Advisory Committee on Earthquake Hazards Reduction
National Earthquake Hazards Reduction Program

September 30, 2019

The Honorable Walter Copan
Director
National Institute of Standards and Technology
100 Bureau Drive
Gaithersburg, MD 20899-1000

Dear Dr. Copan:

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) is authorized by Section 103 of the National Earthquake Hazards Reduction Program (NEHRP) Reauthorization Act of 2004 (Public Law 108-360), 42 U.S.C. § 7704(a)(5), and was established pursuant to the Federal Advisory Committee Act, as amended, 5 U.S.C. App. ACEHR members are non-Federal employees serving three-year terms from research and academic institutions, earthquake-related professions, and state and local governments. We are charged with assessing trends and developments in the science and engineering of earthquake hazards reduction; the effectiveness of NEHRP in carrying out its statutory activities; any need to revise NEHRP; and the management, coordination, implementation, and activities of NEHRP.

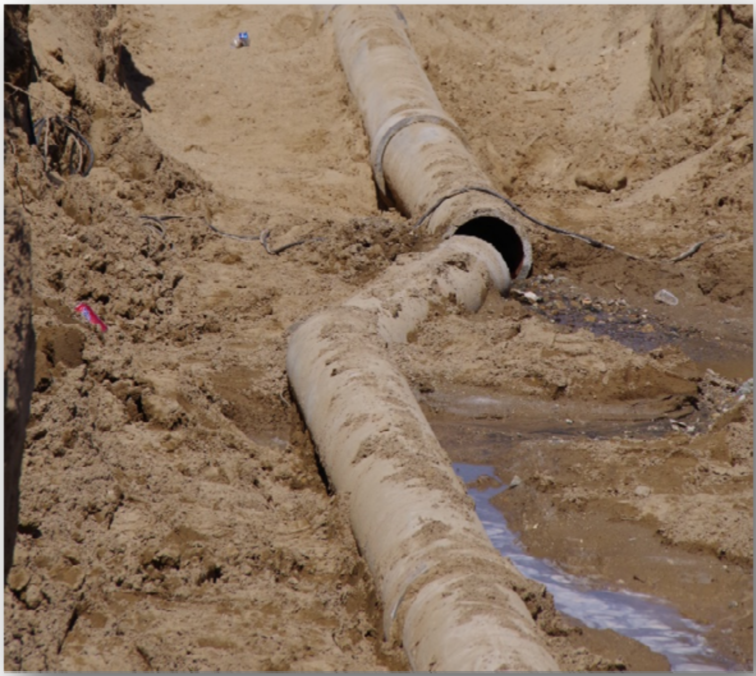
This report is submitted to you, as the Director of the National Institute of Standards and Technology (NIST) and as chair of the Interagency Coordinating Committee on Earthquake Hazards Reduction (referred to in this report as the "Interagency Coordinating Committee"). Our recommendations are also directed to the NIST NEHRP Office (previously NEHRP Secretariat) and the four NEHRP agencies—the Federal Emergency Management Agency (FEMA), NIST, National Science Foundation (NSF), and U.S. Geological Survey (USGS).

Submitted on behalf of the ACEHR members who fully endorse these comments.

Respectfully,

Glenn J. Rix, PhD, PE
Chair
Advisory Committee on Earthquake Hazards Reduction
National Earthquake Hazards Reduction Program

cc: James Olthoff, Associate Director for Laboratory Programs, NIST



Effectiveness of the National Earthquake Hazards Reduction Program

A Report from the Advisory Committee on Earthquake Hazards Reduction

September 27, 2019

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On the cover: Example of damage to subsurface lifeline infrastructure caused by the 2019 Ridgecrest earthquake sequence (Photo courtesy of S. J. Brandenberg, University of California, Los Angeles)

EXECUTIVE SUMMARY

Despite the significant progress toward earthquake risk reduction since the National Earthquake Hazards Reduction Program (NEHRP or Program) was originally enacted in 1977, earthquakes still pose a substantial threat to the United States (U.S.). This threat is exacerbated by numerous emergent social, economic, and political factors that are shaping the nation. The NEHRP Reauthorization Act of 2018 (Act) is an important opportunity to build on the 40-year record of achievement and to reinvigorate efforts to address these dynamic and growing earthquake risks. An important element of the Act is the focus on community resilience, defined in the Act as "the ability of a community to prepare and plan for, absorb, recover from, and more successfully adapt to adverse seismic events." While the Act effectively sets the stage for a revolution in thought and practice, there are many recognizable barriers to action, including complacency, competition for attention with other pressing societal issues, economic inequality, and a potential shortage of scientists and engineers focused on earthquake risk reduction.

ADVISORY COMMITTEE ON EARTHQUAKE HAZARDS REDUCTION

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) provides a biennial assessment of the National Earthquake Hazards Reduction Program as required by the committee charter and Public Law 108-360 as amended. ACEHR is charged with assessing (1) the effectiveness of NEHRP in performing its statutory activities and any needed revisions; (2) the management, coordination, implementation, and activities of NEHRP; and (3) trends and developments in the science and engineering of earthquake hazards reduction.

In addition to their core strengths, each of the Program agencies—National Institute of Standards and Technology (NIST), Federal Emergency Management Agency (FEMA), National Science Foundation (NSF), and U.S. Geological Survey (USGS)—contributes important expertise, knowledge, and technologies to advance toward the goals of earthquake risk reduction and community resilience. However, achieving community resilience will require an integrated, multidisciplinary effort that leverages the strengths of each individual agency and ensures that the whole is greater than the sum of the parts. The leadership and continuity afforded by the Interagency Coordinating Committee on Earthquake Hazards Reduction (Interagency Coordinating Committee), NEHRP Office (previously NEHRP Secretariat), and Program agencies are strong foundations on which to build an integrated program. The updated Strategic Plan as required by the Act is an important opportunity for the Program agencies to develop specific and measurable goals related to coordination, collaboration, and integration among the agencies. Additionally, the Program agencies must be aware, informed, and engaged on the many ongoing, complementary efforts related to functional recovery and community resilience at the local, state, and federal levels.

INTRODUCTION

The National Earthquake Hazards Reduction Program (NEHRP) Reauthorization Act of 2018 (PL 115-307 or the Act) is a significant milestone for the nation. Since NEHRP was originally enacted in 1977, there has been significant progress by each of the agencies (NIST, FEMA, NSF, and USGS) toward advancing the objectives of the Program. As a result, the earthquake community has made considerable strides in understanding earthquakes and reducing earthquake risk through basic and applied research on earthquake processes and earthquake engineering, hazard mapping, improved design and construction practices, stronger building codes and standards, public education, and community-based emergency response programs, among other activities (NRC, 2011; Leith, 2017; references are listed at the end of the report).

THE HAYWIRED SCENARIO

The HayWired Scenario (Detweiler and Wein, 2017) was designed as part of the USGS Science Application for Reduced Risk (SAFRR) project to realistically demonstrate some of the most likely impacts for the San Francisco Bay Area of a magnitude 7 earthquake on the Hayward Fault. This scenario estimates such an event would cause more than \$82 billion dollars in damages, would displace perhaps as many as 400,000 people, could cause 800 deaths and 18,000 injuries, and could lead to loss of water service ranging from weeks to months. The scenario also estimates that fires could follow the earthquake, burning some 52,000 homes and adding an additional \$30 billion in damages. In addition to offering realistic estimates of the myriad consequences of such a large-scale event, the HayWired Scenario also includes actionable information for how these societal threats may be systematically addressed.

The benefits derived from the federal investment in earthquake hazard mitigation far exceed the costs. A recent study (NIBS, 2018) found that federally funded earthquake hazard mitigation grants between 1993 and 2016 saved society \$5.7 billion at a cost of only \$2.2 billion—a benefit-cost ratio of approximately 2.6:1. The savings are due to reductions in loss of service (34%) and reduced damage to property (26%), casualties (19%), and direct and indirect business interruption (21%). This 23-year period was characterized by moderate seismic activity in the U.S.; the benefit that will be realized in future, large earthquakes is likely many times greater.

Despite this progress, earthquakes still pose a substantial threat. All 50 states and several U.S. territories are vulnerable to earthquakes, and nearly half of the U.S. population lives in areas with moderate or major seismic risk. A large earthquake in a major urban center could cause thousands of fatalities and injuries, widespread population displacement and social disruption, and billions of dollars in economic losses.

In addition to the geophysical hazards that drive earthquake risk, there are also emergent social, economic, and political factors that have increased earthquake risks:

- Population dynamics that result in greater exposure of the increasing number of people living in earthquake-prone areas.

- Demographic changes, including factors related to rising economic inequality, the aging of the population, and increasing ethnic and linguistic diversity.

- Aging and deteriorating infrastructure, including numerous existing, seismically deficient buildings, unable to withstand even a moderate earthquake event, and risk of major disruptions due to damage to distributed transportation, water, and energy systems.

- Unwise land-use practices, leading to the development of costly infrastructure, lifelines, and buildings in areas prone to strong ground shaking and ground deformations, concentrating and increasing the potential for major economic losses.

- Cascading failures, attributed to interdependent infrastructure systems, such as electrical power and water distribution systems, that will exacerbate the impacts on communities and may impact regions distant from an earthquake.

- Lack of public awareness, political will, and leadership, yielding non-adoption and non-implementation of state-of-the-art building codes and standards.

- New threats, such as induced seismicity associated with resource extraction, increased risk of ground liquefaction in coastal regions affected by sea level rise, and greater threat of fire following earthquakes associated with climate change.

The Act is an important opportunity to build on the 40-year record of achievement and to reinvigorate efforts to address these dynamic and growing earthquake risks. An important element of the Act is the focus on community resilience, defined in the Act as “the ability of a community to prepare and plan for, absorb, recover from, and more successfully adapt to adverse seismic events.” Each of the Program agencies—NIST, FEMA, NSF, and USGS—contributes important expertise, knowledge, and technologies to advance toward the goals of earthquake risk reduction and community resilience. However, achieving these goals will require a multidisciplinary effort that leverages the strengths of each individual agency and ensures that the whole is greater than the sum of the parts via an integrated program. The NEHRP Office and Interagency Coordinating Committee are key to ensuring that this integration occurs.

THE CASE FOR FUNCTIONAL RECOVERY AND COMMUNITY RESILIENCE

The vision of an earthquake-resilient nation was at the heart of the NEHRP Strategic Plan for 2009–2013. ACEHR also recognized the importance of community resilience as an objective of reducing earthquake risk. The National Research Council of the National Academies, at the request of NIST as the lead NEHRP agency, developed a roadmap (NRC, 2011) to achieve that vision. More recently, the *Community Resilience Planning Guide for Buildings and Infrastructure Systems* (NIST, 2016) and *Research Needs to Support Immediate Occupancy Building Performance Objective Following Natural Hazard Events* (NIST, 2018) are important steps toward the goal of community resilience. In the Act, Congress has recognized the importance of functional recovery performance of buildings and lifeline infrastructure, and community resilience.

> **FUNCTIONAL RECOVERY AND COMMUNITY RESILIENCE**
>
> Functional recovery of the built environment and critical infrastructure can be viewed as an essential or foundational element of community resilience. The definition of functional recovery must extend beyond individual structures to encompass constellations of interdependent buildings or infrastructure components. What might have been construed as a technical issue—for example, designing one new building that will experience minimal downtime after an earthquake—is complicated by the reality that communities include both new and existing buildings that interact with each other through the people who occupy and use them. As increasing numbers of components of the built environment and critical infrastructure are designed, built, or retrofitted to enable their functional recovery, communities should be able to respond to seismic events more effectively—in less time, with fewer resources, and at lower social, economic, and political cost.

The Act effectively sets the stage for a revolution in thought and practice. Current standards for new construction are primarily focused on providing life safety in a large earthquake rather than seismic performance that allows for re-occupancy and functional recovery in a timely manner. This safety-based, rather than recovery-based, approach to the built environment does not explicitly consider the challenges of long-term community recovery in the aftermath of a major earthquake. Community recovery will be further hindered because many of the existing buildings were designed and constructed using less stringent, outdated building codes and standards. Designing new buildings and retrofitting existing buildings to a functional recovery design objective will better align with public expectations regarding seismic performance of the infrastructure, enable our communities to recover more quickly following an earthquake, and ultimately achieve the resilience desired. These efforts will require extensive dialogue and consensus decision making as key stakeholders grapple with both the conceptual (e.g., how to operationalize functional recovery) and the practical (e.g., how to incentivize or require retrofit of existing buildings) aspects of this shift. It will also require a long-term commitment—perhaps decades—as the topics of functional recovery and community resilience evolve from basic research to knowledge transfer to effective implementation in communities throughout the nation. This will take vision, resources, and leadership.

Implementation Challenges

Although a compelling case exists for implementing a functional recovery design objective and striving to achieve community resilience, there are many recognizable barriers to action:

- A major earthquake resulting in significant damage and loss of life has not impacted a heavily populated metropolitan area in the U.S. since the 1994 Northridge earthquake. Complacency regarding earthquake threats is an important barrier to mitigation efforts.
- Over the last generation, other national public policy matters of pressing importance such as those related to terrorism, the border crisis, global trade policy, climate change, and other issues have moved in and out of center stage. It has become increasingly difficult to generate the public interest and political will to focus on low-probability, high-consequence events such as earthquakes.
- U.S. states, territories, and tribal regions are currently confronting an array of natural hazards—most of which are related to weather extremes. Over the last several decades, the U.S. has experienced a dramatic increase in natural hazards losses. In just the last three years (2016 to 2018), the total cost of weather-related disasters exceeded $450

PREVIOUS ACEHR RECOMMENDATIONS ON RESILIENCE

Nearly a decade ago, ACEHR issued a *White Paper on Achieving National Disaster Resilience* (ACEHR, 2010) that recommended that the federal government should:

- set performance standards that can be embedded in building codes;
- be adamant that states adopt up-to-date building codes and include provisions for rigorous enforcement;
- provide financial incentives to stimulate mitigation that benefits the nation; and
- continue to support research that delivers new technologies that encourage cost-effective mitigation, response, and recovery.

These recommendations remain valid today and are consistent with the focus on functional recovery and community resilience in the NEHRP Reauthorization Act of 2018.

billion[1]. These weather-related hazards are often the primary focus of local and state emergency planning efforts, at the expense of earthquake-related concerns.

- Communities across the U.S. experience high rates of economic inequality at the individual and household level (Chetty et al., 2018), which strongly deters many Americans from taking recommended protective actions (e.g., retrofitting a home, securing earthquake insurance) and threatens individuals and families with limited resources with inordinate harm.

- Many of the leading scientists, emergency management professionals, and other practitioners have retired from federal agencies and have not been replaced. This “brain drain” poses substantial challenges to the nation’s efforts to reduce earthquake risks and preparedness for the next major U.S. earthquake.

THE PATH FORWARD

As noted previously, the Act is a significant milestone and an important opportunity for NIST, FEMA, NSF, and USGS to advance the nation toward the goal of community resilience following a large, damaging earthquake. The traditional areas of focus for each agency remain as relevant today as they were in 1977, and this is also a substantial opportunity to continue to lead the way toward a community resilience focus. Agency-specific Program responsibilities are described in Section 5(b) and other portions of the Act that describe the activities and benefits associated with implementing an effective earthquake early warning (EEW) system and establishing and operating the Advanced National Seismic System. To the extent possible, agency-specific activities should also take advantage of recent technological advances. A sampling of technologies that ACEHR considers relevant is presented and described in Appendix A.

ACEHR’s view is that the goal of achieving community resilience will require a more integrated effort by the four Program agencies than has existed previously. A focus on community resilience is necessarily multidisciplinary and will benefit from people in complementary organizational units or agencies working together. Each of the Program agencies—NIST, FEMA, NSF, and USGS—brings important expertise, knowledge, and technologies to the table. Making each other aware of their activities, coordinating their efforts through frequent communication, collaborating on new and innovative programs, and integrating to ensure both efficiency and effectiveness will enable the synergy needed to achieve progress toward the goal of community resilience. Regular meetings of the Interagency Coordinating Committee, which resumed in August 2019, are an essential means for the agencies to collaborate on critical issues in a direct and coordinated fashion. The leadership and continuity afforded by the Interagency Coordinating

[1] *Billion-Dollar Weather and Climate Disasters: Time Series,* https://www.ncdc.noaa.gov/billions/time-series

Committee, NEHRP Office, and Program agencies are strong foundations on which to look forward.

There are two specific requirements of the Act that ACEHR strongly endorses and believes can serve as catalysts to integrate the activities of the Program agencies. Although the NEHRP Strategic Plan for 2009–2013 recognizes that "full Program potential cannot be realized without significant agency interactions" and the agencies agreed on "unified Program planning," there are no specific or measurable goals or objectives intended to ensure that this occurs. The updated Strategic Plan required by the Act should address this deficiency. Second, the Act requires the Comptroller General of the U.S. to perform a comprehensive assessment of the extent to which the efforts of the past 40 years under the auspices of the Program have been applied to public and private earthquake risk reduction. The Comptroller General's review should be used to help develop recommendations to improve the Program, particularly as they pertain to coordination, collaboration, and integration among the agencies.

Additionally, to ensure the flow of ideas in both directions, NEHRP agencies must be aware, informed, and engaged on the many ongoing, complementary efforts at the local, state, and federal levels (e.g., seismic ordinances, state legislation, studies, white papers). An important initiative toward this goal is the committee of experts representing multiple stakeholder groups listed in Section 8(a) of the Act that will be convened by NIST and FEMA to recommend options for improving the built environment to reflect post-earthquake re-occupancy and functional recovery time performance objectives.

RECOMMENDATIONS

1. NIST, FEMA, NSF, USGS, and the NEHRP Office, coordinating through the Interagency Coordinating Committee, should ensure that adequate resources are devoted to developing the Strategic Plan required by the Act and should report to ACEHR on progress toward completing the Strategic Plan. ACEHR is committed to providing review comments on drafts of the Strategic Plan, when appropriate, for consideration by the agencies and NEHRP Office.

2. NIST, FEMA, NSF, and USGS should take ongoing leadership roles in engaging with local, state, and federal agencies and professional organizations to foster consensus on issues related to developing and implementing functional recovery requirements.

3. ACEHR endorses the initiative from the NEHRP Office to structure future ACEHR meetings in a manner that focuses on implementation of the Strategic Plan at a programmatic rather than agency level and recommends that it be implemented as soon as practical.

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APPENDIX A - NEW KNOWLEDGE, TOOLS, AND TECHNOLOGIES

NIST, FEMA, NSF, and USGS will continue to play essential roles in advancing knowledge and technologies to: (1) understand and quantify earthquakes and their damaging effects, (2) engineer buildings and civil infrastructure to be more resistant to earthquake damage, and (3) inform programs and policies for earthquake risk mitigation and recovery that equitably serve an increasingly diverse public and associated social needs. Included in this section are some important opportunities related to new knowledge, tools, and technologies that can be leveraged to achieve these objectives.

Advances in Instrumentation and Monitoring

Information and communication technologies, together with ubiquitous sensors and imaging technologies, will facilitate collection of various types and sources of data that will help to integrate earthquake science and engineering with socioeconomic information to better understand the long-term implications of earthquake damage and disruption on society. Advanced statistical data processing techniques, including artificial intelligence (AI) and machine learning, will help decipher trends that can inform models to develop programs and policies for pre-disaster interventions and post-disaster recovery of societal health and prosperity.

The advent of distributed acoustic sensing with fiber optic cables may allow for unprecedented resolution in recording ground motion. This technology enables spatially continuous recordings of the seismic wavefield and may be effective in environments that are currently difficult to instrument seismically (e.g., ocean basins, continental shelves, heavily urbanized cities). Processing the large volumes of data will be a challenge and likely require new cloud-based sources of storage and computation.

Upgrading existing seismic networks with six-channel sensors that combine high-gain broadband sensors with low-gain strong motion sensors is encouraged so that the entire spectrum of earthquake ground motion can be captured. When possible, older analog short-period instruments should be phased out in favor of modern, digital instrumentation. Methods of noise reduction, such as post-hole deployment, should be encouraged for high-gain instruments.

The development of seismic and geodetic instrumentation that can operate in marine environments (under water) should be encouraged. Near trench geophysical instrumentation is important for understanding megathrust behavior and may be a critical part of subduction zone earthquake early warning (EEW) systems.

The ubiquity of cell phones provides an opportunity for crowd-sourcing earthquake detection. Applications that can detect and transmit information about strong accelerations could be a valuable part of EEW systems if the information from large numbers of cell phones can be quickly pooled together. New pattern recognition algorithms may be required to process data from such heterogeneous, dynamic networks. The cell phone data as well as that from smart buildings, bridges, roads, etc., that are outfitted with vibrational sensors, may also contribute to rapid post-earthquake analysis of shaking-related damage. A key challenge will be quickly recovering and processing such data following a large earthquake.

Advances in satellite and drone imagery technology and processing are enabling high-resolution measurements of fault rupture and ground deformation associated with earthquakes. Imaging by satellite-based Interferometric Synthetic Aperture Radar (InSAR), airplane-mounted Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR), and optical imaging by drones, yield insight into fundamental earth processes, and provide valuable data for mitigation and response. For example, high-resolution measurements of fault rupture inform scientific models of fault behavior, as well as provide engineering design considerations for fault-crossing lifelines. Imaging technologies also provide rapid post-disaster damage assessment data. For scientific, engineering or disaster assessment applications, the most promising technologies require imaging before and after an event for comparison. Thus, development of coordination and collaboration plans between agencies (e.g., USGS and NASA) may be as important as development of the technologies.

Global Navigation Satellite System (GNSS) technology has evolved to the point where near real-time measurements of ground displacement are now possible. This technology can provide an important complement to seismology-based EEW systems in terms of quickly estimating initial epicenters, magnitudes, and finiteness of large earthquakes. Before and after Light Detection and Ranging (LIDAR) surveys can provide important post-earthquake information about regions of high damage/displacement that can enhance emergency response.

High-Performance Computing and Data-Driven Models

Seismic monitoring is a data-rich discipline well-suited for machine-learning applications. In the near future, it is likely that many human intensive tasks associated with detecting and locating earthquakes can be done more efficiently with pattern recognition algorithms. Ultimately, this could lead to more complete and accurate seismicity catalogs, freeing up human capacity for reviewing especially unusual events and higher-order analysis. The high computation load required by new methods of seismic data analysis, and new, non-traditional sources of ground-motion data (e.g., distributed acoustic sensing/fiber optic cables), may require storing data in a cloud environment, where massive, multi-processing algorithms can be harnessed.

High-performance computing, coupled with advances in data-driven scientific and engineering models, offer unprecedented opportunities for high-resolution physics-based simulation of earthquakes and their effects on buildings, transportation systems, and other lifelines infrastructure. By enabling simulations of earthquake scenarios down to the level of individual buildings and other facilities, these capabilities can identify critical vulnerabilities and quantify the benefits of mitigation measures and strategies to help ensure that communities are resilient to earthquakes. Development of the required inventory data on buildings, bridges, and other infrastructure will be facilitated by AI and machine-learning techniques to infer information from drone and satellite images. Images and other data collected during and following earthquake disasters will be important to update and validate regional simulation models.

Advances in Geotechnical and Structural Engineering

Continuing advances in materials science, structural and geotechnical engineering, and construction machinery will enable the design and construction of facilities that are more resistant to earthquake damage. In geotechnical engineering, there continue to be major advances in methods of ground improvement that can reduce ground motion amplification and the risk of liquefaction and ground deformations. These technologies are critical to improve the seismic performance of buried infrastructure because urban regions are growing into sites with marginal soil conditions. In structural engineering, new response modification devices (next-generation seismic isolation systems, dampers and energy dissipators) are critical to make buildings and other facilities more damage resistant and thus able to meet functional recovery expectations to minimize displacement of residents and maintain critical functions to promote rapid recovery from earthquakes.

Social Science Aspects of New Technologies

Changes to the urban landscape and lifelines infrastructure will require new approaches to address earthquake risk assessment and mitigation. Localization of energy generation and water reuse offer both opportunities and challenges for ensuring that these systems can quickly recover after a devastating earthquake. For example, while decentralization of energy generation though wind and solar systems will tend to improve the robustness of the energy grid in aggregate, damage to distributed facilities in earthquake “hot-spots” may lead to localized power outages with long recovery times. Strategies for mitigating this risk may lie more in planning for rapid replacement of damaged facilities, rather than seismically hardening of the entire inventory of distributed facilities. In the transportation arena, future reliance on self-driving cars may present unforeseen disruptions if the systems are unable to adapt as quickly as human drivers to disruptions to transportation networks (due to bridge or roadway damage).

Advances in social science-based approaches to policy development and implementation may be driven by future damaging earthquakes and by implementation of new technologies. For example, the city of Los Angeles recently rolled out the ShakeAlert system for EEW notification within Los Angeles. Messaging and thresholds for ShakeAlert were determined according to best practices in emergency management, where the policy is to avoid excessive alerting to maximize the likelihood of protective action when an alert is broadcast. In July 2019, a few months after ShakeAlert became available to the public, a sequence of magnitude 6.4 and 7.1 earthquakes caused damage in the Ridgecrest area of San Bernardino County. Mild shaking was widely felt within the city of Los Angeles. ShakeAlert did not send out alerts within Los Angeles due to low levels of shaking below the threshold for triggering. Public comments expressed strong desire for ShakeAlert notification prior to any felt shaking, regardless of the need for protective action. The contrast between best practices based on social science research showing that people tend to ignore frequent alerts and the public demand for frequent alerting of low-level shaking, presents a challenge for policymakers.