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DEVELOPMENT OF A FRAMEWORK FOR RESILIENCE RECONNAISSANCE

H. Tremayne [1], M. Mieler [2], D. Martinelli [3], R. Olshansky [4], J. Berger [5]

[1] *Program Manager, Earthquake Engineering Research Institute, heidi@eeri.org*
[2] *Adjunct Assistant Research Engineer of Civil Engineering, Johns Hopkins University (JHU), mmieler@jhu.edu*
[3] *Business Developer Territory Planning E4, Hilti Italia, martinelli.davide5@gmail.com*
[4] *Professor and Department Head, Dept. of Urban and Regional Planning, University of Illinois at Urbana-Champaign, robo@illinois.edu*
[5] *Executive Director, Earthquake Engineering Research Institute, jberger@eeri.org*

Abstract

Earthquake reconnaissance is an approach to rapidly conduct general damage surveys of a region or area following an earthquake to document initial important observations about earthquake impacts, and assess the need for follow-up areas of research. Traditional reconnaissance is typically conducted by a team of earthquake risk mitigation experts who investigate earthquake impacts immediately following search and rescue activites. This paper proposes a unique, new framework that can expand traditional reconnaissance into the realm of community earthquake resilience.

As defined in the proposed framework, the goal of 'resilience reconnaissance' is to understand how an earthquake affects the continuity of different services and functions (e.g., transportation, water, food, shelter, etc.), and how disruption of these vital services and functions impacts different groups within a community. This new approach to reconnaissance will require field investigations that span the dimensions of time, space, and perspective. With respect to time, investigators would attempt to understand the status of a service or function before the earthquake, immediately afterwards, and at subsequent time intervals following the event (e.g., during the response, restoration, short-term recovery, and long-term recovery phases). With respect to space, investigators would attempt to document the availability of a particular service or function across different spatial scales, ranging from an entire region or community to individual districts or neighborhoods, ideally at each time interval of interest. With respect to perspective, investigators would attempt to gain insights on earthquake impacts from a diverse group of stakeholders, including providers of the service (e.g., utility operators, government agencies, etc.), consumers of the service (e.g., businesses, households, etc.), and those entities that regulate or monitor the service (e.g., local, state, and/or federal government). This represents a significant expansion in scope and strategy for reconnaissance.

The proposed resilience reconnaissance framework includes other important concepts and actionable recommendations in the form of research questions, data collection timelines, meeting/interview protocols, and trip planning checklists. A set of implementation recommendations for resilience reconnaissance are also proposed including (1) expansion of traditional reconnaissance team approach, (2) utilization of one organization as a primary coordinator of reconnaissance activities, (3) use of a clearinghouse website for data archival and sharing, and (4) development of an field guide to help invesigators implement the framework. By using this framework, community earthquake resilience can be observed in a thorough and meaningful way that will allow both researchers and decison makers to better understand how vital community services can be improved so that they recover more quickly after future earthquakes.

Keywords: resilience, reconnaissance, framework

1. Resilience Observatory Project Overview and Methodology

In 2012, as part of its National Science Foundation funded Resilience Observatory project (NSF Award #1235573), the Earthquake Engineering Research Institute (EERI) began a project to study how the concept of resilience could be incorporated and studied as a part of earthquake reconnaissance field investigations. The project builds upon the acclaimed multi-decade and multi-disciplinary EERI Learning From Earthquakes (LFE) program by expanding the work of EERI as an earthquake reconnaissance leader to include a new vision and strategy for exploring and measuring resilience of communities after damaging earthquakes [1][2].

The project is lead by an eleven member Resilience Panel, chaired by Laurie Johnson and Rob Olshansky, and supported by EERI staff and interns. The Panel consists of resilience experts from both academia and practice with expertise in structural engineering, social science, urban planning, geography, business interruption, and lifeline networks.

The Resilience Observatory goals are (1) to guide earthquake reconnaissance to maximize resilience learning relevant to the U.S., (2) to conduct post-earthquake reconnaissance efforts focused on seismic resilience, and (3) to develop methods for systematic data collection, archiving, and dissemination of the findings. The major outcome is expected to be an expanded LFE multi-disciplinary reconnaissance approach that will include community resilience observations to enable the most rapid advances in thinking, simulation, and implementation about resilience in the U.S.

Through this project, EERI has supported a large number of efforts, ranging from theoretical exercises (e.g., Los Angeles Shakeout tabletop exercise, development of concept documents) to field studies after recent earthquakes (e.g., Haiti, Chile, Christchurch, Nepal) to tool development (e.g., preliminary draft resilience reconnaissance actionable framework, business resilience survey). Details about many of these activities are included on the EERI Resilience Observatory web page [1].

Given the diverse range of projects undertaken, Mike Mieler was contracted in March of 2016 to develop a set of recommendations for a resilience reconnaissance approach for future earthquakes that can be implemented by EERI in the form of a framework. The project involved reviewing outputs from the various efforts supported by EERI as part of its Resilience Observatory project, interviewing those involved in these efforts to glean best practices, and conducting a pilot study of the proposed resilience reconnaissance approach in Nepal.

This paper describes the concepts behind the resilience reconnaissance framework developed by this project and outlines recommendations for conducting earthquake resilience reconnaissance.

2. Linking Resilience with Reconnaissance

The term "resilience" has developed a myriad of meanings in recent decades with many nuances that allow it to be applied to disaster risk reduction [3],[4]. For example, the National Academies defines it as "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events" [5]. The Rockefeller Foundation defines it as "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience" [6]. Many other prominent definitions have similar structures. Despite a current lack of consensus on the details, resilience is widely regarded as a complex, multi-faceted concept. To help make the concept more actionable within the context of reconnaissance, the following definition is proposed: resilience is the ability of a community to maintain functionality (i.e., a core set of vital services and functions) in the face of a wide range of stresses and shocks.

Earthquake reconnaissance is an approach to rapidly conduct general damage surveys of a region or area following an earthquake to document initial important observations about earthquake impacts, and assess the need for follow-up areas of research. Reconnaissance is typically conducted by a team of earthquake risk mitigation experts who investigate earthquake impacts depending on the earthquake magnitude, location, extent of impacts on the built environment, funding constraints, and many other factors. Observations and findings from these teams support emergency response and recovery activities in the short term and improve the understanding of natural hazards and how to mitigate their impacts in the long term. Reconnaissance teams can consist primarily of members of a single disciplinary or expertise area, or as in the case of EERI teams, they can be multi-disciplinary teams of researchers with a variety of backgrounds from earth scientists and engineers, to social scientists and emergency mangers [2]. Typically this reconnaissance is conducted in the immediate aftermath of an earthquake (within several days to weeks of the earthquake), immediately following any search and rescue phase, to avoid loss of ephemeral data that is often lost when clean-up, recovery and rebuilding begin.

Subsequently, the goal of 'resilience reconnaissance' is to understand how an earthquake affects the continuity of different services and functions (e.g., transportation, water, food, shelter, etc.), and how disruption of these vital services and functions impacts different groups within a community. This new approach to reconnaissance will require field investigations that span the dimensions of time, space, and perspective. With respect to time, investigators would attempt to understand the status of a service or function before the earthquake, immediately afterwards, and at subsequent time intervals following the event (e.g., during the response, restoration, short-term recovery, and long-term recovery phases). With respect to space, investigators would attempt to document the availability of a particular service or function across different spatial scales, ranging from an entire region or community to individual districts or neighborhoods, ideally at each time interval of interest. With respect to perspective, investigators would attempt to gain insights on earthquake impacts from a diverse group of stakeholders, including providers of the service (e.g., utility operators, government agencies, etc.), consumers of the service (e.g., businesses, households, etc.), and those entities that regulate or monitor the service (e.g., local, state, and/or federal government). This represents a significant expansion in scope and strategy for reconnaissance.

3. Need for a Framework

Since resilience reconnaissance is a new concept with a vast potential scope, a framework can be used as a tool that provides guidance for earthquake reconnaissance teams or individual researchers who want to observe, document, and measure community resilience through field investigation and data collection in the months and years following a major earthquake. A framework can provide recommendations on what to observe over time to: (a) understand the overall performance of systems within a community after a major earthquake, (b) identify critical elements that drive system performance, (c) describe interdependences between systems, and (d) determine transformative changes enacted to mitigate possible future disasters. Through the implementation of a framework after future earthquakes, it is expected that the following can be achieved:

- Collection of consistent data across different earthquakes, thus enabling cross-comparison. This comparison would be facilitated by using the framework as a backbone for a data collection repository that could be queried by researchers and other stakeholders.
- Analysis of the observations and data to draw conclusions about the resilience of impacted communities, lessons learned to be shared with other communities, and newly identified research needs. Eventually this may lead to the development of earthquake resilience indicators.

With this impetus, the project created a potential framework that could be used for these purposes. The basic concepts came from the broader resilience panel, while the detailed make-up of the framework was created by EERI Intern Davide Martinelli in 2015. The draft by Martinellli was then further refined by Mieler in 2016. While the current framework still needs refinement and pilot testing to make it more realistic in scope, its components and concepts are outlined in the next section to showcase the development process and support future refinement and development of an implementable version.

4. Resilience Reconnaissance Framework Components

The resilience reconnaissance framework requires the consideration and interaction of many different components. These elements must all be considered to yield reconnaissance outcomes that can effectively observe community resilience. It is important to note that resilience reconnaissance does not need to incorporate the full scope of each area, but each must be considered and incorporated in some way at the outset into any reconnaissance effort.

4.1 Community

A community is an entity with geographic boundaries and shared fate that comprises natural, built, and human infrastructures that influence each other in complex ways (adapted from [3]). See Figure 1. This concept is critical to resilience thus, all resilience reconnaissance observations must be considered at this larger scale and within this context.

Natural infrastructure refers to the environmental surroundings or conditions in which a community exists, and comprises hydrologic, geologic, atmospheric, and biologic features that can enrich, protect, or potentially threaten a community (e.g., rivers, lakes, oceans, mountains, basins, wetlands, faults, climate, watersheds, vegetation, etc.). The built infrastructure includes any physical structure or feature built by humans, including buildings, lifeline systems, and other engineered structures (e.g., hospitals, schools, homes, electric power grids, dams, roads, bridges, etc.). Human infrastructure comprises individuals and groups of people, both formal and informal (e.g., families, businesses, governments, economic sectors, etc.). It also includes the laws, regulations, policies, norms, and customs that govern or influence the behavior of individuals and groups.

These three infrastructures work together through a complex network of interactions and interdependencies to enable a wide range of economic, social, cultural, political, and religious services and functions. Each service and function relies on a unique combination of components and interactions within and between the natural, built, and human infrastructures.

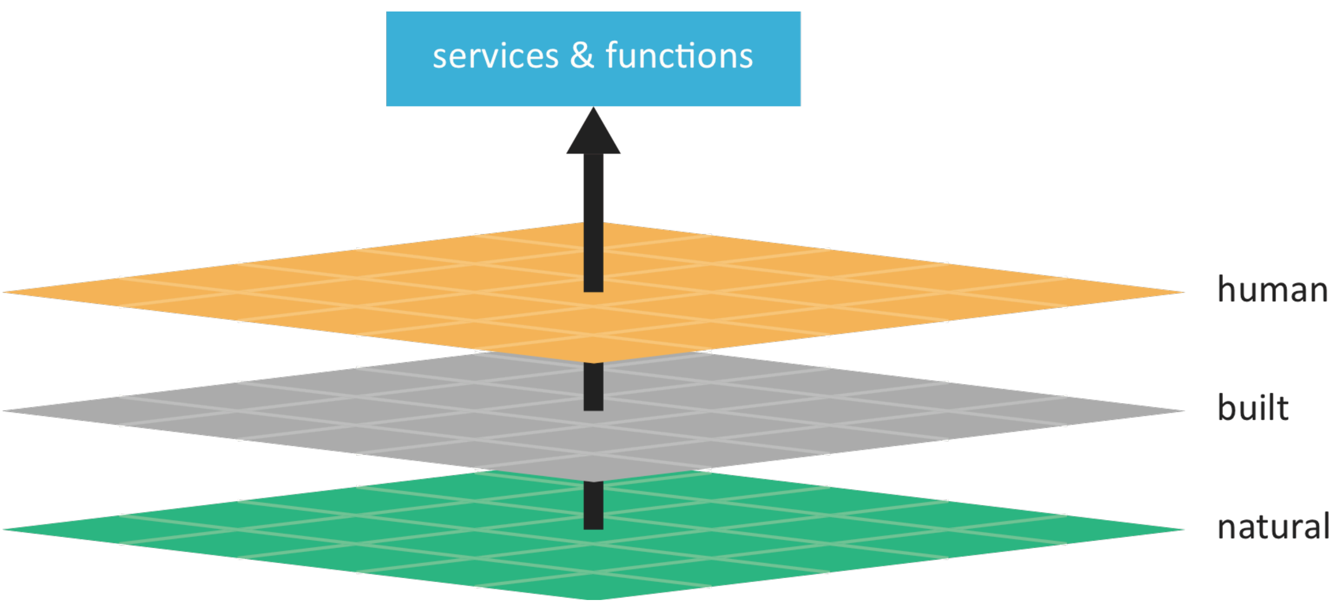

Fig. 1 – Basic Structure of a community (source: Mieler)

4.2 Vital Services and Functions

Vital services and functions refer to those economic, social, cultural, political, and religious services and functions that are essential to the normal functioning of a community, both before and after an earthquake. Examples of these services include (adapted from [7],[8],[9],[10],[11]):

- Energy
- Transportation
- Communication
- Water
- Food
- Sanitation

- Shelter
- Healthcare
- Education
- Economy
- Government
- Public Safety

Note that these examples are strongly connected to the built infrastructure; however services and functions can also include less tangible aspects of a community, including equity, social justice, and community connectedness.

A good example of a vital service is water. A community's water service depends first and foremost on natural infrastructure to provide a supply of water (e.g., rivers, lakes, groundwater, etc.). Various engineered systems, components, and equipment then harvest, treat, transport, and deliver water to residents within a community. These engineered elements, which comprise the water lifeline, often depend on other lifeline systems to successfully operate (e.g., electricity for running treatment facilities, pumps, etc.). The water lifeline is typically managed by one or more organizations within a community (public and private), often with oversight from a government agency. Interactions among these groups affect the provision of water to residents. Additional interactions between the three infrastructures (both within and outside of the community) can also impact water service, including dumping of toxic chemicals by a mining company that contaminates the water supply and changes to local hydrology caused by global warming. Thus the ability of a community to provide safe drinking water depends on more than the quality of its built infrastructure, though this is an important factor.

In many cases resilience reconnaissance can and should adjust its scope to focus on many or just one service. As the example of water service outlines, each service also has many subcomponents so reconnaissance may even just focus on one small aspect of one a vital service. By prioritizing the focus of reconnaissance efforts, more meaningful data and observations will be obtained.

4.3 Time

With respect to time, investigators would attempt to understand the status of a service or function before the earthquake, immediately afterwards, and at subsequent time intervals following the event (e.g., during the response, restoration, short-term recovery, and long-term recovery phases). This represents a significant expansion of the traditional reconnaissance protocol, which typically involves sending a team of investigators to the affected region several weeks after an event, which produces a snapshot of the earthquake impacts immediately afterwards. However, in order to study how the impact of an earthquake evolves over time, multiple trips to the affected region are required. An important component of these trips, in addition to documenting current conditions, involves understanding context (i.e., the condition of the community and its various infrastructures before the earthquake).

4.4 Space

With respect to space, investigators would attempt to document the availability of a particular service or function across different spatial scales, ranging from the entire region or community to individual districts or neighborhoods, ideally at each time interval of interest. This represents a substantial expansion of the traditional reconnaissance scope, which primarily focuses on observing damage to individual components of the built infrastructure (e.g., buildings, pipelines, bridges, transmission towers, etc.). While documentation of damage to individual elements of the built infrastructure is still important, investigators need to understand the broader impact this damage has on the availability of vital services and functions at the neighborhood and community scales.

4.5 Perspective

With respect to perspective, investigators would attempt to gain insights from a diverse group of stakeholders, including providers of the service (e.g., utility operators, government agencies, etc.), consumers of the service (e.g., businesses, households, etc.), and those entities that regulate or monitor the service (e.g., local, state, and/or federal government). These different perspectives would allow investigators to document both the decision-making process for restoring a particular service or function and also the impact that the disruption has on different groups within a community. This represents a new dimension to the traditional resilience scope, as previous reconnaissance missions have not explicitly attempted to obtain multiple perspectives. These multiple perspectives are crucial in gaining a more comprehensive understanding of earthquake impacts. For example, while interviews of utility operators will provide insights into the disruption and subsequent restoration of water service across a community, they will not be able to illuminate the impact these disruptions have on businesses, households, and other customers.

4.6 Data Collection for Resilience Reconnaissance

A critical component for successful reconnaissance is gathering meaningful data and observations. This is especially important for a resilience reconnaissance framework, because many colleagues conducting reconnaissance may not have expertise in resilience concepts and instead may be subject matter experts in their own particular fields of study. Thus, data collection procedures can be facilitated by several framework components described below.

4.6.1 Research Questions

The first of these resources is a set of general research questions that can be applied to any sector or service.

- What was the overall performance of the service?
- Which elements or components proved to be critical to the function of the service and why?
- Did the service have any cascading impacts—positive or negative—on other community systems, services, or functions?
- Were transformative improvements made to the service (or any policies/codes/plans influencing its operation) before the disaster that somehow changed the service and its function in the disaster?
- Are transformative improvements being undertaken in the aftermath of the disaster (or have they already been undertaken) to allow the community to surpass its pre-disaster state/condition?

These general research questions are intended to help users to keep the overarching concepts and characteristics of resilience in mind as they enter the process of data collection. These questions guide researchers into investigating the broader considerations of resilience, especially the interdependencies between sectors. The general research questions above are kept vague so that they are adaptable to the different characteristics of the community.

In addition to these broad questions, specific research questions for different services and sectors can be developed to help researchers consider what types of data should be gathered about baseline pre-earthquake information, damage and functionality, consequences and interdependences, pre-quake mitigation, post-earthquake recovery techniques, resources, and transformative changes. For example, questions for vital service/function of "transportation" are shown below. The transportation service encompasses all the different modes which can be used by customers, workers, businesses during their everyday lives to reach their destinations (roads, railways, subways, ships, etc.). In the questions below, components of transportation are considered all the features which allow a transportation network to be usable and used (physical structures with structural and non-structural components, users, operators and management, etc.).

1. **Baseline data and facts.** What are the modes of transportation in the region? What are the most utilized modes of transportation? What is the pre-quake transportation subsystem capacity? What is the geographical area covered?
2. **Damage and functionality.** What is the level of the transportation subsystem functionality? What damage has been suffered by the transportation subsystem components? How does this damage affect the normal functioning of the network to which it refers? Which transportation components are most critical for each mode of transportation? Is there any damage variation amongst

transportation components across the region, and if so, why? Are there improvements observed or actions taken that increased the restorative capacity of this transportation network? Do the transportation networks satisfy the needs of people and responders after the quake?

3. **Consequences and interdependencies.** Which is the main reason of transportation disruption (bureaucracy, structural/non-structural/contents damage, utilities disruption, employee unavailability, impact of surrounding structures, bad maintenance)? What are the interdependencies between the transportation subsystem and other community systems ("upstream" and "downstream" subsystems)? What are the reasons for delay in restoration?
4. **Pre-quake mitigation.** Did the transportation subsystem management implement pre-earthquake mitigation procedures aimed at increasing redundancy, rapidity, robustness, or resourcefulness? How did these procedures or measures affect operation and functionality of the transportation subsystem? Attempt to document any costs and benefits from these efforts.
5. **Post-quake recovery techniques.** Did the transportation management/owner implement post-disaster techniques in a timely fashion? If not, why? Attempt to document any costs and benefits from these efforts.
6. **Resources.** What were the total resources used in the recovery effort? Attempt to document the flow of financial resources used to facilitate recovery.
7. **Transformative changes.** What changes occurred that surpassed or differed from the pre-disaster state? Were recovery barriers identified then addressed through preparedness policies or actions that mitigate negative impacts of future disasters due to transportation failures?

These specific research questions can supplemented by a list of possible measures, data, and examples that are useful to answer the questions, however users should rely on their own expertise and the earthquake characteristics to identify additional data sets to gather. Some examples of possible data or measures to answer the question #4 about prequake mitigation for transportation services, include:

- Substitution, and/or retrofitting of network physical components located nearby fault areas.
- Implementation of evacuation drills.
- Installation, protection, and functionality of back-up systems in the transportation facilities (emergency power, independent communication network, water and waste tank, dual fuel boilers, etc.).
- Development of a local or regional emergency response or recovery plans, (i.e. transit plans to assign trains, buses to their most productive use; pre-identification of emergency park-and-ride locations).
- Reducing reliance of transportation facilities on external resources that can be impacted by earthquakes, i.e. Closed-loop water (rainwater harvesting, on-site wells); on-site renewable energy or microgrids; low-use plumbing fixtures; passive heating/cooling/lighting strategies.
- Ensure availability of liquid funds and financial resources to make repairs quickly and avoid dependency and delays from financing.
- Contractors and engineers retained on an annual basis to perform post-earthquake repairs.
- Protection measure against geological hazard (landslides stabilization, re-shaping of the layout to increase redundancy in influential areas or avoid areas prone to flooding and liquefaction).
- Implementation of earthquake improvements along with regular upgrades and maintenance of the network.
- Regular maintenance, signage, and creation of redundancy for stairs and egress paths.

- Instrumentation to monitor earthquake impacts enabling quick decision for continuation of operation (diagnostic and damage detection technology).
- Mitigation against spill of hazard material, i.e. fuel tanks, ships with hazardous loads, etc.

4.6.2 Timelines

Data collection timelines can be included in the framework to provide guidance on data collection time windows for the specific research question data examples. The data collection timelines in this framework are based on three general response phases: response, restoration, and recovery, and include idealized time ranges for these phases based on a significant earthquake. Framework users must recognize that (1) post-recovery phases have a varying duration depending on many factors, (2) data can become available at different times for different events, (3) one vital service or function can be in one phase while another service can be in a different phase, (4) various components within a single service may be in different phases, and (5) that some types of data require repeated collection over time. Thus, the timelines are intended only as guides so each data gathering effort should carefully consider and customize the timelines and data collection frequency based on the specific situation.

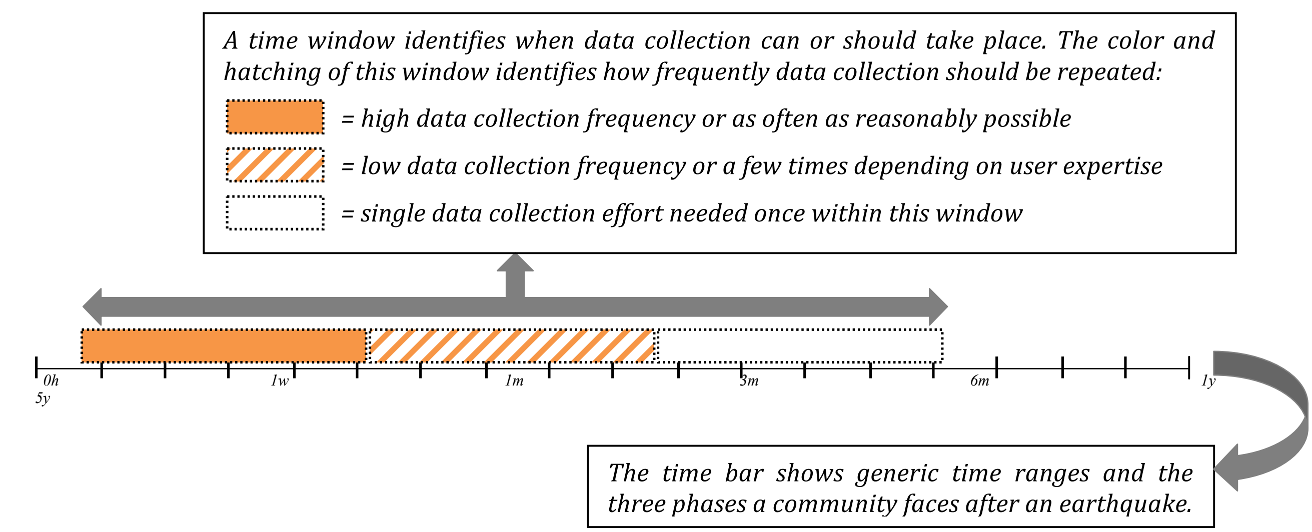

Fig. 2 – Example Timeline

As shown by the example timeline above, the bar chart is nonlinear. The leading thread is that during the response phase, which may takes several days to weeks, high intensity data collection would begin as soon as practical over the first weeks after the earthquake. On the other hand in the recovery phase data collection essential to resilience understanding is less frequent.

4.6.3 Meetings and Interview Protocol

Valuable data about earthquake resilience can be obtained from stakeholders via interviews and meetings. To ensure data from these interviews can be gathered efficiently and compared between events, a sample interview protocol has been developed. The protocol includes questions on topics including opening questions, pre-event overview, pre-event functionality, initial damage and functionality, current functionality, restoration and recovery, and closing questions. Example of questions for pre-event functionality and initial damage/functionality are shown in Table 1.

Table 1 – Sample Interview Protocol Questions

Pre-event Functionality Questions *Attempt to document the state of the system before the earthquake. These questions only need to be asked during the first reconnaissance trip.*	
1	Please describe the metrics used to monitor or assess system functionality on a daily basis (e.g., gallons of water delivered, vacancy rate, average rent, emergency room wait time, business failure rate, unemployment rate, classroom size, student-teacher ratio, etc.)
2	Using the above metrics, please describe the state of the system in the months before the earthquake
Initial Damage and Functionality Questions *Attempt to document the earthquake impacts and the state of the system immediately after the earthquake. If possible, link these observations to earthquake shaking intensity recorded within the selected region. These questions only need to be asked during the first reconnaissance trip..*	
1	For the infrastructure and equipment identified previously, please describe the damage caused by the earthquake.
1a	For building clusters, if there are a large number of buildings try estimate the number in each damage category (e.g., red, yellow, green tags; number collapsed; minor, moderate, severe damage); if there are a small number of buildings try to document damage to specific buildings.
1b	For lifeline systems, try to document failures of major equipment and structures.
2	For the interdependencies identified previously, please describe if any impacted the functionality of the system.
3	Using the metrics identified previously, please describe the state of the system immediately after the earthquake, including:
3a	For building clusters: the percentage of buildings not usable (due to damage, interdependencies, or both)
3b	For lifeline systems, the percentage of service area disrupted and the location(s), if possible

4.7 Trip Planning Checklist

A trip planning checklist has been created to support teams traveling into earthquake impacted regions to conduct resilience reconnaissance. It has been designed to help team members successfully observe and record community resilience after damaging earthquakes by reminding them of important steps and actions that they should take. The checklist draws from best practices developed as a part of EERI's LFE program [2] and has three major sections: Before the Trip, During the Trip, and After the Trip. For example, the 'Before the Trip' checklist contains the following eight topics, each of which have action steps for consideration.

- Develop situational awareness
- Establish tentative plan
- Assemble team
- Understand the context

- Develop data plan
- Identify local contacts
- Establish tentative schedule
- Prepare important documents

Each of these topics has several steps. For example, the "identify local contacts" topic includes the following five steps for consideration:

1. Identify local "gateway" organizations whose support would open doors to important stakeholders or sources of data
2. Identify local individuals and organizations to meet with or interview while in the field
3. For each focus area, try to capture a diverse range of perspectives (i.e., service providers, consumers, regulators)
4. Use local host to facilitate introductions to local individuals and organizations and, if possible, set up meetings before arriving in the field
5. Develop strategies for engaging local contacts after the trip

While every trip may not need each step, the checklist provides important items for teams to consider and ensure successful planning and post-trip dissemination.

5. Recommendations for Implementation of the Framework

A framework with the components described above can and should be implemented after future earthquakes. In this regard, the following four recommendations should be considered by organizations that conduct earthquake reconnaissance and want to expand their scope into observing community resilience.

1. Expand the scope of future reconnaissance to focus on documenting how earthquakes impact vital community services and functions across the dimensions of time, space, and perspective. Continue to quickly send teams into the field after major earthquakes but prioritize follow-up studies as well. Instead of sending a large team immediately after an earthquake, consider supporting several smaller teams that are deployed over time.
2. Utilize one organization as a primary coordinator of reconnaissance activities (i.e. EERI). This will allow smaller teams with more narrow focus areas to coordinate and collaborate with other organizations and individuals in the field so that duplication of focus is avoided and a diverse area of vital services are covered. This will allow the broader earthquake risk reduction community to learn from many teams in an organized way. The individual investigations, when considered together, will yield a detailed record of community resilience that addresses the dimensions of time, space, and perspective.
3. Use earthquake clearinghouse websites to record and document the new resilience reconnaissance observations over time and encourage contributions from many teams.
4. Expand the resilience reconnaissance framework concepts described in this paper into easily actionable documents like a "field guide" to serve as a resource for field investigators conducting resilience reconnaissance after damaging earthquakes.

EERI's LFE Program plans to work on the implementation of these recommendations in the coming years.

6. Conclusions and Next Steps

The components of the framework and the implementation recommendations currently exist in two different documents that still need to be merged into a final framework, however these concepts are the result of several years of consideration by a expert team of EERI members. With proper planning, the proposed framework can be used to conduct reconnaissance in a new, exciting way that expands the time, scale, and perspective of traditional reconnaissance into the realm of community resilience. Observing resilience in a thorough and meaningful way will allow the research community to better understand how vital community services can be improved to recover more quickly after future earthquakes.

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