered in the interviews will be

3650 SCHRIEVER AVENUE, MATHER, CA 95655
(916) 845-8506 TELEPHONE (916) 845-8511 FAX

[redacted]
April 29, 2016
Page 2

integrated into a summary of results that will be provided to Cal OES and the Seismic Safety Commission. Measures will be taken to ensure the privacy of individuals and proprietary aspects of each organization in the summarization of results. If you have any concerns about information handling or confidentiality of your responses during this process we will work with you to address them as necessary. If you have questions about this project please contact Ryan Arba, Cal OES Earthquake and Tsunami Program, by phone at 916-508-6023 or by email at ryan.arba@caloes.ca.gov.

Your input, expertise and candid feedback are vital to ensure the informed and effective implementation of this critical public safety initiative. Thank you in advance for your cooperation.

Sincerely,

MARK S. GHILARDUCCI
Director

cc: Grace Kang, Project Coordinator, PEER, via email: g.kang@berkeley.edu

APPENDIX C: INTERVIEW BRIEF

California Earthquake Early Warning System Benefit Study
Interview Brief

The California Governor's Office of Emergency Services (Cal OES) in partnership with the California Seismic Safety Commission has engaged the Pacific Earthquake Engineering Research Center (PEER) to independently evaluate the anticipated value of a California Earthquake Early Warning System. State legislation passed in 2013[1] tasked Cal OES with developing a statewide earthquake early warning system. Given the importance of this initiative and the sizeable investment that is needed, it is imperative that the state objectively assess the value of a system to key sectors of the state's economy and infrastructure through, for example, public and employee safety, business resiliency, and the protection of critical operations and assets that serve local communities and the economy. The resulting information will be used to develop a preliminary benefit-cost study and to inform a more comprehensive benefit-cost analysis that will likely be conducted over time as the system is developed.

Earthquake Early Warning Overview

California is one of the most seismically active states, second only to Alaska. Dozens of disastrous earthquakes have resulted in loss of life, injury, property damage and economic losses across the state; and it is almost guaranteed that there will be a major damaging earthquake somewhere in California within the next 30 years.[2] In 2013, the State Legislature called upon Cal OES to form a public-private partnership to develop a statewide earthquake early warning system.

As shown in Figure 1, seismometers and other sensing and telecommunications technology can be bundled together so that advance signals and warnings of strong ground shaking can be broadcast to people, information systems, and equipment just as radar and satellites are used to provide advance warnings of tornadoes and hurricanes. However, unlike weather warnings which can come days in advance, earthquake warnings can only be provided within seconds—from the time the first signal of an earthquake is detected to the time strong ground motions arrive at a particular location.

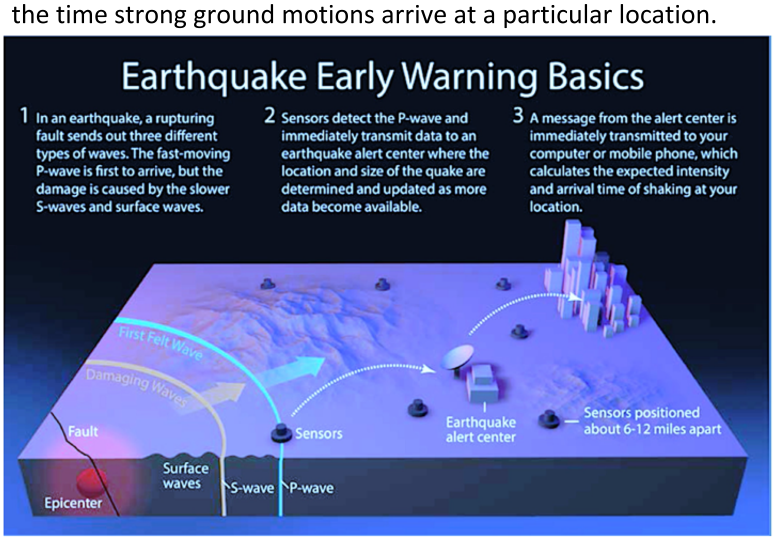

Figure 1. Schematic, three-dimensional diagram illustrating the travel path of a warning to the public during an earthquake. (Source: USGS, Technical Implementation Plan for the ShakeAlert Production System, 2014; original graphic by Orange County Register.)

The amount of warning time at a particular location depends on its distance from the earthquake's origin and rupture path. Locations very close to an earthquake epicenter are within a "no-warning" zone in which there

[1] Senate Bill 135 is codified as California Government Code Section 8587.8.
[2] Edward H. Field et al., "Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3)—The Time-Independent Model," USGS Open-File Report, (2013), http://pubs.usgs.gov/of/2013/1165/.

is insufficient time to process and disseminate a warning ahead of the arrival of strong ground motions. On the other hand, locations far removed from an earthquake epicenter will have lengthier warning times but may not experience damaging shaking. Earthquake early warning offers the greatest risk reduction potential when the region affected by strong shaking from earthquakes greater than magnitude 7 is large.[3] Also once built, the system can provide multiple benefits to users for multiple earthquakes over time.

Earthquake early warning systems are now operational in at least nine countries around the world, including Mexico and Japan; information on these systems is provided in Table 1. Mexico has the world's oldest public earthquake early warning system with development initiated after a magnitude 8.0 earthquake devastated Mexico City in 1985. In April 2014, it provided residents of Mexico City with 80 seconds of advance warning before strong shaking ensued from a magnitude 7.2 earthquake that originated 170 miles (270 kilometers) to the southeast near the Pacific coast.[4] Japan's system, which has been in operation since 2007, provided 15 to 20 seconds of warning ahead of strong shaking from the magnitude 9.0 earthquake that originated offshore of the Tohoku region on March 11, 2011, preventing train derailments and alerting several million people to take protective actions.[5]

In California, much of the state's 39 million residents reside within close proximity to the state's most active faults. This means that the risk exposure is very high and also that advance warnings for the larger and more potentially damaging earthquakes will more likely range from a few seconds to tens of seconds. However, even a few seconds of advance warning can potentially help to reduce the risks to life, property, commerce and societal functioning through a variety of human actions and automated controls. Such actions and automations can reduce direct damage and casualties and also help to prevent cascading failures and other indirect effects.

This has already been proven in California with a demonstration system called ShakeAlert.[6] The system incorporates existing sensors from the California Integrated Seismic Network and the Pacific Northwest Seismic Network that monitor earthquakes and send alerts to a host of test users when they occur. When the magnitude 6.0 earthquake struck in southern Napa County on the morning of August 24, 2014, ShakeAlert used data from four sensors to initially estimate a magnitude 5.7 earthquake and issue a warning within 5.1 seconds after the earthquake originated. This provided ShakeAlert users in Berkeley and San Francisco with about 10 seconds of warning prior to the onset of the strongest shaking.[7] One test user, the Bay Area Rapid Transit (BART), received the ShakeAlert message and automatically activated system-wide train controls to prevent derailments; however, there were no trains running at 3:20 am when the earthquake occurred. ShakeAlert also successfully alerted test users of the magnitude 5.1 earthquake that struck near La Habra, California in 2014.

Figure 2 and Figure 3 show the estimated warning times from ShakeAlert for two scenario earthquakes impacting northern and southern California. Figure 4 shows the features of a typical ShakeAlert computer message for a scenario earthquake.

---

[3] ShakeAlert, 2015, "Frequently Asked Questions", www.shakealert.org.
[4] Erik Vance, "Good Friday Quake in Mexico City Tested Region's Preparations for Bigger One: The City's Unusual Geology Allows Engineers and Seismologists to Rely upon Exceptional Safety Measures," *Scientific American*, April 25, 2014, http://www.scientificamerican.com/article/good-friday-quake-in-mexico-city-tested-regions-preparations-for-bigger-one/.
[5] Yukio Fujinawa and Yoichi Noda, "Japan's Earthquake Early Warning System on 11 March 2011: Performance, Shortcomings, and Changes," *Earthquake Spectra* 29, no. S1 (March 1, 2013): S341–68, doi:http://dx.doi.org/10.1193/1.4000127.
[6] See www.shakealert.org. ShakeAlert is being developed by the U.S. Geological Survey (USGS), in partnership with the University of California at Berkeley, California Institute of Technology, University of Southern California, Swiss Federal Institute of Technology (ETH), and the University of Washington with support from the Gordon and Betty Moore Foundation.
[7] T.M. Brocher et al., "The Mw6.0 24 August 2014 South Napa Earthquake," *Seismological Research Letters* 86, no. 2A (April 2015): 309–26, doi:10.1785/0220150004.

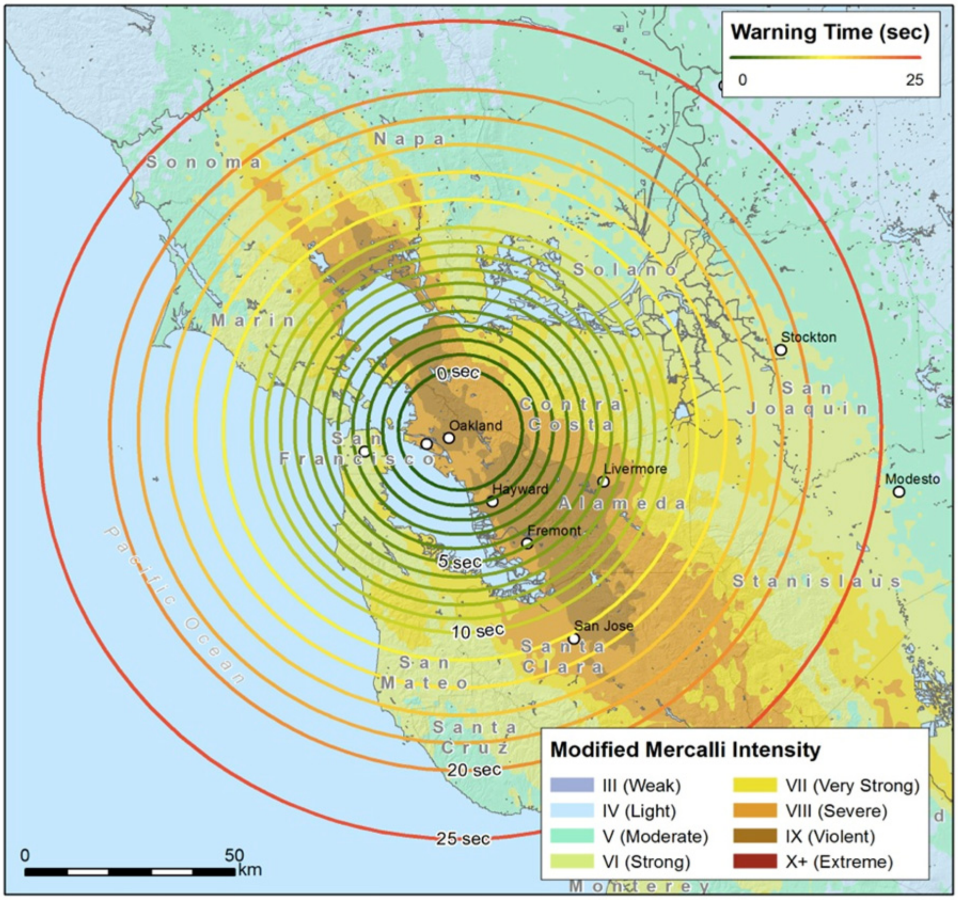

Figure 2. Estimated warning times for a magnitude 7 scenario earthquake centered in south Oakland and rupturing along the Hayward fault. The green to red colored lines show the expected warning times (in seconds). The underlying shading shows the estimated ground shaking intensities with the most intense shaking likely in areas with yellow, orange, and brown shading. (Source: USGS Earthquake Science Center, 2016)

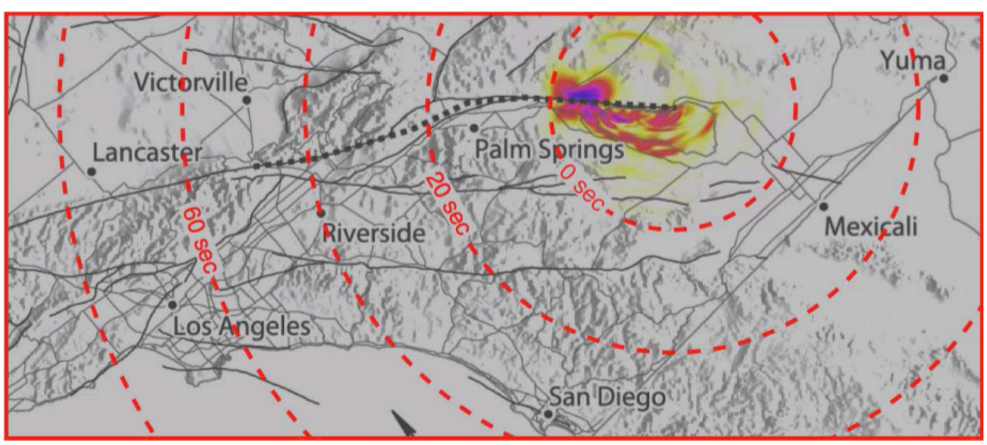

Figure 3. Map of the initial 10 seconds of a magnitude 7.8 scenario earthquake on the southern San Andreas Fault. Red dashed lines show the expected warning times. Faults (solid dark-gray lines) and length of the scenario rupture (dotted black line) are also shown. Purple, red, and yellow colors show the simulated surface velocity levels of the earthquake. (Source: USGS, Technical Implementation Plan for the ShakeAlert Production System, 2014).

Figure 4. ShakeAlert computer message for a magnitude 7.8 scenario earthquake on the southern San Andreas fault. It shows the number of seconds before seismic shaking waves arrive at a location, the expected shaking intensity at that site, and a map with the earthquake epicenter, its magnitude, and the current position of the P and S waves. (Source: USGS, ShakeAlert—An Earthquake Early Warning System for the United States West Coast, Fact Sheet 2014-3083)

On your screen: ShakeAlert

1. Real-time tracking of seismic waves from quake's epicenter.
2. Real-time tracking of the fault rupture (updates intensity).
3. Your current location tracked by GPS.
4. Seconds remaining before seismic waves reach you.
5. Expected intensity of quake at your current location.
6. Estimated magnitude of quake.
7. Intensity scale.

Envisioning a California Earthquake Early Warning System

Since 2013, the California Earthquake Early Warning System Implementation Steering Committee[8] has been working to develop a comprehensive statewide earthquake early warning system that meets the objectives set forth in the 2013 legislation. Objectives include the use of a public/private partnership model for planning and implementation, development of an organizational structure for the system's management and operations, identification of funding sources excluding the state's General Fund, and production of a comprehensive plan for training and education.

Plans for the California system build upon the successes of the California Integrated Seismic Network (CISN) as well as the ShakeAlert demonstration and prototype systems. In addition to the 469 broadband and strong motion sensors already in the CISN, nearly 650 more field sensors will need to be added or upgraded in order to achieve the optimum sensor spacing and density in urban areas and around the hundreds of known faults across California. Telemetry used to convey data from field sensors to central processers will need to be improved and central processing centers will need to be built or upgraded to manage the new data streams received from the field sensors. Warning notification paths will also need to be established. Since the California system will be part of the Advanced National Seismic System (ANSS), it will conform to existing national standards for management, system performance, data quality and completeness, sharing seismic data and validation of methods for the creation and distribution of public earthquake information.

[8] The California Earthquake Early Warning System Implementation Steering Committee is chaired by Cal OES and includes the California Seismic Safety Commission, California Geological Survey, University of California, California Institute of Technology, USGS, and other stakeholders.

The capital cost to construct and launch a California system is estimated to be $28 million and the personnel and operating expenses are estimated at $17 million annually.[9] Thus, long-term, sustainable funding sources are needed from local, state and federal government and private sector investors in order to establish and maintain a robust, timely, and reliable system that is able to maximize notification utility while minimizing false alerts or missed events. In addition, users will need to invest in equipment to monitor, receive and control critical operations. Users' distance from the earthquake epicenter will affect how much time they have to react and take protective actions. Benefits will naturally vary by user and for each earthquake occurrence, including magnitude, time of day, and other factors.

Cal OES, the USGS and other partners will jointly develop and operate the California earthquake early warning system and notifications. California Government Code 8587.8 charges Cal OES with development of California's system through a public-private partnership. As such, Cal OES will work with the California Legislature and other partners to establish a unified governance structure for the system. It will have the necessary authority to establish operational policies, administer program funding and execute contracts and agreements. Cal OES will also lead the implementation of an education and outreach program that will run concurrently with ongoing system build-out and deployment.

An incremental roll-out strategy is planned to enable users to realize the benefits of alerts as quickly as possible when and where system capabilities can meet user needs and expectations. First, knowledgeable organizations and value-added redistributors, including test users of the ShakeAlert demonstration system, will be enlisted as early adopters for the California system. Government agencies, critical infrastructure, specific organizational sectors, and value-added redistributors will be next in line for the rollout. Limited public venues controlled by an organization (such as public areas in airports, malls, and entertainment and sports venues) and limited public releases to test training and education strategies will then follow, prior to granting access to the wider general public.

Study Interview Format and Content

The Pacific Earthquake Engineering Research Center (PEER) is conducting research to prepare a business case for a California Earthquake Early Warning System (EEWS). PEER is a multi-institutional research and education center headquartered at the University of California, Berkeley, and involving investigators from over 20 universities and research institutions, as well as state and federal government agencies and numerous consulting firms. PEER's research focuses on performance-based earthquake engineering in multiple disciplines including ground motion and tsunami hazard, structural and geotechnical engineering, lifelines, transportation, risk management, resilience, and public policy. The PEER team is led by Dr. Steve Mahin, structural engineering professor and principal investigator, and Dr. Laurie Johnson, urban planner and project manager, and also includes Grace Kang, structural engineer and project coordinator, and Dr. Sharyl Rabinovici, disaster mitigation policy specialist and research advisor.

In April and May 2016, the PEER team will be conducting interviews with representatives of fourteen sectors that are critical to the state's economy and infrastructure. The purpose is to gather organizational-level views about the potential applications and benefits of a statewide earthquake early warning system. The PEER team has worked to identify and prioritize key organizations within each sector across the state and it is hoped that both executive/management and technical/operational representatives of selected organizations will participate in each interview.

[9] D.D. Given et al., "Technical Implementation Plan for the ShakeAlert Production system—An Earthquake Early Warning System for the West Coast of the United States," USGS Open-File Report (Reston, VA: U.S. Geological Survey, 2014), http://pubs.usgs.gov/of/2014/1097/.

An Interview Guide accompanying this brief is provided ahead of the interview; however, interview participants are not required to complete it in advance. The Interview Guide is organized around the topics of:

- Your organization's current earthquake/disaster response plans and procedures
- Potential uses, benefits and costs of a statewide earthquake early warning system within your organization.
- Consideration of the interdependent and cascading nature of an earthquake early warning and subsequent decisions and actions taken by various organizations and the public, and
- Broader societal benefits of a statewide earthquake early warning system.

The interviews are expected to last about 60 to 90 minutes. Two members of the PEER team will conduct the interview and, with permission, the interviews will be audio recorded and notes will be taken. The PEER team may also want to have follow-up contact if there are some clarifications needed after the interview. Data gathered in the interviews will be integrated into a summary of results that will be provided to Cal OES and the Seismic Safety Commission and which will be vetted in a public hearing conducted by the Commission. Measures will be taken to ensure the privacy of individuals and proprietary aspects of each organization in the summarization of results. All participating organizations will have an opportunity to review the report before it is released and Cal OES and the Commission will work with organizations on a coordinated release of the report.

As previously noted, the focus of this research is to advance understanding of the overall potential benefits and costs of a California earthquake early warning system. A detailed and objective understanding of the value to key sectors of the state's economy and infrastructure is critical to helping that system evolve in the best ways possible. Your organization's participation is vital to identifying key opportunities, barriers, or issues needing further study.

Table 1: Earthquake early warning systems around the world

Country	System design and implementation	Operational structure and experience
Mexico	Initiated in 1991 following the 1985 earthquake in Mexico City National government provided limited funding to develop the system; operation began in 1993 El Centro de Instrumentación y Registro Sísmico, A.C. (CIRES) is a non-profit formed to develop and manage the system Sensor focus is on detecting large offshore subduction zone earthquakes	System serves over 25 million people in Mexico City, Oaxaca, Toluca, Acapulco, Chilpancingo, and Puebla, via TV and AM/FM radio (since 1993), weather radios and Mexican Hazard Alert System (since 2011) 95,000 receivers in elementary schools; 8,000 loud speakers As of 2013, system generated 34 public alerts and 72 preventive warning from a total of 2,000 earthquakes detected M7.2 offshore earthquake April 2014: 24 seconds of warning in Acapulco and 70 seconds of warning in Mexico City
Japan	Initiated after 1995 earthquake in Kobe Japan government invested $600 million System run by National Research Institute for Earth Science and Disaster Prevention and Japan Meteorological Agency (JMA) sends out warnings Non-profit organization, Real-time Earthquake Information Consortium, includes 70 companies and provides consulting services/products for notifications Over 1,000 seismometers across Japan capture both on- and offshore earthquakes Began operation in 2007	Warnings provided to target users and citizens via broadcast media, internet and telecommunications providers JMA reports a 75% hit (accuracy) rate with a goal to reach 85% M9.0 Tohoku earthquake and tsunami, March 2011: 15-20 seconds of warning in Tohoku coastal region; 80 seconds of warning in Tokyo
Taiwan	Initiated after 1999 Chi-Chi earthquake Taiwan government funded the initial development (US$1 million) led by the National Center for Research on Earthquake Engineering and National Science and Technology Center for Disaster Reduction Central Weather Bureau operates the system	Alerts sent primarily to schools, railway and disaster prevention sectors Between 2001-2009 provided 225 alerts for M4.5 or greater earthquakes originating both on land and off-shore
China	Initiated in June 2015 Focus on 4 regions: north China, southeast coastal, north-south seismic belt and northwestern Xinjiang Builds on demonstration systems already running in parts of China	Plans to deploy 2000 broadband and strong motion seismic stations and an additional 3000 strong motion sensors Target start-up date: 2020
Other countries including Turkey, Italy, Switzerland, Hungary, Israel and the Europe-wide region are in various stages of development and implementation. Some considerations include implementation in specific regions, various types of infrastructure systems such as bridges and tunnels, and a focus on nuclear power plants.		
In December 2015, the United Nations Educational, Scientific and Cultural Organization (UNESCO) held an inaugural meeting of the "International Platform on Earthquake Early Warning Systems" (IP-EEWS)—a new initiative to promote the development of early warning systems in earthquake-prone regions and countries. http://www.unesco.org		

Sources
Mexico: Suarez and Garcia-Acosta, UNISDR Scientific and Technical Advisory Group Case Studies, 2014; Vance, "Good Friday Quake in Mexico City Tested Region's Preparations for Bigger One," Scientific American, 2014
Japan: USGS Technical Implementation Plan for the ShakeAlert Production System, 2014; Japan Meteorological Agency website, 2016; Fujinawa and Noda, 2014; Birmingham, Time Magazine, March 18, 2011
Taiwan: Kuo, "Taiwan Earthquake Alert System Saves Lives," Taiwan Today, 2013; Hsiao, "Development of Earthquake Early Warning System in Taiwan," Geophysical Research Letters, 2009)
China: Zhiling, "Region at Quake Risk Gets Early Warning System", China Daily, 2015; "China Starts Construction of Earthquake Early Warning Projects", xinhuanet.com, 2015
Switzerland: Cauzzi, Behr, Clinton, Wiemer, Leguenan, Douglas, Auclair, Woessner, Caprio, "On the Use of Earthquake Early Warning and Operational Earthquake Forecasting for Real-Time Risk Mitigation at Nuclear Power Plants in Switzerland", Seismological Research Letters, 2014
Israel: Allen, Baer, Clinton, Hamiel, Hofstetter, Pinsky, Ziv, Zollo, "Earthquake Early Warning for Israel: Recommended Implementation Strategy", Geological Survey of Israel, 2012
Europe: "A Global Team Working on an Earthquake Early-Warning System for Europe", European Commission, 2014.

APPENDIX D: INTERVIEW GUIDE

California Earthquake Early Warning System Benefit Study
Interview Guide

On behalf of the California Governor's Office of Emergency Services (Cal OES) and the California Seismic Safety Commission, the Pacific Earthquake Engineering Research Center (PEER) is conducting interviews with representatives of key sectors of the state's economy and infrastructure to independently evaluate the anticipated value of a California Earthquake Early Warning System (EEWS). The purpose of these interviews is to gather knowledge about organizations within key sectors and the potential applications and benefits of a statewide earthquake early warning system. The resulting information will be used to develop a preliminary benefit-cost study and to inform a more comprehensive benefit-cost analysis that will likely be conducted over time as the system is developed.

This Interview Guide is provided ahead of the interviews, but it does not need to be completed in advance. We will follow this general structure of topics in the interviews, but also hope to explore in more depth the potential applications, and the approximate magnitudes of benefits and costs for all potential applications. This type of information is particularly valuable to helping the state achieve its goal of developing the mostly widely beneficial and cost-effective system possible, and it will also help lay the groundwork for more detailed economic studies. We also hope this Guide helps you determine who should be involved in the interview as we hope to gain both management/executive and technical/operational perspectives for each organization.

An Interview Brief accompanying this Interview Guide contains additional background information on earthquake early warning systems, California's vision for a statewide earthquake early warning system, and highlights of other systems in operation around the world, and is provided to help you prepare for the interview.

1. Describe your organization's earthquake/disaster response plans and procedures. What is happening right now to prepare for an earthquake?

a) Where does the responsibility for earthquake response planning reside within your organization? ______

b) What are some of the key objectives of your organization's response plans and procedures (select all that apply):
- ☐ Public safety: ____________________
- ☐ Employee safety: ____________________
- ☐ Property/asset protection: ____________________
- ☐ Equipment/operations protection: ____________________
- ☐ Business resumption/continuity: ____________________
- ☐ Business income/loss protection: ____________________
- ☐ Other: ____________________

Discuss:
____

c) What are some of your organization's topmost concerns about the effects that an earthquake can have on your operations?
- ☐ Impact to employees/public: ____________________
- ☐ Impact on the organization's overall mission: ____________________
- ☐ Key functions or vulnerability points:____________________
- ☐ Interdependencies within your systems: ____________________

Discuss: ____________________

d) Are there certain earthquake magnitude/intensity thresholds or other activation criteria for your organization's response plans and procedures?
YES NO
Who (what organizational entity(ies)) is involved in these decisions/processes? ________________

____

e) Does your organization have automated operational/system controls or monitoring systems that are integral to your response plans and procedures?
YES NO
What technologies or software do you use? ____

____

f) Does your organization incorporate any of the following into your earthquake response procedures (select all that apply)?
- ☐ USGS Earthquake Notification Service (http://earthquake.usgs.gov/)
- ☐ USGS ShakeMap and real-time data feeds (http://earthquake.usgs.gov/data/shakemap/)
- ☐ Other notification system (proprietary, commercial, or government)
- ☐ ShakeAlert earthquake early warning beta system (www.shakealert.org)
- ☐ Other earthquake early warning systems (proprietary commercial, or government)

Discuss: ____

____

g) Are there time-critical activities that are integral to your organization's response plans and procedures?
YES NO
If yes, what are some of the key time thresholds?______________________________________

____

h) How widespread is the culture of earthquake preparedness and readiness in your organization?
1 2 3 4 5
Low High
What, if anything, needs more or better handling? _____________________________________

____

2. How familiar are you and your organization with earthquake early warning systems specifically?
1 2 3 4 5
Low High
Do you have any questions about how it works (refer to the Interview Brief)? __________________

____

3. Considering some scenario earthquakes and warning times (described in the Interview Brief), how could your organization use a statewide earthquake early warning system? Please identify the potential applications—both those that could be automated (if the technology exists or should be developed) and those involving human decision/actions. Also, identify the potential benefits (select all that apply) that are relevant to each potential application. We will discuss the relevant details of each of the benefit categories that are important to you. For example, we might discuss how many employees are located at a particular site, how many facilities could be protected, how many days of downtime and costs that might be saved, or what specific operations might be involved.

Potential Applications	**Potential Benefits** (select all that apply)						**Relevant Details**
Automated Applications	Public Safety	Employee Safety	Property/ Asset Protection	Equipment/ Operations Protection	Business Resumption/ Continuity	Business Income/ Loss Protection	
________________	☐	☐	☐	☐	☐	☐	______________
________________	☐	☐	☐	☐	☐	☐	______________
________________	☐	☐	☐	☐	☐	☐	______________
________________	☐	☐	☐	☐	☐	☐	______________
________________	☐	☐	☐	☐	☐	☐	______________
Decisions/Actions	Public Safety	Employee Safety	Property/ Asset Protection	Equipment/ Operations Protection	Business Resumption/ Continuity	Business Income/ Loss Protection	
________________	☐	☐	☐	☐	☐	☐	______________
________________	☐	☐	☐	☐	☐	☐	______________
________________	☐	☐	☐	☐	☐	☐	______________
________________	☐	☐	☐	☐	☐	☐	______________
________________	☐	☐	☐	☐	☐	☐	______________

a) How might these applications change depending upon the length of warning time for an earthquake (e.g. earthquake closer (<10 seconds) or farther away (>30 seconds))?
Discuss: ____

b) How might these applications change depending upon the earthquake magnitude/level of shaking (e.g. weak, moderate, or strong)?
Discuss: ____

c) How might these applications change depending upon the reliability of the systems and your organization's ability to trust the system performance?
Discuss: ____

d) What kinds of organizational challenges would you anticipate in trying to use an earthquake early warning system?
- ☐ Sources of resistance/friction: ____
- ☐ Implementation difficulties: ____
- ☐ Cost factors: ____

Discuss: ____

e) What is the level of intention or commitment of your organization to use an earthquake early warning system once it is available?

1 2 3 4 5

Low High

Discuss: ____

4. Consider the interdependent nature of an earthquake early warning and the cascading effect of decisions and actions taken by external users and the public. Please rank how interdependent your organization is with organizations in each key sector of the state's economy and infrastructure as well as other sectors that might not be identified but are critical to your industry or decisions/actions. Please also consider how the potential applications of an earthquake early warning system within that sector might impact your organization/sector.

Key Sectors	**Low**				**High**	**Describe** (Action/dependency impact on your organization)**:**
Electricity Utility	1	2	3	4	5	________________________
Telecommunications	1	2	3	4	5	________________________
Mass Transit	1	2	3	4	5	________________________
Transportation	1	2	3	4	5	________________________
Gas Utility	1	2	3	4	5	________________________
Water Utility	1	2	3	4	5	________________________
Public Safety	1	2	3	4	5	________________________
Hospital/Emergency Medical Services	1	2	3	4	5	________________________
Education	1	2	3	4	5	________________________
Financial	1	2	3	4	5	________________________
Insurance	1	2	3	4	5	________________________
Business	1	2	3	4	5	________________________
Commercial/Industrial	1	2	3	4	5	________________________
Information Technology	1	2	3	4	5	________________________
Other:______________	1	2	3	4	5	________________________

a) Considering your organization's key partners, vendors, and suppliers (upstream), how might your organization's use of an earthquake early warning system affect them? ________________________

____

____

b) Considering your organization's users or the people and businesses that you serve or who depend upon you (downstream), how might your organization's use of an earthquake early warning system affect them?

____

____

____

5. Consider the broader societal benefits of a California Earthquake Early Warning System.

a) In terms of the broader public, how valuable would it be for your organization to use an earthquake early warning system?

1 2 3 4 5

Low High

Discuss: ____

b) Identify the potential benefit(s) of a statewide earthquake early warning system and their importance? ____

____

____

c) Identify any potential risk(s) or negative consideration(s) of a statewide earthquake early warning system and their importance? ____

____

____

d) What elements are crucial for a statewide earthquake early warning system to be viable for business and industry use (refer to the Interview Brief)?

- ☐ System development, timeframe, and implementation plans: ____________________
- ☐ System governance and management structure: ____________________________
- ☐ System performance standards, reliability and notification/alert protocols: __________
- ☐ System deployment and rollout plans: ____________________________________
- ☐ System funding for capital costs and annual maintenance: _______________________
- ☐ User training and education: ____
- ☐ User personnel/management issues: ____________________________________
- ☐ User operation/implementation issues: __________________________________
- ☐ User financial/cost factors: ____
- ☐ User legal/policy issues: ____
- ☐ Other: ____

Discuss:

____

____

e) Does your organization have suggestions for magnifying the benefit of a statewide earthquake early warning system? ____

____

f) How would your organization like to be engaged in the development and implementation of a statewide earthquake early warning system? ____________________________________

____