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# IMPLEMENTING A SEISMIC COMPUTERIZED ALERT NETWORK (SCAN) FOR SOUTHERN CALIFORNIA: LESSONS AND GUIDANCE FROM THE LITERATURE ON WARNING RESPONSE AND WARNING SYSTEMS

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# IMPLEMENTING A SEISMIC COMPUTERIZED ALERT NETWORK (SCAN) FOR SOUTHERN CALIFORNIA: LESSONS AND GUIDANCE FROM THE LITERATURE ON WARNING RESPONSE AND WARNING SYSTEMS

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**REPORT PREPARED FOR TASK 2, TRINET STUDIES AND PLANNING ACTIVITIES IN REAL-TIME EARTHQUAKE EARLY WARNINGS**

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This project report was prepared under the supervision of Joanne Nigg and Kathleen Tierney. Jasmin Riad, a postdoctoral scholar at the Disaster Research Center, assisted with the identification of warning system issues and supervised the literature review and the compilation of abstracts and bibliographic entries for the project. Postdoctoral scholar James Kendra assisted with various sections of the report, including LEXIS-NEXIS searches and analyses of warning system liability issues. Disaster Research Center staff members Keith Appleby, Rory Connell, Jill Cope, Kristy Kompanik, Michael Kiley-Zufelt, and Rachel Smedley collected and reviewed publications and assisted with the preparation of the final draft of the report.

The findings and conclusions presented in this report are those of the author. They do not necessarily represent the views of other TriNet study investigators or of the agencies that provided support for the project.

## EXECUTIVE SUMMARY

Plans for using the TriNet SCAN system to provide real-time warnings must be designed to take into account the ways in which warning information is perceived and acted on by warning recipients. Close attention must be paid to developing technologies, warning messages, and dissemination strategies that succeed in enhancing life safety and protecting property. To provide guidance on warning system design, the Disaster Research Center conducted a broad and systematic review of the literature on risk communication, hazard and disaster warnings, and warning response. The review addressed a variety of topics, including the different types of systems that are currently used to issue warnings of impending threats; the components or phases of the warning process; what is currently known about factors that influence the manner in which people respond to warnings; and the problems inherent in issuing warnings that elicit appropriate self-protective responses. The review also considered such topics as which types of settings are the most likely candidates for successful SCAN deployment, what types of warning signals and messages people are most likely to heed in emergency situations, and what lessons can be learned from earthquake alerts that have been issued in Mexico City, the only community that currently uses a real-time system to provide warnings to the public. Other issues considered in this report include the potential for negative consequences following false alarms or missed alerts, the extent to which fully-automated systems could be employed in transmitting real-time alerts, and concerns centering on overall system integration and reliability, equity in the issuing of earthquake alerts, and legal liability.

Existing hazard warning and alert systems vary in a number of ways, including the technologies employed to detect threats and the reliability of those technologies; the length of time needed to produce accurate forecasts; the extent to which they rely on human mediation; the types of devices and signals that are used; the channels employed to issue warnings; the extent to which warning procedures are familiar, routinized, and institutionalized in different settings; the settings in which systems are used; and system goals and objectives. While it is therefore difficult to generalize from one warning system to another, there are many challenges and concerns that are common to all warning systems. One such challenge centers on the need to achieve integration between the *scientific assessment phase* and the *dissemination phase* of the warning process. Good science alone is insufficient to achieve warning system objectives. Rather, scientific assessment must be linked to efforts to put into place organizational arrangements that will enhance the system's ability to disseminate timely, reliable, and effective warnings. For example, warning system design must address issues of coordination among governmental entities involved in the warning process, and relationships among organizations that comprise the warning system, referred to here as the interorganizational seismic alert network, or ISAN, must be clarified. Similarly, *warning technologies* should be thought of as only one component of an overall *integrated warning system* that includes scientific, technological, managerial, and social components. Such integration, which has proved elusive in

the case of most hazard warning systems, will constitute a significant challenge for SCAN.

Most of what is known about warning systems and about organizational and public responses to warnings is based on warning situations that are quite different from those envisioned by SCAN planners. For example, the overwhelming majority of studies have focused on emergencies in which warning times are significantly longer than those the SCAN system would permit. Nevertheless, the literature does contain many lessons that have important implications for SCAN design. First, achieving compliance with warnings is always problematic, and all warnings must seek to overcome the "normalcy bias," or the tendency not to wish to interrupt ongoing activities and act on warning information. People often fail to heed warnings, even in situations in which there is clear evidence of an imminent threat and substantial time to respond and even when clear warnings have been repeatedly issued. Responding to warnings of all types involves a complicated series of perceptual, cognitive, and behavioral steps. If this sequence is interrupted–for example, if people do not perceive or understand warning messages, if they become confused and hesitant, or if they do not feel personally at risk despite having been warned–they will not respond in a timely, appropriate fashion to warning information. The challenge of any warning system, including SCAN, is to make sure that warning recipients are able to complete those steps successfully. This will be a particularly difficult goal for SCAN to achieve because of the very short warning times involved.

Research on the design of warning messages and signals indicates that the warning systems that are most likely to be effective in motivating self-protective actions are those that are accompanied by perceptual cues that signal danger, that employ verbal messages as opposed to non-verbal or visual signals, that use "live" speakers to issue warnings, that provide detailed information concerning both the nature of the threat and what to do in response to the warning, and that are issued repeatedly, with increasing degrees of urgency, over a wide range of channels. Because the time periods involved will be so short and the channels of dissemination will be so limited, very close attention will need to be paid to the design of the warning signals and messages that SCAN will employ. Fortunately, the literature does provide some guidance on how to approach that task.

While warning messages and dissemination strategies are important for motivating warning compliance, compliance is also influenced by a variety of other factors, including the sociodemographic characteristics of warning recipients, prior experience with the disaster agent, trust in the organizations issuing the warnings, and prior education and training in how to respond. If properly carried out, SCAN efforts should be able to build upon Southern California residents' previous experience with earthquakes as well as existing public awareness and training programs. At the same time, careful attention will need to be paid to designing warning strategies that take into account the needs of diverse groups within the population, including low-income, minority, and non-English-speaking groups.

The TriNet/SCAN program plans to disseminate warning messages in a range of different settings, including schools, hospitals, and industrial facilities. Successful dissemination of warning information will be significantly more problematic in some settings than in others. Real-time earthquake alerts can probably function most effectively in settings such as schools, because users of those facilities can be expected to be familiar with recommended self-protective actions and safe areas, teachers and administrators have clear authority, and earthquake education and training programs are already in place. In order to function effectively, SCAN must build upon existing earthquake emergency response programs in participating organizations and facilities. Where such programs are nonexistent or weak, SCAN is unlikely to yield additional benefits.

False alarms and missed alerts are problems that all warning systems must address, and SCAN is no exception. Clearly the SCAN system must be made as free as possible of false alarms, because responding to warnings when there is in fact no danger can be very costly for individuals, organizations, and communities. At the same time, concerns that false alarms will create a "cry wolf" effect in which people will fail to heed subsequent alerts of real danger are probably overstated. In hazards research there is little evidence that false alarms result in a decreased willingness to undertake self-protective measures. In fact, there is some evidence, including evidence from real-time warnings issued in Mexico City, that false alerts can function like disaster drills, giving warning recipients an additional opportunity to practice measures that they would have to undertake in the event of a real threat. The literature also suggests a number of strategies that can be used to minimize the negative behavior effects of false alarms.

Considerable emphasis has been placed on the value of fully-automated systems, both to shut down equipment and processes in order to reduce earthquake damage and to issue warnings to the public. Little systematic data exist on systems that are currently in use, and there is some question about how acceptable automated shutdown and alert systems would be to users in Southern California. Most studies on the use of automated systems as a means to issue warnings to the public have centered on the technologies used, rather than on system effectiveness. Similarly, most research on public response to warnings has focused on systems that are mediated–that is, systems in which human decisionmaking is involved–rather than automated. Safety, cost, and reliability are factors that need to be taken into consideration in determining the feasibility of fully-automated seismic shutdown and alert systems.

This report has addressed three other issues that need to be taken into account in the design and deployment of the SCAN system. First, there is a need to consider equity questions that could potentially arise when the system is implemented. Equity concerns are relevant for SCAN because of the possibility that some segments of the population, organizations, or communities could be less well served than others when the system is put into place.

Second, for the SCAN system to function effectively and to be seen as credible, all components of the system, including alarm and alert systems employed by participating organizations, must consistently perform as they were meant to function. Even if the technologies employed by TriNet work well, technologies used elsewhere in the system could contribute to failure, due, for example, to lack of proper maintenance. A great deal of attention needs to be paid to ensure that critical system components and equipment are strengthened against potential earthquake damage and that they can function even in the event of earthquake-induced lifeline service interruption.

Finally, although DRC was not specifically asked to address concerns about legal liability that might be associated with the operation of SCAN, the literature review did suggest that liability–both for operators of the system and for users–is a topic that warrants further investigation. Although existing laws do grant broad immunity to public agencies that are involved in issuing warnings, those protections are not absolute, and there have been cases in which agencies have been found liable for failure to provide adequate warnings of danger. The TriNet program should seek legal advice on such questions as whether injured parties could sue if the system fails, whether organizations participating in SCAN might face liability exposure for actions that they took or failed to take in response to warnings, and what measures are needed to provide adequate liability protection to all organizations participating in the system.

DRC's review of the warning literature has identified a number of issues that warrant further research. Some of those topics will be addressed by other tasks that are being undertaken as part of this study. With respect to the areas focused on by DRC, additional research is needed on several key topics. Solid conclusions are needed concerning realistic warning response times in different types of settings and for different earthquake scenarios. Information is required on the types of warning devices users plan to employ, how those devices will interface with TriNet technologies, and how effective the overall seismic alert system is likely to be in motivating self-protective actions and achieving other SCAN goals. Studies are needed to identify the most efficient and effective way to convey alert information, and questions regarding training and educational needs must also be addressed. Special emphasis should be placed on assessing ways of reaching residents of the highly diverse Southern California region. Developing a more empirically-grounded understanding of how people and organizations will respond when alert technology becomes available and when actual alerts are issued–and whether those actions actually enhance life safety and protect property–are major research needs.

## Introduction

Plans for using the SCAN system to provide real-time warnings must be designed to take into account how individuals, organizations, and other social units perceive, interpret, and act on warning information. In order to provide guidance on the appropriate design of the warning systems, warning messages, and public outreach programs that will be needed for the implementation of SCAN, the Disaster Research Center conducted a broad review of the literature on risk communications, hazard and disaster warnings, and warning response.

Because the system is still in the process of being developed, the TriNet program faces a number of very significant choices with respect to system design and deployment. The four tasks being addressed in this project are designed to help inform those choices. Results from the UCLA survey conducted as part of Task 1 will shed light on the needs and expectations of potential user organizations. As part of Task 3, EQE will address the very significant policy and cost-benefit considerations that will be associated with system implementation. In performing Task 4, EQE, ImageCat, and other members of the project team will design a small-scale pilot study using a prototype alert system. In approaching its part of the TriNet study under Task 2, DRC has focused its attention on distilling insights and lessons from the warning literature in order to frame warning response issues and provide advice on realistic system objectives and options.

The project staff recognized at the outset that making recommendations on implementing SCAN as a warning system would present significant challenges, since most of what is known about warnings, warning systems, and organizational and public response is based on warning situations that are quite different from those envisioned by planners. The bulk of the empirical work that has been conducted on hazard warning processes focuses on threat situations in which the warning period extends from minutes to hours, and in some cases to days. Moreover, the literature tends to concentrate on topics such as household evacuation in the face of impending threats, as opposed to measures that people can take on a rapid basis to protect themselves while sheltering in place. Developing recommendations from the existing literature often frequently involved attempting to extrapolate from studies on related or analogous emergency situations. However, making these kinds of extrapolations is inherently problematic, because hazards and warning contexts differ on so many dimensions. For example, for most natural disasters for which warning systems exist, there is typically considerably more time for carrying out recommended safety measures than the SCAN system would permit. Some natural hazards, such as tornadoes and hurricanes, occur seasonally, and consequently people are more attentive to risk communications and warnings during those times. Many natural and technological disasters are accompanied in advance by physical cues that help focus public attention and add urgency to whatever warnings are issued. Certain technological disasters, such as chemical plant accidents and hazardous materials releases, can involve short warning periods, and in this respect at least these kinds of emergencies could be considered analogous to situations in which the SCAN system would be triggered. However, along other dimensions, real-time earthquake warning situations present very distinctive design and implementation challenges, in that they involve relatively infrequent, nonseasonal disaster events, and extremely short warning times, with no other environmental cues prior to actual shaking.

On the positive side, as a consequence of prior experience and extensive public education campaigns, many segments of the public in Southern California have a good understanding of the earthquake problem, and many residents already know what to do in the event of an earthquake.

Training has been undertaken in organizations, such as elementary schools, that are logical priority targets for the SCAN system. Members of the public are familiar with the concept of earthquake drills and with recommended self-protective measures, such as getting under desks and away from windows when earthquake shaking occurs. SCAN would give people a bit more time in which to carry out actions that they already know how to undertake. Any real-time warning system that is implemented for the region would thus build upon a broadly-based understanding of the earthquake threat and of safety measures that need to be carried out during the immediate earthquake impact period.

Based on its initial framing of the problem, the Disaster Research Center systematically collected and analyzed findings from the warning research literature. As indicated later in the section on the methodology employed for this task, the scope of the review was intentionally broad, encompassing research on different warning contexts (for example, short versus longer-term warnings), disaster agents, warning systems, and warning technologies. More than fifty different key words were used in this comprehensive literature review, and all relevant scientific databases were searched. In assembling materials and preparing to write the report for this task, members of the DRC team also drew upon DRC's extensive library holdings, their own knowledge of and experience with risk communication, warning response, and warning systems research, previous reviews of the warning response literature compiled by other researchers, and other reports that focused specifically on issues related to earthquake real-time warning issues (e.g. Holden, Lee, and Reichle, 1989; National Research Council, 1991, Goltz and Flores, 1997).

The literature review bore out the project team's initial impressions concerning the dearth of data on warning systems of the type envisioned for the SCAN program. Most studies on warning response have been conducted in emergency situations that differ considerably from those in which SCAN would be implemented. Additionally, the vast majority of credible empirical studies on warning response have been conducted on individuals and households, rather than on organizational response to warnings. Further complicating matters, studies on very short-term warning situations and on responses to different types of devices and warning messages are often based either on anecdotal information or on controlled laboratory studies, as opposed to real-world situations. However, even these studies may well prove useful for addressing issues that are relevant to this project.

On the whole, despite the fact that very little research exists on organizational and public response in warning systems that are comparable to the proposed SCAN system, DRC did identify a considerable amount of potentially useful information through its review of the literature. Following a brief discussion of the methodology used for the literature review, this report outlines key lessons from the warning literature and discusses their implications for SCAN warning system design and deployment.

**Literature Review Methodology**

The literature review DRC carried out for the study was organized around an exhaustive list of search terms, which appears in Appendix I. Many synonyms for primary search terms were used in order to avoid missing articles with unusual key words. For instance, some articles about earthquake warning technologies and warning issues were found under *earthquake alarms* search terminology, rather than under *earthquake warning system*. The group of databases that were searched consisted of ProQuest, American History and Life, Current Contents Connect, ProQuest Dissertation Abstracts, Biblioline, Gender Watch, ISI Citation Databases, JSTOR, Expanded Academic ASAP, PsychINFO, Social Sciences Citation Index, and Sociological Abstracts.[1] Articles that were considered relevant were then retrieved from Disaster Research Center Library, the main University of Delaware library, interlibrary loan, and other sources. Once the articles were found, they were evaluated for their relevance to the study, and for all relevant publications, detailed abstracts were prepared and then compiled.

After the database literature search was completed, a web search was then initiated. The search engine *dogpile.com* was used because it compiles a list of relevant websites by simultaneously searching other search engines. From the websites, relevant sites were identified and reviewed, and all pertinent information was downloaded. Many additional papers were found on various sites in a *.pdf* format. The most important site was *disasterwarning.com* which provided many links to other websites devoted to information on lightning, earthquake, tsunami, flood, and other types of warnings. These links were then examined and items that were judged to contain useful and pertinent information were retained and reviewed.

As part of the literature review, the DRC staff also prepared an annotated bibliography containing approximately 150 publications that were located during the course of the database search. A summary was written for each publication that included the type of hazard and warning phase on which the publication focused, the hypotheses or research questions that were addressed in the study, the data collection and analysis methods that were used, and the study's main findings and conclusions.

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[1] In addition to these searches, DRC also searched the LEXIS-NEXIS database for information on lawsuits and legal decisions involving warning systems.

## Organization of the Report

This report begins with a review of the ways in which systems for detecting hazards and communicating warnings differ and what these differences imply for SCAN system design. It then goes on to discuss the components and phases of warning systems and the factors that need to be taken into account in developing integrated warning systems, i.e., systems that link together threat-detection technologies and the organizational components that are needed in order to issue warnings effectively. The report moves next to a consideration of a series key issues for SCAN system implementation, including human behavioral issues that need to be taken into account in attempting to implement SCAN for life-safety protection, the relative impacts and effectiveness of different types of warning devices and dissemination strategies, and aspects of the warning process that will require special attention because of the unique features of the warning contexts for which the TriNet system will be used. Additionally, the report also considers a number of other factors that are likely to influence the effectiveness of the SCAN network as a warning system, including differences between fully- automated and mediated warning systems, the problem of false alarms and the "cry-wolf" effect, and challenges associated with ensuring that the entire SCAN system actually functions as envisioned in during earthquake events. The concluding section contains a discussion of the implications of the research findings discusses in the report and a set of recommendations for additional research.

## Study Team Findings

### *Types of Warning Systems*

Warning systems for natural and technological hazards and for other threats are numerous and varied. In its review of the literature, DRC encountered discussions of hundreds of different types of warning devices, technologies, and systems. To illustrate this variation, Appendix II contains a table that characterizes a selected group of these systems. Indeed, one of the conclusions that DRC reached after having reviewed the literature is that there is so much variation in the design and application of threat-detection and warning systems that considerable caution must be exercised in generalizing from one system to another.

**Table 1**
**Ways in Which Warning Systems Differ**

- Technologies Employed to Detect Threats
- Reliability of Threat Detection Technologies
- Length of Time Needed to Achieve Accuracy in Forecasts, Predictions
- Reliance on Human Mediation
- Types of Warning Systems and Devices Used
- Channels Employed to Issue Warnings
- Familiarity, Routinization, and Institutionalization of Warning Procedures
- Settings in Which Systems are Used
- System Goals and Objectives

As summarized in Table 1, existing threat-detection and warning systems can be conceptualized on at least nine different dimensions. Variations exist in the *technologies* employed to detect threats, as well as in the *reliability* of those technologies. Some warning systems are highly reliable, while others are prone to various kinds of biases, such as false alarms and misforecasting, as well as to failures and other types of malfunctions. Systems also differ in the length of time and amount of information required to achieve *accuracy* in forecasts and predictions. Some threat-detection systems can achieve high accuracy relatively rapidly, while others, such as hurricane tracking and modeling, can provide accurate predictions only over time as hazardous conditions evolve. Warning systems also differ in the extent to which *human decision making* intervenes in the process of issuing warnings. A general distinction can be made between fully-automated systems in which no human beings are involved and highly mediated warning systems. However, most warning systems fall somewhere between these two extremes, and the majority do rely at least to some degree on human judgement. As discussed later in this report, most warning research in the hazards field has concentrated primarily on mediated systems, as opposed to automated ones.

Systems vary considerably in the types of *warning signals and devices* used, from those that rely exclusively on audible signals, such as warning bells, alarms, and sirens, to those that employ visual signs or images (e.g., various types of signage, lights, or flashing signals), to those that warn through verbal messages. Included in the last-mentioned category are systems that use various kinds of pre-recorded vocal messages, "live," personally-delivered directives from individuals who are present in the setting, and verbal messages that are disseminated through various mass communications media, including both print and electronic media. In many cases, warning delivery systems employ "layers" or sequences of mutually-reinforcing messages, signals, and visual images, rather than relying on one type of signal or device. A warning situation can involve relatively simple devices, such as fire alarms, or very complex sets of devices and signals. Systems at higher levels of complexity include the elaborate multi-layered forecasting and warning systems for hurricane evacuation.

Relatedly, systems vary in the number and types of *communication channels* that are employed to transmit warning information, ranging from single-channel to multiple-channel dissemination routes. Again, some systems, such as fire alarm systems for individual facilities, are relatively simple in terms of the message channels that are used, while others, such as communitywide warning systems for slow-onset events like floods and hurricanes, as well as for more rapid-onset disasters like tornadoes, are more complex, involving a range of different media, communications systems, and warning messages.

Warning systems can further be characterized in terms of the *settings* in which they are used. Systems may be deployed for use in individual buildings, building complexes (e.g., large manufacturing facilities), neighborhoods (e.g., residential areas adjacent to hazardous chemical facilities or nuclear power plants), entire communities, and larger geographic regions. Design and implementation considerations, costs, efficiency, effectiveness, and training requirements can be expected to vary considerably, depending upon the setting in which a warning system is used.

Systems also vary in the extent to which they are familiar to operators and potential warning recipients, and similarly in the degree to which their use has been routinized or institutionalized in particular settings. For example, people who use school buildings have become accustomed to the presence of fire alarms, know how fire alarms sound, and understand the purpose of those systems, and frequent fire drills serve to further reinforce that familiarity. Many residents of hurricane-prone communities understand how hurricane warning systems function–even if they may not know exactly how to evacuate to safe areas–and they are likely to be familiar with other aspects of the system, such as which organizations are responsible for issuing warnings and where to go to seek additional information on potential hurricane impacts. Newer warning systems lack the advantages associated with familiarity and routine use. Other things being equal, systems that have been in place and used for a long period of time, that are familiar to those who need to perceive and act on the warning, and with users that already have substantial experience, are more likely to achieve desired results than newly implemented ones.[2]

Finally, hazard warning systems differ considerably in the *goals and objectives* they seek to achieve, as well as in the extent to which they are able to achieve those goals, given the constraints present in different warning settings. Protecting life safety is a goal that is sought by virtually all warning systems, and a large proportion of systems also attempt to achieve various types of property-protection objectives (although many types of systems do not, and many cannot achieve that objective due to various limitations, including, importantly, those imposed by time). Systems can be further characterized according to the behaviors they seek to encourage as a means of achieving their life-safety objectives. Safety-related behavioral objectives for warning systems can include evacuation from a threatened community, evacuation from an endangered facility, "vertical evacuation" or sheltering-in-place, and self-protective measures of various kinds, such as donning protective devices or sealing up windows to prevent exposure to toxic materials, seeking cover, or moving to safe areas inside structures. The property-protection goals

[2] One problem, however, is that familiarity and routinization can work against warning compliance if there are too many false alarms, or if warnings are issued for events that are not actually dangerous or damaging. The concept of "disaster subcultures" was originally developed to explain how and why people become accustomed and adapt to threats after repeated disaster occurrences, failing to heed warnings and take other recommended precautions.

that warning systems seek to achieve, which are also quite varied, include data protection, reduction of physical damage to structures, and the control of secondary hazards, such as fires and hazardous chemical releases, that could result when a disaster occurs. Further, by identifying areas where disaster impacts are most severe, alert systems like SCAN can also help emergency responders prioritize their response activities and direct appropriate resources to areas of greatest need. Some property-protection measures can be carried out through automated processes upon the detection of a threat, while others are dependent on human behavioral responses (e.g., using fire extinguishers, finding and installing plywood to protect windows). The success of the latter depends both on the transmission of warning information and on human decision making processes.

As the foregoing examples suggest, life-safety and property protection objectives can be relatively easy or relatively difficult to achieve. Some of the behaviors that are required in order to ensure life-safety and protect property are relatively uncomplicated to carry out, while others involve complex sequences of behavior; some require relatively high levels of training and knowledge, while others do not.

Of particular importance for the current study, different safety and property protection measures for which warning systems are used require different amounts of time to complete. For example, while some property-protection measures can be put into place almost immediately when a threat is detected (e.g., the triggering of automatic alarms and sprinklers when heat or smoke are found to be present in a building), others, such as shutting down complex processes in industrial facilities, take longer periods of time. Even under the best of circumstances, carrying out the activities associated with evacuating from a building obviously takes longer than simply sheltering-in-place. Warning times thus place major constraints on warning outcomes. Indeed, a considerable amount of research in the warning response area has focused on attempting to determine how long it actually takes to achieve compliance with warning messages–how long, for example, it takes to evacuate a building or a community, or how long it takes to respond to smoke alarms under different threat conditions.

While the time periods involved in achieving life-safety and property protection goals can be shortened through good planning and through training, they can only be shortened up to a point. Any warning system will only be effective to the extent that it can result in the achievement of system objectives within specified time periods. Put simply, actual warning time–that is, time that elapses between threat-detection and completion of life-safety and property-protection measures–must be sufficient to actually allow those activities to take place before impact, or the system will fail. One practical implication of this point is that those who plan and implement warning systems need to assess both system objectives and time requirements, and then concentrate on promoting the adoption of those safety measures that can realistically be undertaken, given the constraints associated with different warning times.

Plans for deploying the TriNet/SCAN system either for life safety or for property protection must take into account system features such as those outlined above, because those features have clear implications for the system's acceptability and effectiveness. For example, while accurate warnings and damage projections are highly desirable, achieving accuracy typically entails sacrificing time.[3] Warning signals and devices that work in some settings and

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[3] This is, for example, a major ongoing problem with hurricane warnings and evacuations. If authorities wait until model projections are more accurate, allowing them to be fairly certain where high winds and storm surges will strike, there may be too little time

under some threat circumstances may not work well in others. Strategies must be employed to ensure that warning recipients are familiar with warning systems, but without causing them to take systems for granted to such a degree that they discount warnings. As is the case for all systems, developing and deploying SCAN will necessarily involve tradeoffs and optimization among different system features.

***Warning System Components and Phases***

As shown in Figure 1, all warning systems, including the proposed SCAN system, consist of two major components: the phase that involves *scientific assessment* of the physical precursors to an emergency or disaster, and the phase that involves *dissemination*, or transmission of the warning message to recipients (Nigg, 1995). Any efforts to implement warning systems must carry out these two essential warning system functions effectively, reliably, and accurately. The first phase or component, the assessment process, which is undertaken by scientific institutions (in this case, the institutions that participate in the system), must take advantage of the best available scientific knowledge and, equally important, must be conducted in ways that can provide system users with warning information that is tailored to their expectations and needs with respect to accuracy, credibility, reliability, timeliness, and intended use of the information. Thus, one of the key challenges facing the SCAN program will be to assess the extent to which its own threat assessment processes are both scientifically valid and acceptable to potential users. The scientific/analytic phase of the warning process must yield information that users need and

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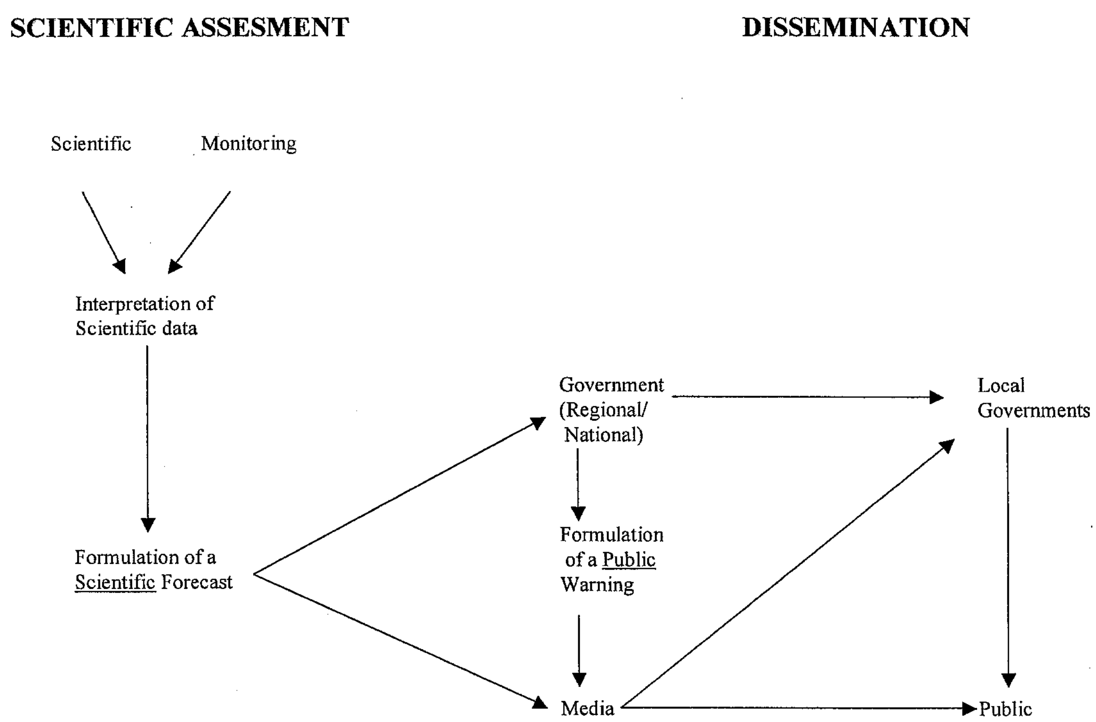
remaining in which to safely evacuate threatened populations. If, on the other hand, they issue early evacuation orders to very wide areas that later do not end up experiencing hurricane impacts, they risk other problems, such as incurring unnecessary public-sector expenses, contributing to business interruption losses, inconveniencing large numbers of people, creating traffic congestion, and losing credibility in future disasters.

that they can trust, and it must do so in a timely manner. For example, if the time needed for achieving accurate scientific assessment of the threat (that is, for analyzing seismic data and developing a credible and reliable alert) is so long that it seriously truncates actual warning time periods, the system may be judged unacceptable by potential users. Similarly, if the uncertainties or the reliability associated with projections derived from the warning technologies are not within limits that are considered acceptable by users, they will not want to take part in the system.

**Figure 1**
**Components of a Warning System**
(Source: Nigg, 1995)



The 1989 CDMG report noted, for example, that potential users of the alert system preferred warning times of thirty seconds or greater. Additionally, while the organizations surveyed in that study could envision a number of possible uses for an alert network, ranging from actions to protect computers, utility systems, and machinery to actions focusing on life-safety, they remained skeptical about the reliability of system.

As part of Task 1, the UCLA survey addressed questions of user needs and expectations, focusing on organizations in sectors that are likely users of the alert system. Survey data indicate that, on the average, the system benefits that organizations consider most important are injury reduction and increased emergency response effectiveness. Other benefits that are highly valued by many organizations include the ability to control secondary earthquake hazards and reduction in losses due to equipment damage. Clearly, TriNet system designers should take these priorities into account in developing the system and should carefully consider whether the system will be able to deliver those benefits that users consider very important, particularly improvements in the area of life-safety.

Warning dissemination, the second stage in the warning process, is in many ways even more complicated than the assessment phase. Nigg (1995) identifies two broad issues that must be considered in planning to disseminate warnings. First, for any warning that is being disseminated by public agencies, issues of intergovernmental planning and coordination must be addressed. The warning system, in other words, encompasses not only warning technologies but also relationships among governmental entities that ultimately have responsibility for public safety. Second, channels of communication and relationships among the organizations that comprise the warning system must be planned and arranged in advance to ensure that warning messages reach their intended audiences as rapidly and with as little potential for error as possible.

More generally, the literature makes the point that, regardless of what kinds of technologies are used in the assessment and dissemination of warnings, *warning technologies* should be thought of as only one component of an overall *integrated warning system.* A warning system consists both of scientific, technological elements and of human and organizational elements. Both these dimensions need to be taken into account in the design of SCAN or any other warning system. As Sorensen notes (1993: 4):

> A key overriding principle that has continued to emerge from 25 years of warning research is that an integrated warning system maximizes public protection. Integration refers to the melding of scientific monitoring and detection with an emergency organization that utilizes warning technologies coupled with social design factors to rapidly issue an alert and notification to a public at risk. Thus warning systems must be considered as having scientific, managerial, technological, and social components which are linked by a variety of communication processes. A breakdown in process can result in ineffective warning even if each individual component is properly performing their [sic] internal role.

The literature also suggests that the goal of developing truly integrated warning systems remains elusive for most hazards. Existing warning systems tend to be deficient, particularly on the human and organizational side of the equation. In a recently-published article entitled "Hazard Warning Systems: Review of 20 Years of Progress," Sorensen (2000) observes that in the past two decades there have been relatively few advances in the ability to detect and forecast natural and technological threats and to issue warnings in a timely fashion. For example, among twelve natural and technological hazard warning systems he assessed, there is only one hazard–hurricanes–for which major improvements in the ability to monitor, predict, and forecast have also been accompanied by significant advances in warning system integration. In most other cases, either little has changed in the ability to monitor and forecast impending disasters, or system integration efforts have not kept apace with scientific improvements.[4]

Research on warning systems for flash floods illustrates the difficulty of bringing about this integration. Floods kill more people and create greater property damage than any other hazard in the US. Flash floods can be particularly deadly, and for that reason a considerable amount of emphasis has been placed on developing warning systems in areas that are prone to flash flooding. In a detailed review of eighteen early warning systems for flash floods and dam failures, Gruntfest and Huber (1989) identified a number of problems that have plagued those systems. For example, system components are often unreliable, elements need to be replaced frequently, equipment is prone to damage, and backup power supplies have failed during power outages. Funding for warning systems is inconsistent and often inadequate to maintain systems in good working order, and systems are often under-budgeted for routine maintenance. There is no good way of gauging how much an effective warning system actually costs, and per capita expenditures on systems vary widely.

Flash flood warning systems also differ in their technical sophistication and degree of formalization. Additionally, communities show significant variation in the extent to which they are committed to and involved with flash flood warning systems. Indeed, the residents for whom the systems were developed often don't appear very interested in taking advantage of that

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[4] Interestingly, Sorensen singles out earthquakes as a "unique case," because "while dramatic improvements have been made in integrating the warning process [and here he is obviously speaking of short-term forecasts and aftershock warnings] our ability to predict earthquakes has not improved" (2000: 119). SCAN would obviously constitute a significant breakthrough in this respect.

protection. Even more important for this discussion, the flash flood detection systems that were reviewed were particularly weak in the area of warning dissemination. Gruntfest and Huber (1989: 284) observe, for example, that

> The warning systems have been designed with the objective of reducing loss of life and property damage. However, few of the systems pay much attention to getting the message out to the population at risk. In most cases the systems can more aptly be termed 'detection systems' since no element of response is included...If the goal of warning systems is to save lives and reduce property losses, there needs to be greater attention paid to warning dissemination and public awareness.

In other words, these warning systems lack necessary integration between warning technologies and organizational and community response planning. These authors even express the suspicion that flash flood warning systems are often adopted as "an inexpensive alternative to politically unpalatable long-term solutions that call for restricting floodplain uses and enforcing existing regulations" (Gruntfest and Huber, 1989: 284), raising the question of whether life and property protection might not be better achieved through strategies other than the use of warning systems.

What the literature indicates, then, is that planning for and implementing an integrated warning system that encompasses the four system dimensions outlined by Sorensen–scientific, managerial, technological, and social–will likely be a major endeavor for SCAN program participants. Quite apart from the major challenges associated with the analysis, modeling, and assessment of earthquake phenomena, and quite apart from the need to design effective warning messages and mechanisms, working out relationships among participants in the interorganizational seismic alert network (ISAN) that will be established by SCAN will be a significant undertaking in and of itself. ISAN participants must be able to articulate what they expect from the system, understand what the system can and cannot do, and be willing to make whatever investments are necessary to effectively disseminate warnings. The scientific organizations that will be responsible for maintaining the seismic arrays, computer networks, and communications systems that constitute the first phase in the warning process will need to establish and maintain ongoing contacts with governmental, emergency management, and user organizations in order to ensure that SCAN functions as a true real-time alert system. Without this level of ongoing active involvement, the loss-reduction objectives of the system are unlikely to be realized.

***Using SCAN to Achieve Life-Safety Objectives: Behavioral Response Issues***

Virtually all discussions of real-time earthquake alert systems center on their potential life-safety value. For example, while the National Research Council's study on real-time warning emphasized the use of automated real-time systems to protect facilities and shut down production processes, the report also highlighted a number of potential life-safety applications, noting that (1991: 20-21):

> Actions to enhance personal safety, such as seeking cover under a strong desk or table or moving away from hazardous equipment, can be taken with an alert time of only a few seconds. School children, office workers, or factory workers who have been drilled in the appropriate action will respond quickly...This type of alert can reduce panic...

Goltz and Flores observe that in the case of the Mexico City seismic alert system, the only system currently in place that attempts to warn the public of impending quakes, "both the providers and users of SAS [Sistema de Alerta Sismica] have unequivocally chosen life safety as the primary system objective" (1997: 730-731). Similarly, because of its potential for reducing deaths and injuries, SCAN planners place considerable emphasis on its potential use in schools and workplace settings. It is thus critical to explore how SCAN will need to be designed in order to effectively broadcast warnings to the public, as well as the extent to which recipients of warning messages will be able to use that additional warning time to engage in self-protective actions. The section that follows summarizes research findings on the warning response process and on factors that influence the manner in which people respond to hazard warnings. It also discusses what is currently known about the extent to which people comply with disaster warnings and how they behave in emergency situations. The section concludes by discussing insights from research on the Mexico City seismic alert system.

As noted earlier in the introduction to this report, the overwhelming bulk of the systematic and empirically sound research that has been conducted on disaster warnings focuses on warning response processes for individuals and households and on situations that involve comparatively long warning times. Moreover, most of that research focuses on one particular type of self-protective response: evacuation in the face of an impending disaster. Indeed, the topic of household evacuation is among the most-studied in the disaster research field. Even though it does not focus on very short-term warning situations, this literature, which serves as the basis for many of the warning response models discussed below, does provide a number of very significant insights into how people receive, interpret, and respond to warning information. At the same time, it is important to keep in mind that many of these insights may not necessarily transfer directly to the alert situations in which SCAN would be employed.

Models of Warning Response

Whether explicitly acknowledged or not, most social-scientific studies on warning response and self-protective actions employ some variant of the well-known Source-Channel-Message-Receiver-Effect-Feedback model (Lasswell, 1948). Following this model, information on the disaster or threat is initially conveyed either by physical cues (e.g., earthquake shaking) or from different social and organizational sources, such as emergency response authorities, the media, scientists, or friends, relatives, or neighbors. Warning information can be transmitted through person-to-person channels or through various types of technological channels. This information, when conveyed to different community sectors and demographic groups, produces a range of psychological and behavioral effects. These effects are produced in several stages, as individual recipients of warning information are first exposed to the warning message, then focus their attention on the warning, comprehend the meaning of the message, and make assessments on the warning's accuracy and validity. These efforts at processing information produce two types of psychological effects in warning recipients. First, people react cognitively, by recognizing and understanding the warning, and then deciding what protective actions to take. Second, they react affectively, for example by becoming more anxious or fearful. These psychological effects then lead to behavioral consequences, which can range from doing nothing in response to the warning message to undertaking recommended self-protective actions. Recipients of warning information then make an effort to obtain feedback, either by looking for more information on the threat, as well as information on what others have done in response to the warning message, or by assessing the consequences of their action (or inaction).

Dennis Mileti and John Sorensen, specialists in risk communication and warning response, describe the process of responding to warning messages as involving a sequence that includes *perceiving the warning*; *understanding the contents of the warning*; *believing that the warning is credible and accurate*; *personalizing the warning*; *confirming that the warning is accurate and that others are taking it seriously*; and *responding by taking protective action*

(Mileti and Sorensen, 1990; Sorensen, 1993). Michael Lindell and Ronald Perry, two other well-known warning researchers, describe a similar sequence, involving four stages: *risk identification* (deciding whether the threat exists); *risk assessment* (deciding whether protection against the risk is actually needed); *risk reduction* (deciding whether it is feasible to undertake protective action); and *protective response* (deciding to act and carrying out that action). More generally, what the literature on warning response and risk communication indicates is that, for threat communications to be effective in bringing about desired actions on the part of the public, recipients of warning information must (1) receive the information; (2) understand it; (3) understand that the warning message applies to them; (4) personalize the risk–that is, understand that they themselves are actually at risk if they do not take protective actions; (5) decide that they need to act on the information; (6) understand what actions they can take in order to protect themselves: and (7) be able to take those actions (Fitzpatrick and Mileti, 1994).

Anything that interferes with the ability of people to successfully complete this sequence of perceptual, cognitive, and behavioral steps–for example, any ambiguity about the meaning, validity, or urgency of the warning, or about what self-protective actions to take–will result in less than satisfactory compliance with warning messages. Each element in the warning response sequence is extremely important, but clearly several stages are critical determinants of action: warning recipients must reach the conclusion that the risks associated with not acting are real, they must understand that they personally are at risk, they must know what to do in order to protect themselves against those risks, and they must be able to carry out those actions–that is, they must both know what actions to perform and have sufficient time to perform those actions.

It is important to note here that if planners intend to use the SCAN system to promote life-safety, strategies must be developed to enable hearers of warning messages to pass rapidly through the seven stages outlined by Fitzpatrick and Mileti. While warnings for other impending threats such as floods and hurricanes typically allow some time for warning recipients to cognitively process warning information, seek any additional information they believe they need, check with others to see how they have interpreted the warning message, and decide what to do in response to the warning, real-time earthquake alerts will not. Instead, they will require warning recipients to carry out recommended safety procedures almost automatically, taking only a few seconds at most to reflect upon and confirm the warning. For reasons that will be discussed in greater detail below, there is some question whether this kind of rapid response can be elicited from many potential earthquake alert recipients, except perhaps from certain segments of the population and under certain circumstances.

Factors Affecting Warning Response

The literature emphasizes that different individuals and groups respond in different ways to warning information. Warning response behaviors have been shown to be subject to the influence of a wide variety of factors. Those factors include disaster agent characteristics, the settings and situations in which warnings are issued, the sociodemographic characteristics of warning recipients, and the types of technologies that are used in issuing warnings. In some cases, there is a solid empirical basis for making judgments about the importance of particular factors. In other cases, existing research is only suggestive, rather than conclusive.

In the newly-published summary of warning response literature discussed earlier, warning researcher John Sorensen presents a review and synopsis of existing research on factors affecting warning response, focusing not only on factors that have been studied and shown to be important

**Table 2**
**Major Factors Covarying with Warning Response**
(Source: Sorensen, 2000)

| Factor (1) | Response due to factor increase (2) | Level of Empirical Support (3) |
|---|---|---|
| Physical cues | Increases | High |
| Social cues | Increases | High |
| Perceived risk | Increases | Moderate |
| Knowledge of hazard | Increases | High |
| Experience with hazard | Mixed | High |
| Education | Increases | High |
| Family planning | Increases | Low |
| Fatalistic beliefs | Decreases | Low |
| Resource level | Increases | Moderate |
| Family united | Increases | High |
| Family size | Increases | Moderate |
| Kin relations (number) | Increases | High |
| Community involvement | Increases | High |
| Ethnic group member | Decreases | High |
| Age | Mixed | High |
| Socioeconomic status | Increases | High |
| Being female versus male | Increases | Moderate |
| Having children | Increases | Moderate |
| Channel: Electronic | Mixed | Low |
| Media | Mixed | Low |
| Siren | Decreases | Low |
| Personal warning versus impersonal | Increases | High |
| Proximity to threat | Increases | Low |
| Message specificity | Increases | High |
| Number of channels | Increases | Low |
| Frequency | Increases | High |
| Message consistency | Increases | High |
| Message certainty | Increases | High |
| Source credibility | Increases | High |
| Fear of looting | Decreases | Moderate |
| Time to impact | Decreases | Moderate |
| Source familiarity | Increases | High |

in influencing warning response behaviors, but also on the extent to which findings regarding these factors have been supported by empirical research (Sorensen, 2000).[5] Table 2, entitled "Major Factors Covarying With Warning Response," is excerpted from the Sorensen article. Again, it is important to stress that much of the research discussed in the Sorensen review focused on the problem of household evacuation in threat situations involving warning times ranging from a few minutes to hours and even days–situations that are not directly analogous to the earthquake alert context. Many of the points raised in Sorensen's review are thus not relevant for real-time earthquake alert systems. Nevertheless, findings from these studies do provide important insights for SCAN design.

To summarize from Table 2, factors and circumstances that have been shown to have a positive effect in eliciting appropriate warning responses in the largest number of studies (and those, therefore, in which most confidence should be placed) include the following:

*SITUATIONAL FACTORS*

- situations in which disaster threats are accompanied by both initial physical cues and social cues indicating that people are taking those threats seriously

*INDIVIDUAL- AND GROUP-LEVEL FACTORS*

- greater knowledge of the hazard
- higher levels of educational attainment
- situations in which household members are together when the warning is received

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[5] It should be emphasized that in reviewing any literature, it is important to be able to distinguish between findings that have received substantial support in the literature and those that have only been found to be significant in a few studies. Obviously, more confidence can be placed in findings for which there is more consistent support across different disaster events, populations, and warning contexts.

- number of kin relationships existing among warning recipients
- recipients' levels of community involvement
- membership in dominant majority, as opposed to minority groups
- higher socioeconomic status

*FACTORS ASSOCIATED WITH WARNING MESSAGES*

- personal, as opposed to impersonal communication of the warning message
- message specificity
- frequency with which the message is issued
- the degree of certainty associated with the warning
- credibility of the source issuing the message
- recipient familiarity with the source issuing the message

Other factors that are considered important in influencing warning response but that to date have received less solid support in the literature include gender (with females thought to be more likely to take warnings seriously and to act on them) and having responsibility for children at the time the disaster occurs.

Although the bulk of these findings are not based on research on very short-term warnings, they do have a number of implications for the likely effectiveness of the SCAN system. Focusing first on warning cues associated with the hazard itself, people are more likely to take self-protective action in emergency situations in which there are clear visual, auditory, or other cues that signal danger--for example, in the case of a tornado, darkening skies, high winds, and the sight of a funnel cloud. In an earthquake, ground shaking serves as the primary cue. Since people are currently accustomed to taking self-protective actions when they initially begin to perceive earthquake shaking, if SCAN is implemented, they will need to be re-trained to react upon initially receiving a warning message, rather than waiting to begin feeling strong shaking. Following this logic, since people currently take self-protective action only when they perceive earthquake shaking, earthquake alerts may be more effective in motivating people to act if they are accompanied by sounds that most people associate with earthquakes, because the sounds would provide an additional warning signal.

People respond best to perceptual cues that are also reinforced by social cues, such as the sight of other people initiating precautions. In the real-time alert situation, to best utilize the influence social cues exert on response behavior, persons in visible leadership positions in the settings in which SCAN is deployed, such as teachers and work supervisors, must be trained to take protective measures and issue verbal commands immediately, so as to exert influence on others in the setting. If these individuals hesitate or fail to take appropriate action when alerts are issued, other warning recipients will be confused and will be less likely to act on the basis of the warning.

The literature also suggests that, like other warning systems, SCAN will need to address the needs of diverse populations. Research has consistently found that sociodemographic characteristics of warning recipients have a significant influence on their ability to receive, cognitively process, and act on warning information. For example, to achieve compliance with SCAN warning messages, it will be necessary to take into account barriers associated with low educational levels and minority group membership. Less-educated people may have trouble understanding what alarm systems are designed to do and may have more difficulty recalling recommended safety actions when an emergency occurs. Minority group members, particularly those whose first language is not English, may experience similar difficulties comprehending the purpose of warning systems and understanding safety instructions, particularly if those instructions are given only in English (Aguirre, et al., 1991).

Although developmentally-disabled, learning-impaired, elderly, and physically-disabled populations are not mentioned specifically in Sorensen's review, these populations will also need special attention and extensive training if they are to be expected to comply with earthquake alert messages.[6] Elderly persons and individuals with physical disabilities may be significantly less likely to comply with warnings than younger, able-bodied persons, either due to difficulties associated with perceiving and understanding warning information, or due to physical limitations that may restrict their ability to undertake self-protective actions in a timely manner (Tierney, Petak, and Hahn, 1986; Rahimi and Azevedo, 1993). Extensive training will be necessary in all settings in which SCAN alarms are deployed, but special efforts will be needed to ensure that needed information reaches these segments of the population. Other populations requiring special consideration and planning efforts include people in prisons, mental institutions, hospitals, and nursing homes. As later discussions suggest, failure to address the needs of special populations in the design and deployment of SCAN could raise significant social equity issues.

As later discussions explore in more detail, people can be expected to react more rapidly and appropriately to real-time warnings if they are already familiar both with the warning

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[6] This assumes that effective training is already taking place in schools in Greater Los Angeles and that training for real-time alerts will be able to build upon and reinforce ongoing programs. Even individuals with severe cognitive impairments can be trained to carry out some types of self-protective actions, provided sufficient resources are invested in that training (see, for example, Israel, et al., 1993). However, whether they would be able to do so in situations involving extremely short warning times is a matter for further empirical exploration.

systems themselves and with the settings in which warnings are issued. Compliance will be higher when individuals are present with others with whom they have close ties when they hear the warning message (e.g., classrooms, work groups, family gatherings), as opposed to being alone or being transients in the warning setting (e.g., simply passing through public buildings, stores, shopping in malls, or other settings). To further expand on the importance of familiarity with warning systems, it is important to note that, as is the case with other large US cities, the daily population of Los Angeles contains large numbers of people who are tourists or short-term visitors, and who therefore can be expected to have little familiarity either with earthquakes or with earthquake alert systems. Drabek (1994; 1995; 1996), who studied a variety of issues related to preparedness and warning response for tourists and other transient populations, observes that tourists constitute a particularly hard-to-reach population when warnings are issued, especially since they may not be familiar with hazards in the areas to which they travel, and since they may not be as attentive to warning messages issued by the media while they are traveling. Travelers are typically very dependent on the lodging and tourist industry for information on hazards and preparedness, yet the hospitality industry is generally not well-prepared for disasters.

Research findings centering on warning message-related factors again pose a number of cautions for the SCAN system. The literature stresses that personally-delivered warning messages (e.g., evacuation orders issued by public safety officials traveling through neighborhoods, or delivered live by authoritative speakers) are more effective in encouraging appropriate warning responses than impersonal messages. However, unless the SCAN system can in some way incorporate or approximate live warning messages, the system will need to overcome the disadvantages associated with non-personal warnings. Warning effectiveness is also positively associated with the frequency with which messages are issued for a particular event, as well as with their consistency, specificity, and certainty–all things that need to be taken into account in the design of the SCAN system. Clearly, an emphasis should be placed on achieving both a high degree of accuracy in shaking projections at particular sites, as well as on reinforcing warning messages, to the extent that would be feasible in the real-time warning context.

The credibility of the sources issuing warning information and the extent to which target groups are familiar with the source issuing the warning both have a positive influence on the likelihood that people will respond appropriately to warning information. SCAN is likely to be seen as very credible and authoritative, but steps will need to be taken to increase familiarity with the SCAN system in the Greater Los Angeles region. Since many organizations and Southern California residents are already familiar with the CUBE system, and since media reports have discussed the possibility of a real-time alert network, the new alert system will not be completely unfamiliar to residents. However, there is a clear need for broader educational campaigns targeting both the general public and potential organizational users. Additionally, as later discussions suggest, warning source credibility can be negatively affected by false alarms and missed alerts, as well as by problems with overall system reliability.

<u>How Well Do People Currently Respond to Warnings, and How Do They Behave During Disaster Impact?</u>

Policies and recommendations for the TriNet/SCAN system should take into account what is currently known about how well people generally respond in warning situations, as well as how they react when earthquakes occur. Part of determining whether a system like SCAN is likely to be effective involves assessing the success of alert and warning systems for other hazardous situations. Similarly, since SCAN will build upon existing programs encouraging people to take self-protective action when an earthquake strikes, it is also important to consider the extent to which people currently comply with those recommendations. More broadly, like any other warning system, SCAN should build on existing knowledge concerning how people actually behave during emergencies.

*Warning Compliance.* DRC's literature review failed to locate studies systematically comparing compliance rates across different types of hazardous situations in which alarms, alerts, and warning messages are used. The literature does suggest that achieving compliance by all or even a substantial majority of warning message recipients has remained an elusive goal. Unfortunately, even in warning situations involving long lead times, clear evidence of a threat, and carefully-executed warning dissemination plans, compliance with warning messages is by no means universal. For example, before Hurricane Andrew struck, a very large and concerted effort was undertaken to move residents out of unsafe areas. Surveys indicate that 54% of households in designated evacuation areas did evacuate; in the highest-risk coastal evacuation zones, about 71% of households complied fully with evacuation advisories (Peacock, Morrow, and Gladwin, 1997). In other words, nearly one out of three households that were at very high risk from one of the most severe storms ever to strike in the US either did not receive or (much more likely) decided not to act on warning information.[7] Other research indicates that public

[7] In this disaster event, important factors predicting evacuation included being located in a designated evacuation zone, living in a single-family dwelling, having a smaller-sized household, and having children present in the home. Elders were significantly less likely to evacuate than younger residents.

responses to tornado and hurricane warnings vary widely, both across communities in any given storm and for different storm events that strike the same community (Baker, 1991). As summarized by Dow and Cutter (1998), evacuation rates for twelve southeastern US communities that were threatened by four hurricanes between 1984 and 1996 (Diana, Hugo, Bertha, and Fran) ranged from a low of 10% to a high of 81%. Citing the "disaster subculture" concept as a possible explanatory factor, Dow and Cutter observe that "despite more aggressive coastal and hurricane education programs, we still see a significant evacuation-resistant population varying among locations" (1998: 251). According to data collected by Liu et al. (1996), when a tornado struck Calhoun County, Alabama in 1994, 88% of the residents in the geographic area for which warning sirens had been provided heard the sirens, but only 31% sought shelter. On the basis of their research, these authors concluded that public education is needed in order to ensure that people actually respond appropriately when warnings are issued. Problems with noncompliance have been documented for a range of other warning technologies, including very familiar ones. Regarding railroad crossing alert signals, for example, one recent report observed that (Sheridan, Gamst, and Harvey, 1999: 12)

> in 1997, more than half of the 3,446 train-automotive vehicle collisions involved grade crossings equipped with active warning devices. Motorists simply did not heed them. During 1997, Amtrak passenger trains were in 245 collisions with automotive vehicles, and 183 were attributed to motorist inattention or impatience.

Thus, the first challenge any warning or alert system faces is simply achieving acceptable levels of warning compliance. Many systems currently in operation fall far short of that goal.

*Panic and Other Maladaptive Behavior.* In light of the fact that motivating people to recognize and heed warnings is so difficult, it is ironic that both laypersons and some public officials seem to focus instead on concerns that issuing alerts will cause warning recipients to panic. Nearly fifty years of social-scientific research has disproved the myth that people react in a panicky fashion, either upon disaster impact or upon receiving warnings of impending threats. Quarantelli's study on panic (1954) was among the first studies that explored exactly how people react at the time disasters strike. That research demonstrated that panic (conceptualized here as intense fear, accompanied by extremely individualistic behavior in which people seek to flee to safety, even if that means disregarding the safety of others) is extremely rare in disaster situations. Research since that time has borne out the finding that the vast majority of people respond in a positive, adaptive fashion when disasters strike. For panic to develop, five conditions must be present: (1) there must be strong pre-existing beliefs that particular situations will lead to panic; (2) crisis management measures must be so completely ineffective that people feel they are being left totally on their own; (3) people must begin to believe that there is an immediate danger of entrapment–that is, that routes to safety are rapidly closing; (4) people must begin to believe that they have no means of saving themselves, other than through flight; and (5) social bonds within the setting must break down and people must feel socially isolated (Quarantelli, 1977). These conditions are typically not present in threat situations or during and immediately following disaster impact Panic behavior rarely occurs even in situations that many assume would create panic, such as life-threatening fires and major explosions. Part of the reason panic is not generally a problem is that the social ties that exist among victims are so remarkably resilient (see, for example, Johnson, 1988; Johnson, Feinberg, and Johnston, 1994 on the persistence of social bonds and adaptive behavior during the 1977 Beverly Hills Supper Club fire and Aguirre, Wenger, and Vigo, 1998, who found no evidence of panic at the time of the

1993 World Trade Center bombing ).

The survey conducted for this project by UCLA suggests that organizational officials are concerned about the question of panic in earthquake situations, but many appear to believe that by increasing warning response times, SCAN could serve as a safeguard against the development of panic. Data from open-ended questions on potential benefits of the TriNet system suggest that many respondents, particularly those in the educational sector, see the real-time alert system as a means of reducing the likelihood of panic and other maladaptive behaviors. Respondents opined, for example, that a warning would give people "an extra ten seconds to be emotionally ready" to respond, and that even a short warning would "help emotionally prepare us" and enhance the "potential to be proactive." Even a few seconds of warning time were seen as beneficial, because that would give people more time to mentally prepare to respond should strong shaking occur. According to many respondents, this could help warning recipients respond more appropriately when the actual shaking begins.

Little is currently known about how Southern California residents respond when earthquakes strike, but available evidence suggests that many of those who have experienced earthquakes do understand what to do during earthquake shaking and are able to take steps to protect themselves. The best available data on responses during actual earthquake events in California comes from research conducted at UCLA. Using telephone surveys with randomly-selected community respondents, TriNet project member Linda Bourque and her associates studied the behavior of community residents during and immediately following the Whittier Narrows, Loma Prieta, and Northridge earthquakes. Their research found that people generally behaved in an active and adaptive manner during and after those earthquake events and that when those events occurred many residents did undertake recommended self-protective actions. However, there were still some people who engaged in actions that public education campaigns have tried to discourage, such as running outside during earthquake shaking. Behavior during earthquake shaking was found to have been influenced by a range of socioeconomic, situational, and social-psychological factors, notably education, income, presence of children in the home, location at the time of earthquake impact, and levels of fear experienced during earthquake shaking. (Findings on the Whittier Narrows and Loma Prieta earthquakes are summarized in Goltz, Russell, and Bourque, 1992 and Bourque, Russell, and Goltz, 1993).

According to research evidence, then, panic behavior is quite unlikely following the issuing of a real-time earthquake warning. But couldn't the opposite problem occur? Would the issuing of an earthquake warning cause people to freeze in place, to be so dazed and stunned that they would be unable to respond effectively? Again, the idea that large numbers of people within victim populations are dazed, in shock, or otherwise unable to function in disaster situations is another longstanding belief that has been countered by a substantial amount of research. The so-called "disaster syndrome" is in fact quite rare in emergency situations. When it does occur, it appears most frequently in disaster events that happen without warning, in which there is extensive physical destruction and loss of life. Even when these kinds of behaviors develop, they are typically confined to only a small segment of the victim population, and they tend not to last long (Tierney, Lindell, and Perry, 2000). Based on the literature, then, the notion that people will be in such an intense state of shock and confusion that they will be unable to act, either upon hearing an earthquake alert or upon earthquake impact, appears to be quite unfounded.

However, even if SCAN developers need not concern themselves with problems like panic and the disaster syndrome, they will still need to address a variety of other issues, such as how to encourage compliance with alert messages, how to make sure that people react rapidly when they receive alerts, and how to ensure that people do in fact take recommended self-protective actions upon hearing a warning, rather than doing something else that might actually jeopardize their safety. As noted earlier, there is almost no situation in which large percentages of those who receive warning messages comply immediately with recommended safety actions, and in warning situations of all types, there will invariably be people who fail to heed warnings. While 100% compliance with warnings may never be achievable, low compliance rates could be very deleterious for SCAN, owing in part to the tendency people have to look to others who are present in a setting for behavioral cues. If even a substantial minority of people fail to react or hesitate before reacting to earthquake alerts, they could influence others who receive warning messages to hesitate as well.

The literature on warning response indicates that in order to motivate action, warnings must cause people to be genuinely concerned with their own safety. They must, in other words, inspire a relatively high degree of personal concern and even a degree of fear. At the same time, especially in warning contexts that require a response within a very short time-frame, warnings must not terrify, startle, or induce feelings of helplessness in warning recipients, because those kinds of reactions will interfere with the ability to act rapidly. When information is communicated indicating that an individual needs to act, he or she must be able to concentrate exclusively on performing recommended safety measures, rather than on managing high levels of anxiety or wondering what to do next.

Similarly, care must be taken to ensure that earthquake alerts stimulate not just any action, but actions that are consistent with recommended earthquake safety procedures. This is a challenge for all warning systems. For example, in a study on a 1997 accident and hazardous release at a chemical repackaging plant in West Helena, Arkansas, Vogt and Sorensen *(1999)* noted that only about one quarter of the residents who were told to shelter in place to protect themselves against the airborne toxins actually did so. Instead, a large proportion of those who were told to stay in their homes evacuated, evidently because they did not feel that their houses would provide adequate protection. They may, in other words, have put themselves into even more danger by taking the warning seriously, but then taking actions other than those recommended by authorities.

Paralleling this idea, earthquake researchers, including Bourque and her colleagues, have noted that despite public education efforts, some California residents still attempt to run out of structures when earthquakes strike. Even if evacuation would be advisable for some structures in the event of an earthquake, the warning times projected for SCAN would likely not allow sufficient time for orderly building evacuations to take place. Thus one challenge will be to ensure that people do not misinterpret earthquake alerts as a signal to evacuate or ignore advice to shelter in place and elect to evacuate instead.

As the foregoing examples suggest, public education and training will be required in order to increase the probability that large numbers of warning recipients will carry out appropriate actions upon receiving warnings and that they will avoid undertaking inappropriate ones. The education and training requirements for SCAN will likely be more extensive and intensive than for many other types of warnings, both because so little time will be available for people to confirm and act on the information they receive and because people who do not understand alerts or do not know what measures to undertake when an earthquake strikes might exert a negative behavioral influence on those who do. While "contagion" models of behavior in emergency situations have received no support in the literature, it is nevertheless true that in emergency situations individual behavior is quite sensitive to social cues in the environment–including in particular what people see others doing. To an even greater extent than during normal times, individuals model their actions on the behavior of others in crisis situations. Thus, in settings in which initial compliance with warning messages is low or delayed, there is a possibility that people will become confused and hesitant to act.

*Lessons From the Mexico City Experience.* Because Mexico City's Sistema de Alerta Sismica (SAS) is currently the only real-time seismic alert system that is being used to issue warnings to the public, it is important to take into account what has been learned about the functioning of that system. Unfortunately, however, there is not a great deal of information available on behavioral responses when warnings are issued by that system. Research by Flores and Goltz (1997) provides the best available English-language account of how the system has been used to warn the public of impending earthquake events. Their study focused on a warning that was issued when the system was triggered by a 7.2 earthquake that occurred 190 miles south of Mexico City and about 95 miles east of Acapulco at 8:04 am on September 14, 1995. At the time of that event, a signal was received and alarms were triggered in Mexico City approximately 72 seconds before ground motions arrived in the capital. Radio stations broadcast a warning message,[8] and alerts and signals were sent out to schools and neighborhoods. According to

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[8] The report notes that of 46 radio stations that issue alerts, only 18 disseminate the warning automatically, without the involvement of human intermediaries. At the other 28 stations, diskettes containing recorded warning messages must be put into the broadcasting

individuals who were interviewed by Flores and Goltz, the dissemination of warning messages was followed by orderly evacuations and appropriate self-protective measures. In one neighborhood, for example, Flores and Goltz report that (1997: 729):

> Residents indicated that they and others around them were frightened when the signal sounded but responded by turning off gas and lights and evacuating their buildings according to established procedures and with the assistance of residents assigned to direct people to the pre-designated evacuation routes and outdoor assembly locations. No one with whom we spoke reported witnessing behavior such as running, shoving, or other actions associated with extreme fear and flight reactions.

The authors describe similar accounts from schools, where evacuations were reportedly "orderly and well coordinated" (Flores and Goltz, 1997: 729).[9]

The Flores and Goltz report did not include a discussion of how many schools, neighborhoods, or individuals were involved in responding to the warning or on what proportion of those who were warned took any action in compliance with warning messages. Additionally, because the earthquake did not cause significant damage in Mexico City, the authors were unable to assess the extent to which the warning would have helped reduce deaths and injuries. Nevertheless, their findings do have important implications for the design and implementation of the SCAN system. First, because warnings are issued by SAS when large earthquakes occur at relatively remote locations, warning times for Mexico City are significantly longer than they would be for most earthquakes in the Southern California region, enhancing the potential life-

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equipment by station personnel. All 46 stations reportedly issued messages at the time of the September 14 event.

[9] It seems reasonable to ask, however, how many schools–either in Mexico City or in Southern California–could be safely evacuated in such a short period of time. Southern California students will undoubtedly be instructed to shelter in place in their classrooms, as opposed to evacuating.

safety and property protection value of the Mexico City system. Only an earthquake on the southern San Andreas fault would provide comparable warning times for Southern California.

Second, several factors contributed to the orderly and adaptive public response to the 1995 earthquake alert. Mexico City had experienced a devastating and deadly earthquake in 1985. Following that event, the government launched major public awareness campaigns and sponsored organized efforts to educate the public on what to do when earthquakes occur and when warnings are issued, and those efforts appear to have paid off when the September 1995 event occurred. For example, Flores and Goltz note that in El Rosario, one neighborhood that received and acted on the earthquake alert, "[a] community organization had been created after the 1985 earthquake disaster that conducted training in appropriate response actions including those that should be taken in a warning situation" (1997: 729) and that trained residents helped coordinate self-protective responses to the 1995 event. These three factors–recent experience with a very severe earthquake disaster, sustained public education efforts, and training for community residents, school personnel, and other groups–likely made a significant positive contribution to the public response to the September 1995 earthquake alert. This case illustrates the importance of linking real-time warning technologies to a broad range of activities designed to prepare the public for earthquake events. Absent extensive experience and preparedness efforts, it is unlikely that the system would have functioned as intended.[10]

<u>Other Relevant Lessons From the Literature</u>

*The "Normalcy Bias."* The literature also raises a number of issues that need to be taken

[10] However, Goltz and Flores (1997) also point to some difficulties with SAS reliability, including one missed event in which the system should have been triggered but was not and two false alarms.

into consideration in the design and implementation of the SCAN system. As suggested in the preceding section, a key overriding issue concerns whether people can be counted on to respond to earthquake alerts, and whether they can do so quickly enough to make a difference. The warning literature stresses that all warning efforts must overcome what social scientists refer to as the "normalcy bias," or the tendency for people to continue to believe that things are proceeding normally and unproblematically, even when obvious environmental cues and warning messages suggest the contrary. In his review of the warning literature, for example, Drabek (1986: 73) observes that "members of threatened populations will seize upon any 'vagueness' in a warning message which allows them to reinterpret the situation in a nonthreatening fashion." There are numerous documented cases in which people have resisted acting on warnings even when those warnings were personally conveyed to them by people in authority. Despite emphatic warnings those individuals still did not respond either because they did not give credence to warning messages, or because they did not feel personally at risk. The literature suggests that, to counteract the normalcy bias, warning systems must provide accurate and credible information and use as many different channels and media as possible; messages must be as precise and concrete as possible; and warnings of impending threats must be issued with increasing degrees of urgency.

What the literature also suggests is that, in order to be effective, a real-time seismic alert, which will likely only be broadcast for a short period of time, through a single channel, must be able to make a decisive impact on recipients–and to achieve that impact very rapidly. Considerable ongoing training is likely to be needed in order to help overcome the natural tendency all individuals exhibit to delay taking protective action, and to motivate people to act rapidly upon receiving earthquake alert messages.

This will present particular challenges, because the literature also makes it clear that human beings cannot be trained to react instantaneously or automatically to warnings. Some period of lead time is always needed for people to assess and confirm warning information, decide what to do, and then actually carry out those actions. For example, upon hearing a warning of an impending threat, people often consult with friends, neighbors, relatives, and coworkers, either face-to-face, by phone, or through some other medium of communication, before taking action. As noted earlier, social cues and processes of social influence also play a role in warning response. Residents who are warned that they must evacuate from their homes typically look around their neighborhoods to see what their neighbors are doing; if they see other people leaving the area, they are more likely to do so. These same information-processing, confirmation, and influence processes will also occur when a real-time seismic alert is issued. The time needed for warning confirmation and for undertaking self-protective action can no doubt be shortened through extensive public education and training, but the need for additional time before actually responding to warning messages will never be completely eliminated. Thus, the additional "lead time" that warning recipients need to actually respond when a warning is broadcast needs to be factored in as an integral part of the warning process.

The fire safety area constitutes one warning situation that has important parallels with situations in which the SCAN system will be used. Problems with eliciting building occupants' compliance with fire alarms and building evacuation orders are well-documented in the literature (see, for example, Canter, 1980; Keating, 1985). In the tragic 1977 Beverly Hills Supper Club fire, in which nearly 500 people lost their lives, patrons delayed evacuating even when they were told to do so by staff members, and even though sensory cues indicated that there was a fire. As one author notes with respect to fire evacuation situations (Proulx, 1993: 137):

> When an emergency occurs in a public building and evacuation is required, it is expected that users will move quickly towards an area of safety. Administrators of public places presume users will leave the building immediately by the nearest exist on hearing the sound of an alarm, however, the analyses of people's behavior in such a situation have revealed a different picture...Long delays before deciding to move, time spent looking for others or gathering personal items, as well as attempts to evacuate by dangerous routes, were readily observed behaviors.

Because of the influence of the normalcy bias and because there is generally a time-lag between the receipt of any warning message and the initiation of self-protective action, some social scientists have already questioned whether SCAN can be effective for protecting life safety. In an article on earthquake alarm systems that was published in the early 1990's, for example, sociologist Dennis Mileti was quoted as stating that "a 1-minute warning is not enough time for people to process the information and act on it" (quoted in Bjerklie, 1993: 19).

*Variations in Behavior Across Settings.* When the SCAN system is implemented, it will also be important to take into account the characteristics of the different types of settings in which the system could be deployed, and to choose only those types of settings in which an alert system is likely to be effective in protecting life-safety. Settings differ in the extent to which occupants can be expected to heed warnings, as well as in the difficulty associated with deploying a system that functions effectively. For example, the Federal Emergency Management Agency's course on Earthquakes and Fires in High-Rise Buildings (Federal Emergency Management Agency, 1989)[11] makes the point that physical settings differ in four ways that have

[11] This course was originally developed with funding from the Southern California Earthquake Preparedness Project under the supervision of Paul Flores. The team that designed the course was headed by TriNet study investigator Ronald Eguchi, then at Dames and Moore.

an influence on the ease with which life-safety measures can be implemented:

- *The extent to which occupants and users are familiar with the setting.* Is the setting one that occupants use on a regular or routine basis, or only very infrequently? On any given day, what proportion of building occupants will be so unaccustomed to being there that they will be unaware of any alarm systems that might be in place and of what safety measures to use in that particular setting?
- *The extent to which users of the building can rely on networks of mutual support.* Do the building occupants know one another, or are they strangers? Do they interact on a regular basis? Is it possible to develop support systems and train building occupants in appropriate earthquake safety behaviors?
- *The extent to which the setting is under the jurisdiction of an emergency management body that has the authority to train building occupants and require them to comply with recommended safety procedures.*
- *The complexity of the setting, in terms of ownership, management, tenancy, and other aspects of property control.* For example, is the structure a school building or government office, where issues of ownership and control of the setting are relatively straightforward, or is it a high-rise building with multiple tenants or some other type of structure in which different entities have responsibility for different areas?

When these kinds of issues are taken into account, it is clear that a system like SCAN has a greater chance of being successfully implemented in certain types of settings, as opposed to

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Kathleen Tierney provided information on human behavioral aspects of fire and earthquake response.

others. Taking schools as an example, the vast majority of people who use school buildings on a daily basis are routine users of those settings and are familiar with (or can made familiar with) building layout, hazardous areas, and procedures to ensure life safety. Social ties have had time to develop, and roles and responsibilities are clear. Safety procedures are in place for earthquakes and other emergencies, such as fires, and drills are routinely conducted. School officials have clear authority over safety procedures inside the school. For example, they can see to it that drills and training take place, that safety literature is distributed, and that teachers are held accountable for passing on preparedness information to students.

At the other end of the continuum are settings such as large shopping malls and airports, in which most occupants are transients; many building users are unfamiliar with the setting and lack knowledge of safety procedures and safe areas; groups using the facilities are essentially unconnected to one another, rather than linked together on a regular basis in mutually supportive groups; and various tenants' facilities may adopt very different approaches to disaster preparedness–or may do little or nothing to prepare. It is difficult to envision how a real-time alert system could function effectively in these types of settings without very extensive public education, pre-planning, and training efforts. It is also likely to be difficult to work out arrangements with potential user organizations in these kinds of settings.

In making decisions about where to deploy alarm systems for life-safety protection, SCAN designers should first target those settings in which there is a high likelihood that alarms will evoke desired behavioral responses. Schools are clearly good candidates for deployment, as are industrial facilities, public safety facilities, and other structures that are used primarily by employees (rather than by transients) on a regular, routine basis. More-complex buildings and settings occupied primarily by people who are temporarily passing through are poor candidates for deployment, because warning messages have such a high probability of being misunderstood or not followed in a timely fashion.

Organizational emergency response capacity is also an important consideration in decisions regarding how and where to deploy the system. Because training for occupant response to SCAN warnings must build upon existing safety programs, settings in which effective emergency procedures are already in place for earthquakes are clearly preferable to those in which little or no planning has occurred. Additionally, if those who have responsibility for ensuring the safety of building occupants are not already performing that function effectively for earthquakes and other emergencies, there is no reason to expect that they will do so with respect to SCAN.

What this assessment suggests is that, as the developers of SCAN concentrate on improving the scientific assessment phase of the warning process, careful attention will also need to be paid to concerns associated with how technologies will function in an overall warning system. These concerns include carefully thinking through relationships among the organizations that make up the system; making sure that participants in the ISAN understand and are capable of adequately performing their roles, educating personnel in ISAN constituent organizations, and training potential recipients of warning messages. More broadly, there will be a need to keep government and emergency response officials continually up to date on SCAN, as well as to educate the general public about plans and expectations for the system.

Alarm System and Warning Message Design

Another issue facing the SCAN system concerns the selection of appropriate warning devices and mechanisms and the design of the warning messages that will be issued during earthquake impact. It is important to emphasize at the outset that, as sociologists, DRC researchers are not qualified to make scientific recommendations on the design of alarm systems and messages. Those types of concerns are best addressed by experts in fields such as acoustics and human ergonomic design. Instead, the goal of this section of the report is to cite relevant findings from the research literature in order to outline the kinds of issues that will need to be considered if a decision is made to deploy SCAN as a real-time alert system protecting the life safety of building occupants.

In reviewing and assessing the literature, DRC focused primarily on research on audible warning systems, on the assumption that the seismic alert system SCAN would use would be based either wholly or primarily on some sort of audible signal. Audible alert systems are considered preferable to visual ones, because they are more capable of attracting the attention of warning recipients (Edworthy, Loxley, and Dennis, 1991). Auditory signals are not dependent on light levels, lines of sight, or whether recipients are moving or stationary. In settings where people are concentrating carefully on what they are doing (such as in job settings), they are quite likely to miss visual cues entirely, but they will pay attention to properly-designed audible ones. Although there is not an abundance of useful published research on the ideal characteristics of warning alarms, the literature does point to a number of important alarm design considerations.

First and foremost, it is necessary to stress that in deploying SCAN or any other alert system, steps need to be taken to ensure that whatever alarms are used can actually be heard by their intended recipients. While this may seem too obvious to even warrant mention, the literature suggests that ensuring that alarms are audible can be quite problematic. It cannot be assumed either that building owners will automatically know how many alarms are needed to adequately convey warning messages or where to place them, or that whatever alarms are currently in place are actually functioning effectively. For example, Nanthavanij and Yenradee (1999) note that although employee alarm systems are required for many work settings by Occupational Safety and Health Administration standards, OSHA does not actually specify the number of alarms that are needed for different types and sizes of settings or where those alarms should be located. These researchers have developed a methodology for determining how many alarms are needed in manufacturing facilities, taking into account factors that affect the ability of occupants to hear alarm signals, including ambient sound levels, where workers and workstations are located, and the intensity of the sound that needs to be broadcast by the alarm.

Since planners envision deploying SCAN in settings ranging from schools, to government buildings, to manufacturing and industrial facilities, considerable attention will clearly need to be given to ensuring that the alarms that are used to broadcast earthquake warning messages are placed in such a way that they can effectively reach occupants of those settings.[12] It is important also to keep in mind that settings vary greatly, both in terms of ambient noise levels and in terms of the types of sounds that are typical for those settings. Warning signals that are audible in one setting may be masked by the sounds in another.

One important system design consideration centers on the question of whether the seismic alert message should consist of audible sounds, verbal messages, or a combination of the two.

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[12] Of course, auditory alarms will be completely ineffective with deaf and severely hearing impaired individuals. For these special populations, visual cues will have to be employed. Alarms are also considerably less effective when people are asleep than when they are awake. Research on smoke detector alarms has also shown that children are more likely than adults to sleep through alarms, even loud ones (see, for example, Bruck, 1999).

The literature suggests that other things being equal, verbal messages are superior to non-verbal ones for conveying hazard warning information. Further, as noted earlier, personally-delivered verbal messages are probably the most effective. Warnings that do not incorporate spoken instructions are limited in a number of ways. For example, warning sirens have proven quite problematic in emergency situations (see, for example, Vogt and Sorensen, 1999). Sirens may not actually be heard by everyone who is at risk, or even if they do hear, people may have difficulty understanding what a particular siren alert signifies. Nonverbal signals other than sirens (bells, buzzers, etc.) have the same kinds of deficiencies. They are confusing and difficult to interpret. While they may warn people that a hazardous situation exists, they provide no concrete direction on what people should do next. Tones and sounds can alert people of danger, but verbal messages are superior in their ability to inform and instruct message recipients.

Well-designed vocal warnings have an immediacy and specificity that make them preferable to sound alarms, and this is one reason spoken messages are used so extensively in emergency situations. Verbal hazard warning messages are typically conveyed using a "live" speaker, such as a television or radio broadcaster. However, various types of automated human voice warning devices are also used in emergency situations. For example, McIntyre and Nelson (1989), who focused on the use of automated verbal devices in hospital intensive care units, found that those devices were effective and that they came across as less threatening and less confusing than non-verbal alarms. Because of the very short time frame in which seismic alerts will be issued in the real-time earthquake alert system, there appears to be little choice other than to employ pre-recorded messages that are linked to the warning system. Similarly, because of time constraints, whatever verbal alerts are developed will need to be quite brief, consisting of at most a few words. To reinforce the message, those alerts should be repeated.

A study conducted in England focusing on ways of encouraging people to evacuate from underground metro stations illustrates the complexities involved in encouraging people to take rapid self-protective action, especially when they have not been trained in advance to do so. The study also suggests that in order to be effective, warning systems in public places should employ "layers" of warning messages–alarm sounds, accompanied by verbalizations and (where possible) live instructions that reinforce one another. In a series of field experiments,[13] researchers assessed the effectiveness of five different types of warnings: (1) alarm bells; (2) alarm bells accompanied by evacuation directions given by two staff members; (3) alarm bells accompanied by brief public announcements stating that people should evacuate; (4) alarms accompanied by more detailed recorded verbal instructions broadcast through a public address system, as well as by directions from staff; and (5) alarms and a broadcast of detailed instructions but no direct instructions from staff members. Alarm bells alone evoked virtually no response from metro passengers. According to the researchers who carried out the study "while the alarm was sounding, passengers pursued their normal activities: entering and leaving the station, reading or chatting while waiting for a train, boarding and getting off trains" (Proulx, 1993: 143). In other words, alarms were totally unable to overcome the "normalcy bias." While other approaches were somewhat more effective, only the fourth experimental condition–that is, the alarm, accompanied by specific instructions and reinforced by staff members who were present

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[13] Field experiments differ from laboratory experiments in that they are carried out in "real world" settings–in this case, in underground stations with regular passengers, rather than in a lab setting. Properly controlled field experiments are considered superior to those conducted in laboratories, because they more closely resemble real-life situations.

in the setting–succeeded in eliciting widespread and rapid compliance with evacuation orders (for discussions on this series of experiments, see Proulx and Sime, 1991; Proulx, 1993). As this experiment illustrates, in warning situations of all kinds, the challenge is always to overcome the natural human tendency to normalize and fail to personalize risks.

Another consideration is that although the literature indicates that verbal messages are generally more effective than nonverbal alarms, there can be circumstances in which the latter might actually be more effective and appropriate than warnings containing verbal messages. For example, Edgeworthy (1994) notes that in work settings where there is a high level of background noise, such as industrial facilities, workers can often be reached more effectively by nonverbal signals than by voice alarms. Nonverbal auditory warnings also tend to be used extensively in hospital settings, so as to avoid alarming patients unnecessarily. Although facility management and staff members clearly need to know that an earthquake is occurring, it would almost certainly be counterproductive to automatically issue verbal warnings or instructions in settings such as hospital intensive care units or nursing homes that care for individuals with severe physical or cognitive disabilities, where occupants are unable to perform self-protective actions on their own. This last-mentioned example also raises the question of whether different parts of particular facilities might need to have different types of alarms, or perhaps no alarms at all.

A good deal of scientific research has been conducted on nonverbal alarm systems, and much of this work has applicability both for sound alerts and for warnings using verbal messages. Patterson, whose work focuses primarily on alarm systems for aviation applications, has set out a number of guidelines for designing auditory alarms. Those guidelines include such design considerations as the optimal level of loudness for warning messages, the appropriate methods for designing "bursts of sound" that serve as warning signals, and the use of sound to create an increasing sense of urgency as the warning message continues. Other research on alarm systems has centered on such questions as how to make alarms reliably audible but not so loud and aversive that people seek to deactivate alarm systems, how to make particular alarms distinctive enough from other sounds (including other alarm signals) that message recipients understand immediately what they are hearing, and how to design warning signals that alert people without causing an intense fear reaction. For example, Patterson (1990: 38) argues that to be consistently audible, alarms should be "15dB above the threshold imposed by the background noise on the individual spectral components." Others (see, for example, Edgworthy, 1994) recommend warning sound levels of 15-25 dB above background noise. In order to avoid producing startle reactions among those who hear the alarm, Patterson recommends that warning sounds should start at a relatively low level and then increase in loudness.

As noted earlier, a key challenge facing the proposed system is to heighten risk perceptions and action without causing warning recipients to be overly fearful. The question of how to urge people to act very rapidly without overly alarming or confusing them is central to SCAN system design. Edgworthy, Loxley, and Dennis (1991) and Edgworthy (1994) have conducted research to determine how to design non-verbal alarms that convey an appropriate sense of urgency. They point out that sound intensity, frequency, and tone can be manipulated to communicate heightened levels of danger and the need to act immediately. It is important to note that simply making warning signals loud is not sufficient to communicate urgency, or to bring about an appropriate response. Instead, very loud signals evoke startle reactions, which actually slow down response times. Research has also demonstrated that when alarms are considered intolerably loud by people in a particular setting, they are simply turned off and not turned back on. Instead, the challenge is to immediately attract people's attention and communicate how rapidly they must act, but without using signals that are aversive.

"Urgency mapping" (Edgworthy, 1994) of non-verbal messages is one set of techniques used by alarm system designers for conveying the seriousness of a situation through warning sounds themselves. SCAN designers should pay careful attention to building an urgency component into whatever alarms are deployed, particularly since seismic alert technology should permit more accurate estimation of earthquake severity as shaking continues. For example, it should be possible to design a sequence of warning messages that first communicates that an earthquake is in the process of occurring and tells recipients to take self-protective action, and that then becomes increasingly urgent if the data show that the earthquake is likely to be large and very damaging in a given location.

While the literature is very consistent in stressing the value of verbal alarms, as suggested earlier, it may be that the best strategy for SCAN would be to employ a mix of alarm sounds and verbal alerts, beginning with a sound that listeners can immediately and unambiguously associate with an earthquake, accompanied rapidly (or even simultaneously) by short, precise verbal instructions, which would then be repeated for maximum impact, and by spoken directions from persons in authority in settings where such directions are feasible. If earthquake alert systems currently exist in some settings, and if those systems have proven effective in encouraging timely, appropriate self-protective action, those systems should not be changed.

As the foregoing discussions suggest, SCAN designers will also need to work with users to determine what types of alarm systems would be most appropriate for different facilities and settings. It may be the case that a particular facility, such as a hospital or a utility provider, might elect to use more than one type of warning device within different parts of the same facility.

Before leaving the topic of alarms and devices, it is again important to stress that inducing people to respond to alarms and warnings of all types is a difficult and complex process. The best success with warning systems has occurred in threat situations that are very different from real-time earthquake alerts. In hurricanes, for example, there are typically very long lead times, warning information is accompanied by physical cues (e.g., radar images on television screens, darkening clouds and high winds), detailed warnings are issued repeatedly over a variety of channels by credible warning sources (e.g., the National Weather Service, the National Hurricane Center, the Weather Channel, local news media), and message recipients have time to consult with others and confirm warning information. And as discussed earlier, even with all these facilitating factors, compliance with warnings is still far below one hundred percent.

***Other Significant Issues and Challenges for the SCAN System***

In addition to lessons discussed above, DRC's review of warning system and warning response issues identified a number of concerns that seem particularly relevant for SCAN implementation. Those include likely behavioral responses to false alarms and the "cry wolf" effect; questions about the relative advantages of automated and mediated systems; equity issues associated with warning availability and SCAN system implementation; the reliability of the technologies used in transmitting alerts; and liability concerns. Because of the gaps in the literature, DRC cannot provide definitive answers to many of the questions raised in the sections that follow. SCAN implementation raises a number of complex issues that require further investigation. Some of the concerns discussed here will be addressed in other project tasks, and some will need to be explored through further research and policy analysis.

False Alarms and the "Cry Wolf" Effect

All alert and warning systems seek to achieve high levels of reliability. That is, their goal is to issue accurate warnings in situations in which threats actually exist and people and property actually are vulnerable, and to do so consistently. Alarms should not be set off by triggers other than the threats they are designed to detect, they should issue alerts only for situations in which there is actual danger, and they should do so on every occasion in which that danger is present. The 1989 CDMG study on the feasibility of implementing an earthquake early warning system for Southern California correctly emphasized the importance of addressing problems that could be associated with both false alarms (situations in which alert systems are triggered, but no earthquake occurs or no earthquake damage is experienced at a given site) and missed alarms (situations in which no alert is issued prior to the occurrence of a damaging earthquake or in which an alert is broadcast, but after earthquake impact).

Unreliable alert and warning systems create a host of problems. Responding to warnings when there is in fact no danger can be very costly for individuals, organizations, and communities. Processes that are automatically shut down must be restarted at some cost–and occasionally at some risk–to operators. Organizations pay for unneeded warning responses in the form of unnecessary "down time" and loss of employee productivity. People who undertake protective measures on the basis of inaccurate warnings can also pay a price, in terms of inconvenience as well as psychic costs, such as embarrassment. Similarly, failure to issue accurate and timely warnings in situations in which they are expected can also have negative ramifications for operators of warning systems, in the form of lost credibility, public disapproval, and even legal liability. False alarms are quite widespread in many organizations and industries that rely on alert technologies. Bliss and Gilson (1998), for example, discuss the problems various kinds of false alarms have created for the US military and for the aviation, mining, and health care industries.

Overall warning system effectiveness and the costs associated with false and missed alarms are being considered by other TriNet study investigators. As part of this task, DRC focused primarily on the ways in which system reliability could affect subsequent willingness to undertake protective actions, either by individuals or by organizations taking part in the warning system.

With respect to individual behavior, there is a considerable amount of evidence supporting the notion that repeated false alerts and missed alerts decrease warning system credibility. In his influential book <u>Cry Wolf: The Psychology of False Alarms</u> (1984), which is based on a series of experiments involving warning systems, Breznitz observes that both false alarms (the "cry wolf effect") and failures to warn when dangers actually do materialize undermine the trust people place in warning systems, lessening the chance that they will take self-protective action when subsequent warnings are issued. Interestingly, Breznitz argues that loss of credibility resulting from false alarms is actually greater among persons who initially put more trust in warning systems. He explains this pattern by noting that individuals who consider warning systems highly credible and take threats seriously have invested more psychologically by trusting those systems, and consequently feel more of a loss when danger does not materialize. They then feel a sense of regret, and in order to minimize that regret, they begin to discount the importance of the system. People tend to disbelieve subsequent warnings because they begin to view taking recommended protective action as wasting effort and emotion, and also as involving a loss of face. Breznitz's experimental evidence also suggests that when repeated false alarms are issued that are perceived by recipients as similar to one another, the "cry wolf" or false alarm effect (FAE) is magnified, and conversely, that warnings that seem different from one another have less of a tendency to generate the FAE.

Supplementing Breznitz's explanation of the "cry wolf" effect, which emphasizes the need to keep effort and psychic costs to a minimum, Bliss and Gilson (1998) review five different theoretical perspectives that could offer explanations for why false alarms lead to declines in subsequent adaptive behavior, particularly in situations in which individuals (such as equipment operators) must act in response to alarm signals: signal detection theory, conditioning theory, risk management theory, theories focusing on decision-making under uncertainty, and multiple resource theory.

These same authors also note that as threat-detection systems have become more sensitive, false alarms have proliferated. This trade-off between the ability to detect anomalies in the environment and the risk of issuing unnecessary warnings is very relevant to SCAN: the more sensitively the system is calibrated, the greater the probability that it will produce false alarms. The less sensitive the system, the greater the likelihood that it will fail to provide warnings in situations in which they are actually warranted–another outcome that could damage the credibility of the system.

Data from the UCLA survey indicate that respondents are quite concerned about system reliability, particularly about the FAE. Overall, they seem to express the most concern about how false alarms might affect employee attitudes as well as how these unwarranted alerts might make demands on personnel time. The questions survey respondents raised about false alarms were quite wide-ranging. In response to open-ended questions, for example, respondents specifically voiced concerns over the "cry wolf" effect, noting that too many unwarranted alerts would cause people to ignore subsequent warning messages. They also worried about issues such as employee downtime, employee resentment that might be generated if ongoing organizational activities are interrupted too often by alerts that turn out to be false, and the costs that could be associated with false alarms.

The literature does suggest, however, that negative behavioral effects following false alarms are neither inevitable nor irreversible. Expectations play a role in the manner in which people react to false alarms. For example, in an experiment designed to see whether the "cry wolf" effect can be reduced, Bliss, Dunn, and Fuller (1995) told experimental subjects that 75% of the warnings they would hear would be true rather than false alarms, while in reality only half were. Even though the actual rate of false alarms used in the experiment was higher than they had been led to believe, the expectation of fewer false alarms influenced subjects to continue to respond appropriately. Breznitz (1984; 1985) recommends several strategies for reducing the FAE that have potential relevance for the SCAN system. Those include keeping the threshold for issuing warnings relatively high, in order to avoid requiring people to act in situations where there turns out to be little potential for harm; differentiating warning systems into discrete alert stages, so that it is possible to cancel false alarms before the final stage in which the warning is issued; keeping probabilities associated with warnings low, so as to avoid damaging credibility if threats do not materialize; making sure people understand that warning systems are not infallible; and influencing people to believe that a threat did not materialize because of protective actions they themselves took ("It could have been worse..."). When false alarms are issued, their negative effects can be reduced by specifying which element in the warning system failed, reassuring warning recipients that attempts are continually being made to make the system more accurate, explaining in precise terms the nature of the event that did in fact occur (in cases where a threat materialized but was milder than anticipated), and stressing that the threat that resulted in the false alarm was unique, and that subsequent threats may indeed be quite different–and more accurately detected by the system. Breznitz also stresses that training can help overcome the FAE, as can social norms that encourage self-protective behavior. Potential negative impacts can also be reduced if those issuing warnings stress the extent to which warning compliance contributes to some overall good, such as the welfare of others. When responsibility for issuing alarms is shared among groups of people, individuals who disseminate warnings that later turn out to be unwarranted will suffer less psychic strain and will remain willing to communicate warnings in the future.

Breznitz points out that the negative fallout from false alarms can also be offset by requiring people to respond to alarms, rather than allowing them to decide on their own whether or not to do so. In the case of SCAN, for example, very clear instructions could be given to take immediate action in each and every case when an alert is disseminated, even while recognizing that false alarms could occasionally occur. For groups such as school personnel, students, and emergency personnel, responding to alerts could be made mandatory, rather than optional.

In short, there is some evidence to suggest that even when systems issue alerts unnecessarily, steps can be taken to reduce some of the negative consequences of the FAE for future warnings and to ensure that self-protective actions continue to be undertaken even where there have been false alerts. Both training programs and normative pressures can further help to overcome the tendency to discount alerts following warning system failures.

It should also be emphasized that not all hazards researchers believe the FAE has a significant negative effect on subsequent self-protective behavior, and some even believe that crying wolf can have positive behavioral consequences. Atwood and Major, while taking the position that the "cry wolf" effect should be taken into account in issuing hazard advisories, also note that "[f]ield research support for the 'cry wolf' hypothesis is limited" (1998: 279). Based on his review of the warning literature, Sorensen (2000: 121) argues that [t]he likelihood of people responding to a warning is not diminished by what has come to be labeled the 'cry wolf' syndrome *if the basis of the false alarm is understood* [emphasis added]." Repeated warnings that are not followed by actual increases in danger have been shown to change how people *perceive* warnings and the organizations that issue them, but those false alarms may not actually have a discernable effect on self-protective behavior. Focusing on areas that had been repeatedly threatened by hurricanes that later turned out not to be damaging, Baker (1991) noted that those who had evacuated in response to those false alarms were only slightly less likely to evacuate when subsequently ordered to do so, and that those declines were not statistically significant. In some cases, a false alarm might even function as a type of disaster drill. In research on hurricane evacuation, for example, Riad and Norris (1998) found that having evacuated previously was a more significant predictor of future evacuation behavior than actual disaster experience. These researchers reasoned that having left home in response to prior warnings gives an individual a repertoire of evacuation actions that can be used in future threat situations, and may also increase the individual's sense of control and self-efficacy. In their study of the Mexico City SAS, Goltz and Flores note that the Mexico City school district "considers a possible false alarm as simply another opportunity to drill faculty and students" (1997: 731). Thus, carrying out self-protection measures–even if those measures prove unnecessary–can facilitate learning and the mastery of skills that are transferrable to future situations. If, as the literature suggests, feelings of self-efficacy have a positive influence on willingness to undertake protective actions (see, for example, Mulilus and Duval, 1995; Riad and Norris, 1998; Duval and Mulilis, 1999), then it can be argued that having successfully completed a sequence of actions in response to an earlier earthquake alert should increase feelings of self-efficacy and should encourage future adaptive action, even in cases where taking the action was shown to be unwarranted in some cases.

Dow and Cutter (1998) studied South Carolina residents who had been warned of impending hurricanes that ultimately struck in North Carolina. Earlier false alarms actually had little influence on decisions regarding whether or not to evacuate. In other words, there was little behavioral evidence of a "cry wolf" effect. What did change, however, was the faith people placed in government officials as an important source of evacuation information. Once "unnecessary" evacuation orders had been issued by officials, residents subsequently placed more reliance on other sources, particularly the media, in deciding whether to evacuate. One relevant question that was not directly addressed by these researchers is whether residents took more time to consult different information sources and to confirm warnings than they may have previously.

Research from the literature on longer-term earthquake forecasting suggests that in some cases, missed forecasts and predictions may even turn out to have productive consequences. Citing studies such as those conducted by Mileti and Fitzpatrick on the Parkfield earthquake "prediction" (1993) Atwood and Major (1998) argue that if officials explain reasons for false alarms and missed predictions, that information can increase public awareness and make people more likely to respond to subsequent hazard advisories. Research on the 1990 Iben Browning prediction (see, for example, Farley, Barlow, Finkelstein, and Riley, 1993) also indicates that concern with earthquake hazards remained high in the New Madrid region even after the prediction was withdrawn.[14]

The foregoing discussions have concentrated more on the FAE (that is, on the behavioral consequences of issuing alerts when no event or no damaging event occurs) than on the failure to warn when an event actually does occur, although the latter situation has equally clear implications for system credibility. Clearly, users will question the value of participating in any warning system that cannot provide reasonable assurances that accurate and timely alerts will be issued for events for which the system claims provide protection. This is an area in which TriNet may be particularly vulnerable, since it can provide the kinds of warning times users need for some earthquake events, but not for others. The challenge for TriNet will be to clearly articulate what the system can and cannot do in terms of providing real-time alerts. It is important not to "oversell" the system, because doing so could seriously undermine SCAN's credibility for all types of earthquake events.

Automated Versus Mediated Warning Systems

As noted earlier, warning systems can be classified according to the degree to which they

[14] Even though these studies focus on earthquake forecasts, rather than on warnings, it can be argued that the fundamental social-psychological question remains the same: Does risk perception and willingness to take self-protective action decline when forecasts are not borne out? However, it should also be noted that long-term predictions cannot be equated with short-term alerts along other important dimensions.

are mediated (that is, the extent to which human decision-making intervenes in the issuing of a warning), on the one hand, or automated, on the other. Most warning systems currently in place (and, importantly, most of the systems that researchers have studied) involve a high degree of human mediation and decision-making. Typically, organizations such as the National Weather Service, the mass media, and emergency management agencies receive scientific or other information on an impending threat, and they then go through a process of interpreting that information prior to deciding to disseminate a warning. This is the procedure that is followed, for example, for hurricane and many other types of disaster warnings. For most hazards, in other words, the two phases (scientific assessment and warning dissemination) are separated by an intermediate step involving organizational evaluation and decision making, which occurs prior to communicating the warning to organizations and the public.

In contrast with these mediated systems, there are also a number of examples of existing, prototype, or newly-implemented fully-automated alert systems, both for other hazards and for earthquakes. These systems eliminate the intermediate stage involving human intervention in the warning process and either issue warnings or shut down machines or manufacturing processes automatically. Automated alert systems are in place worldwide for hazards such as tsunamis, dam failures, chemical releases, and lightning strikes (Chironis, 1991). Automated or partially-automated seismic alert systems include Mexico City's Seismic Alert System, the world's only real-time public earthquake warning system, which was installed as a result of the devastating 1985 Mexico City earthquake (Goltz and Flores, 1997; Michael, 1999; Espinosa-Aranda et al., 1998). The Taiwan Rapid Earthquake Information Release System (TREIRS) is a real-time, telemetered accelerograph network deployed throughout Taiwan for rapid reporting of large earthquakes that could function as a warning system but currently does not. Automated seismic shut-down systems include the Japan Railways UrEDAS system that is in place in Japan to stop shinkansen trains under conditions of seismic shaking (Nakamura and Tucker, 1988).

The National Research Council's report on real-time earthquake warning systems (1991) stressed the value of fully-automated warning systems and took the position that human intervention was not only unneeded, but also potentially problematic, in that the involvement of people would raise the possibility of indecision and hesitancy and waste precious time. The authors of the report concluded bluntly that "human intervention in responding to an early warning will reduce the effectiveness of and may actually vitiate the entire system" (1991: 22)[15] Discussions of the proposed SCAN network (see, for example, Kanamori, Hauksson, and Heaton, 1997; Monastersky, 1998) center on its potential as a fully-automated alert or automatic shut-down system, for obvious reasons. The assumption is that the short time period involved in detecting earthquakes, analyzing that data, and then disseminating warnings simply does not allow for an intermediate step involving an organizational assessment of the scientific evidence, or for weighing decisions about how to proceed with issuing a warning. Implementation will only be feasible if the middle step between scientific assessment and warning dissemination (the step involving human information-processing and decision-making) is virtually eliminated and if loss reduction measures (either automated shut-down of equipment or the issuing of warning messages) are undertaken very rapidly upon transmission of information of an earthquake's occurrence.

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[15] It should be noted, however, that the NRC report assumed that fully-automated warning systems would be sufficient to motivate compliance with warning messages and that the panel that produced the report had only one member who had social science training.

DRC's review of the literature has uncovered a number of points regarding fully-automated systems that warrant consideration–and caution. First, the vast majority of empirical studies on the efficacy of warning technologies and warning systems have been conducted on mediated systems, rather than fully-automated ones. As noted above, findings from the warning literature are overwhelmingly based on studies in which intermediaries are involved in interpreting threat-related information, and then deciding on strategies for warning dissemination. Very little is known about the effectiveness of fully-automated systems for protecting life safety and preventing damage and losses. Although published reports make a number of claims about automated hazard-detection, alert, and shutdown systems, those reports contain little empirical data on exactly how those systems actually function in the warning process and to what effect. For example, articles on automated warning systems for tsunamis (Bernard and Milburn, 1991; Walker, 1995) and chemical weapon stockpile accidents (Scott, 1994) focus on the technologies involved in identifying hazards and broadcasting warnings, rather than on the efficacy of those systems for protecting people and property. Their concern is directed toward the scientific assessment phase of the warning process, rather on the overall effectiveness and benefits of those warning systems.

Second, the earlier study by CDMG suggests that potential users of the SCAN system prefer mediated, rather than totally automated systems. Based on data collected from potential users, that report observed that "many respondents appear to be reluctant to delegate a shutdown decision to automated equipment, thereby removing humans from the decision process. In some cases, a false alarm could be extremely costly–and dangerous–to potential users" (Holden, Lee, and Reichle, 1989: 22). The survey conducted by UCLA as part of Task 2 yielded similar findings.

Other research also suggests that in most warning situations technological improvements still have not eliminated the need for human mediation. For example, in describing a pilot "satellite-based emergency alert system" for tsunamis, called THRUST, which was developed for Valparaiso, Chile in the 1980s, Bernard and Milburn (1991) note that while the computer processing for the alert system is automated, "[t]his does *not* imply that there is no human verification that the alarm is real...In our opinion, there is no substitute for the human element in the final decision to evacuate people." In the case of the THRUST system, the tsunami alarm was broadcast to the Tsunami Warning Center in Chile, where staff who were present at the center 24 hours a day were given the responsibility of issuing the tsunami warning to the public.[16]

Use of automated control and shutdown systems can often involve considerable risk, and that is one reason why organizations generally prefer to have human beings "in the loop" and able to override shutdown decisions. For example, following a study on accidents involving automated systems aboard shipping vessels, including an incident in which the freighter Bright Field crashed into the Riverwalk Marketplace in New Orleans because of an automated shut-down system, the Navigation Safety Advisory Council (1999) issued a report recommending that computer-operated vessel control systems should not be configured in ways that inhibit the ability of ship masters to maneuver vessels. Other reports have detailed problems with highly-automated control systems in rail transportation (see, for example, Sheridan, Gamst, and Harvey, 1999).

Thus, while reports like the one issued by the National Research Council (1991) argue

[16] Although the article argued that satellite-based systems could be useful for warning people in rapid-onset disasters, the article focused solely on the threat-detection technology and provided no data on its effectiveness as a system for communicating warnings.

unequivocally for fully-automated seismic alert systems, concerns remain about acceptability to potential users, reliability, safety, and cost effectiveness. As plans move forward for implementing the SCAN system, considerable emphasis will have to be placed on identifying those organizations and settings in which automated shut-down systems are likely to be cost effective, acceptable to users, and safe, as well as those in which their use should be ruled out. Given the very real time constraints involved, what kinds of automated shut-down or safety systems seem warranted? What are the risks associated with their use? How might large processing systems in industrial plants respond to suddenly being taken off line? What costs and risks might be associated with restarting those systems? What levels of reliability would participating organizations expect before agreeing to employ automatic shut-down devices, and to what extent can that degree of reliability be ensured for most earthquakes that could strike the region? What are the tradeoffs involved in interrupting services and processes on an automatic basis in order to protect lives and property? These kinds of questions clearly warrant extensive further study prior to devising an implementation plan for the system.

Equity Concerns in the Dissemination of Alerts

System designers must also seriously consider equity questions that could potentially arise when the system is implemented. Equity concerns are relevant to SCAN because of the possibility that some segments of the population, organizations, and communities may be less well served than others when the system is put into place. It was pointed out earlier, for example, that existing warning systems for many hazards have difficulty reaching low-income, minority, and non-English-speaking populations and that special measures will need to be undertaken to ensure that the SCAN system is tailored to the needs of diverse groups. The same is true for people who may have physical, mental, and cognitive disabilities that might limit their capacity to take rapid self-protective actions. These concerns are likely to be particularly relevant for schools and for health-care facilities–exactly the types of organizations in which the life-safety objectives of the SCAN system are paramount. Special public education and training initiatives will be required to ensure that all members of at-risk populations in the settings in which the system is deployed benefit from whatever additional protection the system may offer.

Similarly, care will need to be taken to make sure that the system does not disproportionately benefit only communities and organizations that are able to invest substantial financial resources in participating in the system. Since SCAN is funded by public monies, and since the expressed intention of the system is to provide a public good for residents of Southern California, equity questions could be raised if the system is implemented in ways that render it affordable for only a limited number of participants.

Relatedly, equity concerns could arise for system participants if, after operating for a time, SCAN fails to deliver on the claims it has made regarding the benefits of participation. For example, if the system fails to live up to its initial promise, organizational participants could feel justified in criticizing SCAN and its operators, or even in requesting reimbursement for expenses they incurred by taking part in the system.

This report assumes that questions regarding equity in the implementation of the SCAN system will be addressed more extensively in the policy analysis and key informant interviews that will be undertaken as part of Task 3. However, such issues warrant mention here because they could affect both the overall credibility of the system and public support for the TriNet program.

Concerns With Overall System Reliability

The reliability of the alert system will inevitably be an extremely important factor influencing both willingness to take part in the system and behavioral responses to whatever alerts are issued. With this point in mind, it is important to note that for *the system* to be seen as reliable and credible, *all components of the system*, including alarm and alert systems employed by participating organizations, must consistently perform as they were intended to function. This will indeed be a major undertaking, particularly since so many factors that could affect system performance are outside the control of the TriNet organization. For example, even if the technologies that are employed by TriNet work extremely rapidly and well, technologies used *elsewhere in the system* could still be a source of system failure. As noted earlier in the discussion of flash flood early warning systems, lack of maintenance and problems with individual components at any point in a warning system can jeopardize its ability to provide timely and reliable warnings–and such problems are very widespread in existing systems. The literature has documented many cases in which alarm systems in facilities have actually been turned off, either to avoid annoying people in those settings or because of operator concern over false alarms. For example, at the Three Mile Island nuclear power plant accident, it was discovered that malfunctioning warning lights had been covered with pieces of cardboard so as to render them less of a distraction (Goldsteen and Schorr, 1991). (For another recent example, see Lipton, 1999, concerning an automated warning system used by a major urban utility).

SCAN could fail to operate as its designers intended for any number of other reasons, including in particular earthquake damage to the warning system itself (National Research Council, 1991). Obviously, considerable emphasis will need to be placed on assessing the vulnerability of system components to earthquake shaking and on taking steps to ensure that those components do not fail in ways that compromise system performance. The transmission of warning signals is dependent not only on the smooth operation of Southern California's seismic networks, but also on lifelines such as telephone and electric power systems. To cite just one example, if an earthquake-induced power outage occurs that affects a facility that is participating in the ISAN, seismic information will not be received and the system will be of no use to that organization.

Along these same lines, it is also important to note that if failures occur in elements of the warning system that are not under the direct control of TriNet, it is still likely that those failures will be attributed to the scientific organizations managing the TriNet system, because they will be perceived by warning recipients as malfunctions in the SCAN system. In other words, by directing and managing the system and by making claims about its effectiveness in providing earthquake alerts, TriNet will likely be blamed and lose credibility as a result of any and all system deficiencies, even those for which it is not directly responsible. This raises questions about the extent to which TriNet agencies will be willing to invest in ensuring reliable system performance and how many resources it would require to do so.

Liability Issues

Addressing questions concerning potential legal liabilities that could arise as a consequence of implementing SCAN is beyond the scope of DRC's expertise. Legal issues associated with SCAN deployment will be addressed more fully as part of Task 3. However, it is still important to at least raise such questions in a report of this kind. In its 1989 report on the feasibility of an early warning system, the California Division of Mines and Geology took the position that the implementation of the system would not be a source of liability for the State of

California, and that problems that might arise if private entities were to contract with the state to operate the system could probably be addressed successfully. Specifically, the report concluded that (Holden, Lee, and Reichle, 1989: 76)

> implementation and operation of an EWS is not likely to be a source of significant liability to the State. This conclusion is conditioned on the following: (1) the limitations of the system are made known to end users, and (2) EWS employees exercise reasonable care in operating the system...The State may also limit liability from damages to end users of an EWS by including indemnification clauses in contracts with end users.

The 1989 report expressed confidence that the liabilities associated with the deployment and management of the system could be contained. It is important to point out, however, that the report was written from the point of view of the State of California as the operator or contractor for an early warning system. While the needs of organizational participants for protection from liability were acknowledged, the question of liability protection for those entities was not explored in depth in the CDMG report.

The National Research Council's report on real-time earthquake monitoring also discussed liability, but only very briefly. That report opined that "[i]f a government agency installs or operates the system, it can rely on the doctrine of sovereign immunity to protect itself, and it could extend that immunity to governmental employees, agents, or suppliers. *This protection would not extend to the general public*" (National Research Council, 1991:44. Emphasis added.)

Both reports express confidence that public entities issuing real-time warnings can be shielded from liability. However, there are precedents indicating that government agencies and other organizations can be sued for actions and omissions related to forecasts and warnings, and moreover that immunity does not extend to all actions public organizations take in their efforts to issue warnings concerning hazardous situations. For example, there have been a number of suits filed against the National Weather Service (NWS) for issuing incorrect forecasts or failing to forecast extreme weather events. Because the Federal Tort Claims Act does offer very broad protection to agencies like the NWS, these suits have generally either been decided in favor of the agency or reversed on appeal. In *Bergquist v. United States* (1994), for example, following a deadly tornado that struck in Illinois in 1990, relatives of tornado victims sued the NWS, claiming that the agency had not interpreted its radar properly and had therefore failed to warn the public. In this case, the NWS argued that its policy of "underwarning" threatened areas (a policy that was intended to reduce the problem of the "cry wolf" effect) was justified, and the agency was shielded from liability on the basis of its ability to make policy decisions regarding its warning systems. In another case, *Brown v. United States*, (1984), fishermen were shipwrecked during a severe storm, leading to a suit against the National Weather Service for failure to maintain an ocean buoy that was supposed to provide information on hazardous weather. The Weather Service was found liable in U. S. District Court, but the ruling was overturned on appeal. The Weather Channel has also successfully defended itself against liability for providing inaccurate forecasts. In *Brandt v. the Weather Channel* (1999), a case in which damages were sought because a fisherman drowned as a result of encountering bad weather, the court took the position that weather forecasts are not "an exact science for which a broadcaster should be held liable."

Despite the broad legal protections offered to governmental agencies when they carry out officially-designated duties, there have been cases in which agencies have been found liable for failure to provide adequate warnings of danger. For example, in *Indian Towing Co. v. United States,* the U. S. Coast Guard was found liable when a boat ran aground because a lighthouse maintained by the Coast Guard had not been operating properly. In this case, the court found that while choosing to operate a lighthouse is a policy decision (and therefore covered by tort claims protection), "the Coast Guard, once it exercised its discretion to undertake to operate a lighthouse, is obligated to use due care to make certain that the light is kept in good working order." In *Tringali Brothers v. United States* (1980), the Coast Guard was also found to be partially at fault in an accident for failing to repair a navigation buoy.

Air traffic control is another area that in some ways parallels the issuing of earthquake alerts. There have been cases for example *Ingham v. Eastern Airlines* (1967) and *Barna v. United States* (1999) in which air traffic controllers were found liable for issuing bad directions. Cases like *Indian Towing* and *Barna* indicate that while government entities do enjoy broad legal protections, those immunities are far from absolute.

The liability issues associated with the operation of SCAN are in fact quite complex. For example, when the system is deployed, will liability protection extend both the users and the operators of the system? To both public and private entities that take part in the system? Could organizations that participate in SCAN be open to lawsuits for actions that they took or did not take in response to warnings? For example, if employees should get injured rushing out of a building when an alert is issued, could they sue their employers for failing to train them properly or frequently enough? Could users initiate lawsuits against SCAN operators if systems do not function as designed? If there are failures in some components of the warning system, could injured parties argue that those operating the system did not exercise sufficient care to ensure system reliability? Could organizations that elect not to take part in SCAN be found liable for not offering the same life-safety protections that participating organizations provide? Does the existence of a SCAN system create an obligation or duty to warn? Are there ways of shielding participants in SCAN from liability through the use of written contracts and agreements? Is additional legislation needed?

A more general issue concerns how a real-time earthquake alert system is likely to be perceived and defined for purposes of legal liability. Will real-time alerts be seen as similar to weather forecasts, or as more closely resembling warnings issued to the public concerning events that have already occurred? Would a malfunctioning system be seen as analogous to an incorrect weather forecast, on the one hand, or to a lighthouse that has been improperly maintained, on the other? In the lawsuit against the Weather Channel that was cited earlier, the court expressed the view that because no contract exists between the Weather Channel and the people who receive and act on its forecasts, the Weather Channel has no contractual duties toward those recipients. But would relationships between TriNet operators and subscribers be seen as more closely resembling contracts? The key point here is that the ways in which real-time warnings are framed for users, the public, and the legal system could well influence exposure to subsequent lawsuits.

**Summary and Recommended Research**

This report has identified issues that need to be addressed in implementing SCAN as a real-time earthquake alert system for Southern California. Throughout the report, an effort has been made not only to summarize findings from research on warning systems and on sociobehavioral aspects of warning response, but also to point out the implications of these findings for the Southern California region and for the types of alerts SCAN is likely to issue. A number of themes have emerged from DRC's literature review. Almost all the research that has been conducted on behavior in response to hazard warnings has focused on situations that are very different from real-time earthquake alert scenarios. Research findings show that in order to act on warnings, individuals must pass through a complicated series of perceptual, cognitive, and behavioral steps, and they make efforts to confirm warning information prior to taking action. Responding to warnings always takes time, and the process can be slowed further by ambiguities in warning messages or in the circumstances surrounding the warning. Like all warnings, SCAN alerts face the challenge of overcoming the "normalcy bias," or the natural tendency to assume that nothing problematic is happening. In virtually all warning situations, even those involving long warning times and very specific directives, there are problems with achieving full warning compliance. Behavioral responses to warnings and alerts are influenced by a range of factors, including hazard, warning message, and warning recipient characteristics. Because of the very short warning times that SCAN would permit and because the alert messages that are broadcast will necessarily be quite simple, there is reason for concern about the extent to which warning recipients will be able to hear, understand, interpret, and act on those alerts.

On the positive side, as a result of extensive public education and training programs, residents of the Southern California study region understand what self-protective measures they should undertake when an earthquake strikes. Research on recent earthquakes suggests that people know what to do and are able to carry out those actions and that by and large their behavior at the time of earthquake impact is appropriate and adaptive. Efforts to implement SCAN can therefore build upon a solid base of public understanding. If a decision is made to go further with SCAN, it will be essential to integrate those efforts with other ongoing earthquake preparedness and training programs in the Southern California region.

The literature on warning systems of all types stresses the importance of developing integrated systems that address not only warning technologies but also the organizational and sociobehavioral aspects of the warning process. Put simply, no matter how sophisticated and reliable, warning technologies will not function effectively unless close attention is paid to involving users in the development of warning systems, to tailoring those systems to their needs, and to understanding the social factors that affect warning system performance and human warning response behavior. This report has used the term ISAN, or interorganizational seismic alert network, to highlight the point that SCAN developers must work closely and on a continuing basis with the organizations and entities that will participate in the system. Such close ties are needed not only to ensure that system designers understand what users need and expect from the system, but also to provide assurances that users are deploying warning technologies and devices appropriately. Like any warning system, SCAN will not operate effectively unless all components of the system–including those not directly under the control of the TriNet program–function properly.

Similarly, SCAN system developers must take into account what the ultimate recipients of warning messages require in order to respond rapidly and appropriately in threatening situations. This includes understanding what actions people can reasonably be expected to undertake given the warning times that are likely for SCAN, what types of alert signals and messages are most likely to motivate action, and what types of education and training will be needed to prepare the public to respond to earthquake alerts. This report has suggested guidelines for the development of alert messages for SCAN, but clearly more work is needed in this area.

In addressing the likely behavioral consequences of false alarms and missed alerts, this report has noted that while false alarms do have a number of negative consequences, research in the hazards area does not support the notion that false alarms always result in failure to comply with subsequent warnings. Strategies can be used to offset the potential negative effects of false alarms. Moreover, acting on even inaccurate warnings can give people and organizations a chance to rehearse what they would do in an actual disaster event. Possible false alarm effects can also be reduced if individuals and organizations are required to respond to all alerts.

This report has also attempted to offer guidance on what kinds of settings appear most appropriate for SCAN deployment, with particular emphasis on how the system can be used to protect life safety. It has been noted, for example, that SCAN is most likely to be effective in settings such as schools, because users of those facilities are familiar with recommended self-protective actions and safe areas, teachers and administrators are clearly in charge and can require students and other building occupants to respond when alerts are issued, and earthquake education and training programs are already in place. A more general point is that in order to be effective, SCAN must build upon existing earthquake emergency response programs. Where such programs are nonexistent or weak, the introduction of SCAN is unlikely to yield additional benefits.

As part of this task, DRC was asked to recommend areas in which future studies are needed. Since so little research has been done on warning situations that resemble those envisioned by the TriNet program, the entire topic of real-time earthquake alerts is ripe for additional research. A number of important research questions are being addressed in other project task areas, including questions about user needs and expectations, the potential for implementing fully-automated alert systems in some facilities, legal liability concerns, funding options for SCAN, and overall management of the system.

With respect to the topics focused on as part of this task, additional research seems warranted on several topics. More work is needed to arrive at more solid conclusions about likely warning response times–including the total elapsed time from initial shaking at the point of fault rupture through the completion of self-protective and mitigative actions–in different types of settings and for different earthquake scenarios. Research is needed to identify the types of warning devices the participants in the ISAN plan to use, how these devices will interface with TriNet technologies, and how effective the overall system is likely to be in motivating self-protective actions and achieving other SCAN goals. Studies are needed to arrive at a better understanding of the most effective and efficient way to convey alert information–that is, through what combination of verbal, auditory, and visual signals–to different populations in different settings. Questions regarding training and educational needs for real-time earthquake alerts must also be addressed in future research. Because the population of the Southern California region is perhaps the most diverse population in the entire country, close attention will need to be paid to developing training and warning dissemination strategies, as well as warning signals and messages, that meet the needs of that population.

This report has synthesized material from a wide range of research sources in order to arrive at conclusions that are applicable to the SCAN system. However, because so little is currently known about social and behavioral responses under very short-term warning conditions, many of those conclusions should more appropriately be viewed as hypotheses–and in many cases as no more than educated guesses. Virtually all the issues that being addressed in this project warrant further systematic research. Based on this review, however, developing a more empirically-grounded understanding of how people and organizations will behave when alert technology becomes available and when actual alerts are issued–and whether these actions make a real difference in terms of lives saved, injuries averted and economic losses contained–are clearly overriding research needs.

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**Appendix I**

# LITERATURE SEARCH TERMS

Advanced warning systems
Aftershocks
Alarm reaction
Automated system
Avalanche alarms/sirens/alerts
Avalanche detecting system
Contingency planning
Cry-wolf alarm, scenario
Detection alarms
Earthquake alarm/sirens/alerts/
signals/sensors
Earthquakes
Emergency communications systems
Emergency preparedness
Emergency response
False alarms
Fire alarms/sirens/alerts/signals/sensors
Flash flood warnings
Flood warnings system
Foreshocks
Habituation
Hazard communication
Hazard function
Hazard warnings
Instantaneous responses
Instantaneous warnings/alerts
Labor warning/sirens/alerts
Landslide/mudslide
Lightning
Magnetic storm warning systems
Motor ability
Natural disasters
Panic response
Prediction/earthquake storm
Risk communication
Risk perception
SCAN
Seismic alarm/sirens/alerts/signals
Seismic strong motion
Smoke alarms
Stimulus response alarms/sirens/alerts/
signals/sensors
Storms
Technological/nuclear/industrial/chemical
Tonal alerts
Tornado alarms/sirens/alerts/signals/sensors
Tornadoes
Tsunami warnings
Trinet
UrEDAS (Urgent Earthquake Detection and
Alarm System)
Volcanic eruption warning
Warning alarms
Warning communication
Warning devices/systems
Warning messages
Warning/risk
Warning/sirens/alerts
Weather forecasting

**Appendix II**

# SELECTED ALERT AND WARNING SYSTEMS REVIEWED BY DRC

| Type of System | Type of Hazard | Warning Period | Published Descriptions |
|---|---|---|---|
| Ground Proximity Warning System | Aircraft Accidents | Not Specified | Loomis, 1982 |
| Minimum Safe Altitude Warnings | Aircraft Accidents | Not Specified | Loomis, 1982 |
| Community Alert Network | All Hazard | Hours (realistically) | CAN, 1999 |
| Disaster Warning Network Real Time Warning System | All Hazard | Seconds - Hours | DWNetwork, 2000 |
| Emergency Alert System (Emergency Broadcast System) | All Hazard | Not Specified | American Meteorological Society, 1997<br>Rogers, 1994 |
| Automotive Headway Maintenance Collision Warning Devices | Auto Collision | Seconds | Dingis, McGhee, Manakkal, Jahns, Carney and Hanley, 1997 |
| Hazardous Release Sirens | Chemical Leak | Minutes | Bowander, Kasperson and Kasperson, 1985 |
| Advanced Warning System | Earthquake | Seconds | High Technology Business, 1989 |
| Mexico Seismic Alert System (SAS) | Earthquake | Seconds | Carmean, Kramer, and Lengyel, 1995<br>INCEDE, 1995<br>Espinosa, Jiminez, Ibarrola, Alcantar, Aguilar, and Inostroza, 2000 |
| Red Systems | Earthquake | Not Specified | Red Systems, 2000 |
| Taiwan Earthquake Early Warning System | Earthquake | Seconds | Wu, Chung, Shin, Hsiao, Tsai, Lee, and Teng, 1998 |
| TRINET Earthquake Warning System | Earthquake | Seconds | TRINET, 2000<br>Eguchi, Goltz, Seligson, Flores, Blais, Heaton, and Bortungo, 1997 |
| Urgent Earthquake Detection and Alarm System | Earthquake | Not Specified (Seconds?) | Yamazaki, 1997 |

| | | | |
|---|---|---|---|
| Audible Smoke Detector | Fire | Minutes | Bruck |
| Non-Audible Strobe Fire Alarms | Fire | Minutes | Bowman, Jamieson, and Ogilvie, 1995 |
| Automated Flash Flood Warning Systems | Flash Flooding | Hours to Minutes | Platt and Cahill, 1987 |
| ALERT (Automated Local Evaluation in Real Time) System | Flood | Minutes to Hours | Farr and Curtis, 1997 Platt and Cahill, 1987 |
| Flood Alert System (Integration of ALERT System with GIS, advanced radar and technologies) | Flood | Minutes to Hours | Hoblit, Vieux, Holder, Bedient, 1999 |
| Lycoming County Flood Warning System | Flood | Hours to Minutes | Schware and Lippoldt, 1982 |
| Olympus Dam Early Warning System | Flood | Not Specified | Fisher, 1997 |
| Tropical Cyclone Warning Systems | Cyclone (Hurricane) | Not Specified | Parker, 1999 |
| Lightning Strike Warning System | Lightning | Seconds | Chironis, 1991 |
| National Lightning Detection Network | Lightning | Not Specified | Global Atmospherics, 1999 Hollel and Lopezl, Vavrek, and Howard, 2000 |
| Railroad/Highway Vehicular Moment Warning Systems | Railroad-Vehicular Crossing Accidents | Not Specified | Longrigg, 1975 |
| Doppler/GIS system Alerts (Final Alert) | Storm, Tornado | Minutes | GIS Frontiers, 2000 Tatom, Knupp, and Vitton, 1995 |
| National Weather Service Severe Storm Alerts | Tornado | Minutes | Aguirre, Anderson, Balandram, Peters, and White, 1991 |
| Non-automated Community Warning systems | Tornado<br>Flash Flood<br>Hurricane | Days to Minutes | Carter, 1979 |
| Seismic Tornado Detection Systems | Tornado | Seconds | Tatom, Knupp, and Vitton, 1995 |

| | | | |
|---|---|---|---|
| Central American Tsunami Warning System | Tsunami | Minutes to Hours | Fernandez, Jens, Kuvvet, 1999 |
| Central Emergency Management Communication Network | Tsunami | Minutes to Hours | Furumoto, Tatehata, and Morioka, 1999 |
| Pacific Tsunami Warning System | Tsunami | Hours | Mansfield, 1988 |
| Project THRUST | Tsunami | Seconds? | Bernard and Milburn, 1991 |
| Tsunami Seismic Switch | Tsunami | Minutes? | Curtis and Adams, 1985 |
| Tsunami Trigger System (Tsunami Seismic Trigger System) | Tsunami | Minutes | Adams and Curtis, 1984 |
| Tsunami Warning System (Seismic Sea-Wave Warning System) | Tsunami | Minutes to Hours | Mooney, 1975 |

Generic Types of Alerts and Alarm Systems

| Type of Alarm | Type of Hazard | Response Time | Citation |
|---|---|---|---|
| Non-Audible "Attention Getting Alarms" (Strobe lights, bed shakers) | Fire<br>Tornado | Minutes | Bowman, Jamieson, and Ogilvie, 1995<br>Wood, 1998 |
| Audible/ Non Verbal Alarms (Sirens, Tonal Alerts) | Not Specified | Not Specified | Edworthy, 1991<br>Sorensen, 1992 |
| Automated Human Voice Alarm Systems | Not Specified | Not Specified | McIntyre and Nelson, 1989 |
| Automated Systems | Earthquakes | Not Specified | Strand, 1997 |
| Non-automated Warning systems | Tornadoes, Flash Floods, Hurricane | Days to Minutes | Carter, 1979 |