



DEVELOPING THE ‘PEOPLES’ RESILIENCE FRAMEWORK FOR DEFINING AND MEASURING DISASTER RESILIENCE AT THE COMMUNITY SCALE

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ABSTRACT

The objective of this research was to establish a holistic framework for defining and measuring disaster resilience for a community at various scales. Seven dimensions of community resilience have been identified and are represented by the acronym **PEOPLES**: **P**opulation and Demographics, **E**nvironmental/Ecosystem, **O**rganized Governmental Services, **P**hysical Infrastructure, **L**ifestyle and Community Competence, **E**conomic Development, and **S**ocial-Cultural Capital. The proposed *PEOPLES Resilience Framework* provides the basis for development of quantitative and qualitative models that measure continuously the resilience of communities against extreme events or disasters in any or a combination of the above-mentioned dimensions. Over the longer term, this framework will enable the development of geospatial and temporal decision-support software tools that help planners and other key decision makers and stakeholders to assess and enhance the resilience of their communities.

Introduction

In recent years, the concept of resilience has gained attention recognizing the fact that not all threats or disasters can be averted. Indeed, societies are turning their attention to efforts and ways that can enhance the community resilience of entire communities against various types of extreme events. Resilience is clearly becoming increasingly important for modern societies as states come to accept that they cannot prevent every risk from being realized but rather must learn to adapt and manage risks in a way that minimizes impact on human and other systems. While studies on the disaster resilience of technical systems have been undertaken for quite some time, the societal aspects and the inclusion of various and multiple types of extreme events are new developments. In this regard, countries and states around the world are increasingly debating ways to enhance community resilience.

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At this time, there is no explicit set of procedures in the existing literature that suggests how to quantify resilience in the context of multiple hazards, how to compare communities with one another in terms of their resilience, or how to determine whether individual communities are moving in the direction of becoming more resilient in the face of various hazards. Considerable research has been accomplished to assess direct and indirect losses attributable to earthquakes, and to estimate the reduction of these losses as a result of specific actions, policies, or scenarios. However, the notion of resilience suggests a much broader framework than the reduction of monetary losses alone. Equally important, in addition to focusing on the losses produced by multiple hazards, research must also address the ways in which specific pre- and post-event measures and strategies can prevent and contain losses (Alesch, Arendt, & Holly 2009; Bruneau et al. 2003).

Resilience (R) may be defined as a function indicating the capability to sustain a level of functionality or performance for a given building, bridge, lifeline network, or community, over a period defined as the control time T_{LC} . The control time is usually decided by building owners or society, for example, and corresponds to the expected life cycle or life span of the building or other system. *Resilience* is defined graphically as the normalized shaded area underneath the functionality function of a system, defined as $Q(t)$. $Q(t)$ is a non-stationary stochastic process, and each ensemble is a piecewise continuous function as shown in Figure 1:

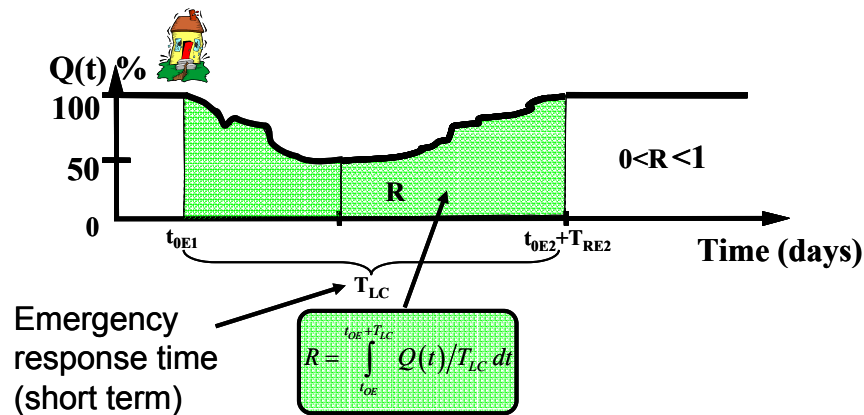


Figure 1 Schematic Representation of Community Resilience

where $Q(t)$ is the functionality function of the region considered. The functionality is the combination of all functionalities related to different facilities, lifelines, etc.

The Seven Dimensions of Community Resilience

Disaster resilience is often divided between *technological units* and *social systems*. On a small scale, when considering critical infrastructures, the focus is mainly on technological aspects. On a greater scale, when considering an entire community, the focus is broadened to include the interplay of multiple systems – human, environmental, and others – which together add up to ensure the healthy functioning of a society. At the community level, the human component is central, because in the case of a major disruptive event, resilience depends first on the actions of *people* operating at the individual and neighborhood scale (Figure 2). Community

resilience also depends heavily on the actions of different levels of government and its agencies at the local and regional scales when a disruptive extreme event occurs (see the geographic scales I and II in Figure 2).

In order to emphasize the primary role of the human system in community sustainability, we are using the acronym “PEOPLES.” This nomenclature highlights both the physical and environmental assets as well as the socio-economic-political/organizational aspects of a particular community (see Figure 2).

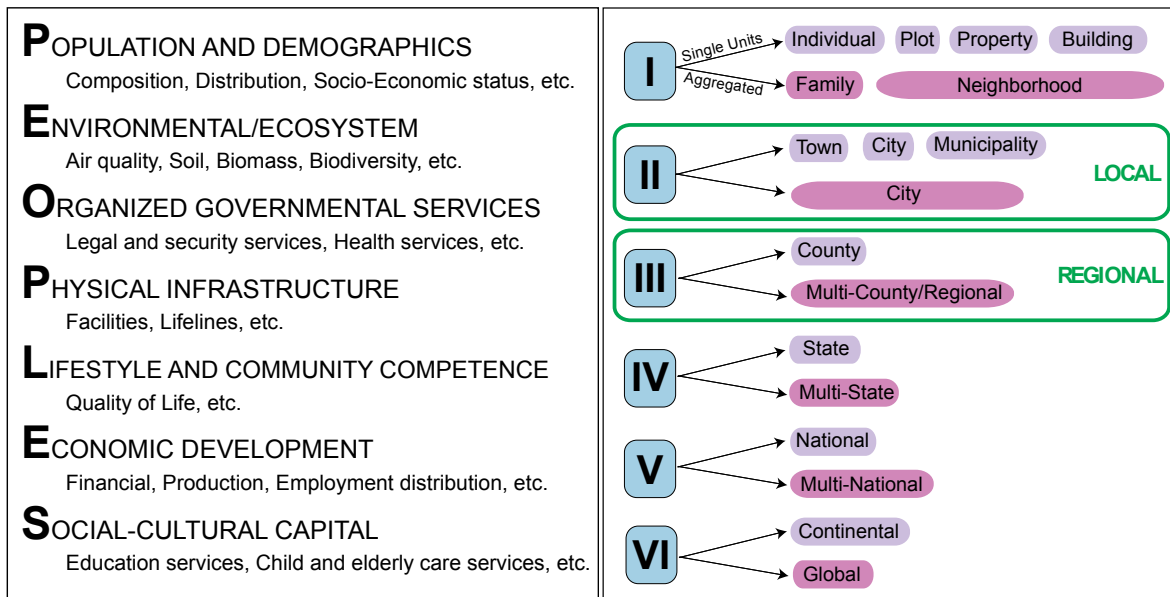


Figure 2 The *PEOPLES Resilience Framework* and associated Geographic Scales

The *PEOPLES Resilience Framework* is built on and expands previous research at MCEER linking several previously identified resilience dimensions (technical, organizational, societal, and economic) and resilience properties (r^4 : robustness, redundancy, resourcefulness, and rapidity) (Bruneau, et al. 2003). *PEOPLES* incorporates MCEER’s widely accepted definitions of service functionality, its components (assets, services, demographics) and the parameters influencing their integrity and resilience.

The *PEOPLES Resilience Framework* defines components of functionality using a geospatial-temporal distribution within its influence boundaries. Interdependencies between and among these components are key to determining the resilience of communities. *PEOPLES* enables the use of various community resilience indices that integrate over space and time the system functionality and services of a community in a landscape setting. In this particular dimension, historical and continuously gathered information through remote sensing and Geographic Information Systems (GIS) will play a major role in assessing the resilience of all integrated systems and feed a predictive resilience model. Resilience can be considered as a dynamic quantity that changes over time and across space. To be able to expand the assessment of resilience to a community and landscape perspective, the *PEOPLES Resilience Framework* is

based on basic community organizational units at a local (neighborhoods, villages, towns or cities) and regional scale (counties/parishes, regions, or states) (see Figure 2).

The following describes briefly each of the seven dimensions associated with the *PEOPLES Resilience Framework* and some potential indicators. The dimensions are neither orthogonal nor synonymous. While they are discussed as distinct dimensions and while we anticipate developing measures that are often independent, the nature of community resilience is such that interdependence between and among the dimensions is expected. The potential indicators are intended to be illustrative rather than exhaustive. Importantly, the indicators that are identified are those that may be used to describe a community and its resilience at any time, and not simply post-extreme event. Ultimately, the value of the *PEOPLES Resilience Framework* is that it (a) identifies the distinct dimensions and related key indicators but also (b) aggregates the dimensions in ways that reflect community realities.

The *PEOPLES Resilience Framework* requires the combination of qualitative and quantitative data sources at various temporal and spatial scales, and as a consequence, information needs to be aggregated or disaggregated to match the scales of the resilience model and the scales of interest for the model output.

1. Population and Demographics

A measure of functionality of population and demographics Q_p within a given community could be quantified by using the social vulnerability index (SoVI) proposed by Cutter (1996). Social vulnerability (a counterpart of social resilience) is defined as the inability of people, organizations, and societies to withstand adverse impacts from multiple stressors to which they are exposed. These impacts are due in part to characteristics inherent in social interactions, institutions, and systems of cultural values. Social vulnerability is a pre-existing condition of the community that affects the society's ability to prepare for and recover from a disruptive event.

This dimension of vulnerability can be measured using a social index that describes the socioeconomic status, the composition of the population (elderly and children), development density, rural agriculture, race, gender, ethnicity, infrastructure employment, and county debt/revenue. The social index described is based on Cutter's Hazards-of-Place Model of Vulnerability framework that integrates exposure to hazards with the social conditions that make people vulnerable to them (Cutter 1996; Cutter et al. 2000). High SoVI indicates high vulnerability, and conversely, low SoVI indicates low vulnerability. Analytically, functionality of population can be given as follow:

$$Q_p(\mathbf{r}, t) = 1/(f_1 + f_2 + f_3 + f_4 + f_5 + f_6 + f_7 + f_8 + f_9 + f_{10} + f_{11}) \quad (1)$$

where f_1, f_2, \dots, f_n are the 11 independent factors considered. Among the 11 independent factors are socioeconomic status, elderly and children, development density, rural agriculture, race, gender, ethnicity, infrastructure employment, and county debt/revenue. Additionally, qualitative and quantitative measures about population and demographics from the US Census database are an essential component for this dimension of the *PEOPLES Resilience Framework*. Key

indicators include educational attainment, marital status, annual income, age, gender, race/ethnicity distribution, and other data that describe and differentiate the focal population.

2. Environment/Ecosystem

Ecological or ecosystem resilience is typically measured by the amount of disturbance an ecosystem can absorb without drastically altering its functions, processes and structures (Gunderson 2000), or by the ability of an ecosystem to cope with disturbance. In the context of the *PEOPLES Resilience Framework*, environmental and ecosystem resources serve as indicators for measuring the ability of the ecological system to return to or near its pre-event state.

The Normalized Difference Vegetation Index (NDVI) is a simple numerical indicator calculated from satellite-derived remote sensing imagery that analyzes the density of green vegetation across a region. This NDVI is used in the framework as a proxy for ecosystem productivity and is calculated using the red (Red) and near infrared (NIR) absorption bands:

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}) \quad (2)$$

NDVI correlates strongly with above-ground net primary productivity (NPP) (Pettoirelli 2005, Olofsson et al. 2007, Prince 1991), which measures biomass accumulation and can be an indicator of ecosystem resilience. Simoniello et al (2008) characterized the resilience of Italian landscapes using a time series to calculate NDVI trends, and Diaz-Delgado et al. (2002) used NDVI values derived from Landsat imagery to monitor vegetation recovery after fire disturbance.

Building on previous research, the *PEOPLES Resilience Framework* quantifies ecological resilience through a comparison of stable-state NDVI trends to post-disturbance NDVI trends to determine differences in ecosystem productivity across spatio-temporal scales. NDVI is applicable for quantifying ecosystem structure following disturbances such as fire, flooding, and hurricanes. In other types of disasters such as terrorist attacks or blizzards, vegetation density and ecosystem structure may not be altered. In these instances, ecological resilience quantification through NDVI would be negligible and other indicators would be more relevant.

3. Organized Governmental Services

In contrast to the more or less spontaneous individual and neighborhood responses to extreme events, organized governmental services are designed to allow an orderly response. Organized governmental services include traditional legal and security services such as police, emergency and fire departments and in extreme cases, the military. In this dimension, we also include the services provided by public health and hygiene departments as well as cultural heritage departments. Each of these organized government services plays a key role in sustaining communities both before and after extreme events. A good example of the necessity of a well-functioning government may be seen in the devastating January 12, 2010 earthquake in Haiti. In

the aftermath, the news media has reported a lack of government services and orderly control, and a general perception that the government is not in a position to help its people (Schwartz 2010).

Key indicators for this dimension include the number of available response units and their capacity. Population and Demographic numbers would be used to normalize the number and capacity of these services. In addition to assessing the availability of government services in terms of personnel and equipment, this dimension also includes an evaluation of emergency preparedness planning. For example, surveys may reveal the extent to which organized government services have developed MOUs and other types of mutual aid agreements, and the extent to which various organized government services participate in emergency and evacuation drills and table-top exercises (Tierney 2009).

4. Physical Infrastructure

The physical infrastructure dimension incorporates both facilities and lifelines. Within the category of facilities, we include housing, commercial facilities, and cultural facilities. Within the category of lifelines, we include food supply, health care, utilities, transportation, and communication networks.

In terms of housing, key indicators may include proportion of housing stock not rated as substandard or hazardous and vacancy rates for rental housing (Tierney 2009). In terms of communication networks, key indicators may include adequacy (or sufficiency) of procedures for communicating with the public and addressing the public's need for accurate information following disasters, adequacy of linkages between official and unofficial information sources, and adequacy of ties between emergency management entities and mass media serving diverse populations (Tierney 2009).

5. Lifestyle and Community Competence

Norris et al. (2008) describe community resilience as “a metaphor, theory, set of capabilities and strategy for disaster readiness” (p. 127). One of the capabilities they discuss is community competence. Community competence is essential to community resilience in the same way that individual competence is essential to personal hardiness. Community competence deals with community action, critical reflection and problem solving skills, flexibility and creativity, collective efficacy, empowerment, and political partnerships (Norris et al. 2008).

This dimension reflects the reality that community resilience is not simply a passive “bouncing back” to pre-disaster conditions (Brown & Kulig 1996/97) but rather a concerted and active effort that relies on peoples' ability to creatively imagine a new future and then take the requisite steps to achieve that desired future. It captures both the raw *abilities* of the community (e.g., ability to develop multifaceted solutions to complex problems, ability to engage in meaningful political networks) and the community's *perceptions* of its ability to effect positive change. Communities that collectively believe that they can rebuild, restructure, and revive

themselves are more likely to be persistent in the face of environmental, governmental, and other obstacles.

Quality of life surveys often reveal whether members of a given community are committed to the community and willing to engage in the activities necessary to sustain the community, regardless of whether a disaster strikes. Less soft general indicators of community competence may include measures of migration, measures of citizen involvement in politics, and others. Disaster-specific indicators may include the comprehensiveness of community warning plans and procedures, and the extensiveness of citizen and organizational disaster training programs (Tierney 2009).

6. Economic Development

For our purposes, economic development includes both the static assessment of a community's current economy (economic activity) and the dynamic assessment of a community's ability to sustain economic growth (economic development). As described in the RICSA Poverty Project (2010), economic *activity* takes into account the supply of labor for the production of economic goods and services, which includes "all production and processing of primary products whether for market, for barter or for own consumption, the production of all other goods for the market and, in the case of households which produce such goods and services for the market, the corresponding production for own consumption." Economic *development* addresses the future and growth. It addresses a community's efforts to increase its "productive capacities ..., in terms of technologies (more efficient tools and machines), technical cultures (knowledge of nature, research and capacity to develop improved technologies), and the physical, technical and organizational capacities and skills of those engaged in production."

Resilient communities are characterized by their involvement in a diverse array of products and services that are both produced in and available to the community. Diversity in production and employment is linked to a community's ability to substitute goods and services and shift employment patterns as the situation demands. The *PEOPLES Resilience Framework* incorporates three illustrative subcategories within this dimension: industry – production, industry – employment distribution, and financial services. Primary indicators of this dimension include the proportion of the population that is employed within the various industries, and the variability that might characterize a community's industrial employment distribution.

This dimension is closely interwoven with the Population and Demographics dimension. For example, key indicators of economic development beyond employment and industry distribution include literacy rates, life expectancy, and poverty rates. Disaster-specific indicators related to economic development include extent of evacuation plans and drills for high-occupancy structures, adequacy of plans for inspecting damaged buildings following disasters, and adequacy of plans for post-disaster commercial reconstruction (Tierney 2009).

7. Social-Cultural Capital

According to Norris and her colleagues (2008), “individuals invest, access, and use resources embedded in social networks to gain returns” (p. 137). For our purposes, social/cultural capital incorporates several subcategories, including education service, child and elderly services, cultural and heritage services, and community participation. Social/cultural capital is prerequisite to community competence (Norris et al. 2008) in that it incorporates the array of services that the community has chosen to provide for itself, understanding that community health requires more than good jobs and infrastructure. It also includes several intangible “goods,” such as social support, sense of community, place attachment, and citizen participation (Norris et al. 2008).

For example, *social support* underlies many of the services associated with social/cultural capital. It includes both the “helping behaviors within family and friendship networks” and the “relationships between individuals and their larger neighborhoods and communities” (Norris et al. 2008, p. 139). People choose to provide social and cultural services that manifest and extend their *sense of community*, defined as an attitude of bonding with other members of one’s group or locale (Perkins et al. 2002, cited in Norris et al. 2008). They may feel an emotional connection to their neighborhood or city, which may or may not relate to the people who inhabit those places (Manzo & Perkins 2006). For example, after Hurricane Katrina, many displaced residents of New Orleans expressed a strong desire to return home, irrespective of the people they knew or the jobs they once had. It seems likely that people with a strong “*place attachment*” would be more willing to act in order to help their community bounce back after a disaster, assuming that other essential factors such as employment and housing were available. *Citizen participation* takes into account the “engagement of community members in formal organizations, including religious congregations, school and resident associations, neighborhood watches, and self-help groups” (Norris et al. 2008, p. 139). Participation in community organizations is a means of demonstrating one’s care for one’s community. Pragmatically, participation in community organizations is a means for meeting and understanding one’s fellow citizens. It increases individuals’ circle of influence and perception of control.

Measuring social/cultural capital requires acquisition of tallies, such as the number of members belonging to various civil and community organizations. It also requires surveys of community leaders and their perceptions (e.g., quality of life surveys). Disaster-specific indicators include existence of community plans targeting transportation-disadvantaged populations, adequacy of post-disaster sheltering plans, adequacy of plans for incorporating volunteers and others into official response activities, adequacy of donations management plans, and the community’s plans to coordinate across diverse community networks (Tierney 2009).

Integration of Dimensions using Time Dependent Functionality

Within the *PEOPLES Resilience Framework*, each dimension and its indicators or term of functionality and/or service will be represented with a GIS layer of the area of interest as suggested in the example portrayed in Figure 3, where Q_{EP} = functionality of electric power system; Q_H = functionality of health care system; Q_{RN} = functionality of road network; Q_{WS} =

functionality of the potable water distribution system and so on. This list of functionality terms that can be inserted within the physical infrastructure is not complete. Additional terms can be added, such as functionality of schools, dams, fire stations, oil and natural gas systems, emergency centers, communication towers/antennae, etc.

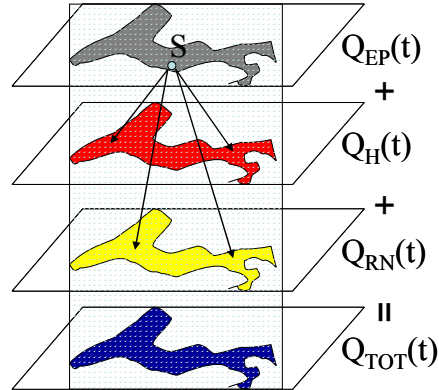


Figure 3 Schematic representation of time dependent community functionality maps

Community resilience indices for each dimension, or as a combined index, will be dependent on a defined temporal and geographic scale. First the geographic scale needs to be defined (see Figure 2), and then it is possible to plot a time dependent functionality map. When the time scale is also defined, then the resilience map of the region of interest can be plotted. The map will vary in space, but it will be time independent. Finally the community resilience index is given by the double integral over time and space as follows:

$$R(\mathbf{r}) = \int_{t_{OE}}^{t_{OE}+T_{LC}} Q_{TOT}(\mathbf{r},t)/T_{LC} dt \quad (3)$$

where $Q_{TOT}(\mathbf{r},t)$ =global functionality that is a function of time and space and combines all functionality terms considered; \mathbf{r} =position vector; t = time parameter; T_{LC} = control time.

Concluding Remarks

The seven dimensions of community resilience are indentified within the new *PEOPLES Resilience Framework* as Population and Demographics, Environmental/Ecosystem, Organized Governmental Services, Physical Infrastructure, Lifestyle and Community Competence, Economic Development, and Social-Cultural Capital. *PEOPLES* builds on and expands previous research at MCEER (also known as the Multidisciplinary Center for Earthquake Engineering Research at the University at Buffalo) linking the four resilience properties (robustness, redundancy, resourcefulness, and rapidity) and resilience dimensions (technical, organizational, societal, and economic) so as to measure the disaster resilience of capital assets (e.g., hospitals) and asset classes (e.g., health care facilities). Over the longer term, the *PEOPLES Resilience Framework* and its associated database access will enable the development of decision-support software tools that help planners and other key decision makers and stakeholders to enhance the disaster resilience of their communities.

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