NIST GCR 16-001

A Conceptual Framework for Assessing Resilience at the Community Scale

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This publication is available free of charge from:
http://dx.doi.org/10.6028/NIST.GCR.16-001

National Institute of
Standards and Technology
U.S. Department of Commerce

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A Conceptual Framework for Assessing Resilience at the Community Scale

Prepared for
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http://dx.doi.org/10.6028/NIST.GCR.16-001

January 2016

U.S. Department of Commerce
Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie May, Under Secretary of Commerce for Standards and Technology and Director

Acknowledgments

This report documents research conducted by the authors under the Community Resilience Assessment Methodology task order of the Disaster and Failure Studies Program (NIST contract SB1341-12-CQ-0014, Task Order 14-373).

The NIST Project Manager and Technical Point of Contact for this Task Order was Dr. Erica Kuligowski. The authors would like to express our gratitude to Dr. Kuligowski for her guidance and feedback throughout the course of the project and for her thoughtful comments on this report. The authors also wish to thank Mr. Stephen Cauffman, Dr. Therese McAllister, and Ms. Nancy McNabb of the NIST Community Resilience Group and Mr. David Mizzen of Applied Research Associates for their valuable inputs and comments throughout the project.

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1. Introduction

The objective of the NIST Community Resilience Assessment Methodology (CRAM) project is to provide a technical foundation for a methodology to assess resilience at the community scale. For the purposes of this project, community resilience is defined as "the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions" (PPD-21 2013). A key point to note is that the concept of community resilience and its incorporation into routine planning, engineering, and community administrative practices is largely in its infancy in the United States. As such, the observations and recommendations incorporated into this report have been developed as part of an evolving effort which will continue to advance as new knowledge, experience, and research results become available.

This report is the second of two reports produced under the CRAM project. The primary objective of the first report (Lavelle et al. 2015) was to review and critically assess nine existing tools and methodologies. The nine selected methodologies were not all specifically developed for the purpose of community resilience assessment, but each was found to address one or more important aspects of community resilience assessment. The purpose of this second report is to build upon the strengths of these exiting approaches, identify gaps or needs, and recommend a conceptual framework for filling those gaps.

In Section 2, we discuss our motivations and goals. Section 2 also describes the intended audience for this report as well as the intended users of the CRAM. Section 3 provides background on the NIST *Community Resilience Planning Guide for Buildings and Infrastructure Systems*, the CRAM critical assessment report completed in Task 2 of this study, and other related efforts. In Section 4, we provide a definition of the community used for the purposes of this project, and we discuss the concepts of community dimensions and community services. We also discuss the systems and resources that are required to provide community services and support community dimensions. Finally, we examine interdependencies and how different infrastructure elements serve as inputs to a service or rely on the outputs of another service.

In Section 5, we choose a specific community dimension, health, to illustrate the spectrum of services and systems required to support this dimension of a community. We use health as a focal point for thinking through the CRAM process, identifying system attributes and interdependencies, and illustrating how these ideas can be brought together for the purpose of resilience evaluation. The overarching question under consideration is how can communities of various sizes and resources objectively assess the extent to which proposed changes in the configuration or management of supporting infrastructure systems are expected to improve their short-term, medium-term, or long-term ability to provide health care services in the aftermath of a future routine, design-level or extreme event?

The report concludes in Section 6 with a discussion of findings, limitations, and recommendations that can be adapted for use in a first-generation methodology to assess resilience at the community scale.

At the highest level, the intent of this report is to inform readers on key aspects of resilience assessment and how ideas from other domain-specific areas of infrastructure system management can be applied in a broader context to assess the overall resilience of whole communities. Because it is clear that there is no appropriate one-size-fits-all approach to assessing resilience, the report does not contain prescriptive, specific, or systematic step-by-step details that users can apply directly. However, the value of this report is in its suggestions of ideas and illustrations from which persons tasked with assessing their community's resilience can start. It is expected that these concepts will be adapted and modified for use in specific communities for the specific hazards and threats that confront them.

2. Objective

This project is intended to lay the groundwork for a tool or methodology than can eventually be used by communities of all sizes and resources; therefore, it cannot be too academic, theoretical, or computationally heavy. It also must be flexible, responsive, and comprehensive to include all key stakeholders within a community and account for their needs. As a result, this report provides a framework and an illustration of how a community level assessment might be conducted. The general approach is inherently conceptual. However, in order to meet the goal of being widely applicable, it also provides an explanation of how the various concepts relate with practical notions and with application. In particular, Section 5 provides an illustration of the concepts.

The work described here was developed in response to the following task order elements:

- Select, in conjunction with NIST, up to five physical and up to three social systems that must be represented in a first generation community resilience assessment methodology.
- For the identified physical and social systems, identify attributes of each system and the dependencies between these systems that need to be included in an assessment methodology for community resilience.
- Document the physical and social systems identified for the first-generation community resilience assessment methodology, the attributes of each system and dependencies between these systems, information sources, and the basis for inclusion in the model.

In addition to the elements listed above, several other guiding assumptions influenced our approach. First, we felt it was important that the assessment approach be focused on local government decision makers. In other words, while the focus of the approach is on the "community" it emphasizes the kinds of activities that local government representatives are able to facilitate, as opposed to household or other organizational activities from the broader community. A future document or series of documents could be developed that more completely consider how other kinds of actors in community might facilitate resilience. Users should include decision makers, planners, researchers, insurers, designers, builders, system operators, emergency mangers, etc.

This project draws upon the extant research base from a number of fields and disciplinary perspectives. It should be seen as an interpretation of the science developed, with the intent of simplifying those insights for the purposes of implementation by communities who do not have the technical expertise to conduct complex analyses or modeling activities. This approach allows for both sophisticated and simplified modeling depending on the place in which it is being used. Further, it allows for more detailed or sophisticated evaluations by considering more detailed models and by making less constrained assumptions. The approach is intended to have applicability at any scale and be used in a number of governmental settings. For example, it is expected that the approach developed here can be used by both rural communities and large cities. Thus, it needs to have a "flexible" and "modular" structure that would allow, for example, users to focus on a reduced number of systems and recovery time-frames. It should also allow for the reality that different places have different needs and priorities. The main challenge for such a modular approach is presented by the complex mesh of dependencies found in communities of all sizes.

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3. Background of this Effort

This section provides background on the CRAM critical assessment report completed in Task 2 of this study, the NIST Community Resilience Planning Guide, and other related NIST efforts.

a. Relationship to Task 2

This report is the second of two reports produced under the CRAM project. The main objective of the first report (Lavelle et al. 2015) was to review and critically assess nine existing tools and methodologies: (1) the San Francisco Planning and Urban Research Association (SPUR) framework, (2) the Oregon Resilience Plan, (3) the United Nations Disaster Resilience Scorecard and (4) the Community Resilience System, (5) the Communities Advancing Resilience Toolkit (CART), (6) Baseline Resilience Indicators for Risk (BRIC), (7) the Rockefeller Foundation's City Resilience Framework and City Resilience Index, (8) the Coastal Resilience Index and (9) the Hazus Loss Estimation Methodology. The nine selected methodologies were not all specifically developed for the purpose of community resilience assessment, but each was found to address one or more important aspects of community resilience assessment. The nine existing methodologies were assessed in five broad areas: (1) comprehensiveness, (2) utility, (3) impacts assessed, (4) techniques used, and (5) an overall critical assessment with respect to maturity, uniqueness, objectivity, scientific merit and future development needs. Although each of the methodologies reviewed was found to have some strengths as a potential tool for community resilience assessment, none was found to be consistently strong in each of the five dimensions assessed. As a result, it was suggested that a reasonable strategy would be to attempt to combine the best features of several existing and/or emerging methodologies.

Assessing community resilience poses several challenges. One of those challenges is to identify a quantitative resilience metric for each system. For physical systems (i.e., buildings and infrastructure), a concept analogous to that of availability in reliability theory could be used. For social systems, one can envision a general set of measures such as employment level, economic activity, life expectancy, educational achievement level, etc., but it is more difficult to develop quantitative metrics that can universally capture the needs of different communities. Further, once a set of metrics is identified, significant challenges will exist when considering how the metrics will be calculated and/or to how the metrics will respond to different planning scenarios, such as the type of hazard, intensity, the location where the community is applying this tool (because there could be site-specific vulnerabilities), and the specific changes in the building or infrastructure system configuration or management under consideration by the community.

Another challenge that, in reality, applies to any resilience assessment tool is the need to represent the dynamic nature of resilience, including the effect of temporal "inertia" creating "time constants" in the way resilience will change over time. Yet one more challenge is to represent and accurately account for the effects of changes to the physical and social environment on community resilience. This environment includes aspects such as political conditions and regulations. It could be argued that all such aspects could be part of a community system, such as local government. However, this physical and social environment also represents external entities outside the community jurisdiction, such as state or federal laws, international trade, or the effects of relying on a large interconnected power grid, communications network, or transportation network.

Addressing the effects of dependencies and interdependencies also presents important challenges. In modern communities, the operations of most systems are interrelated through the services they provide. For

example, services provided by communication networks or health care facilities need reliable electric power, usually provided by electric utilities. Hence, the performance of these and other community services during extreme events is affected by the performance of systems upon which these services depend. After a disruptive event, dependencies lead to a need for sequential restoration processes in services, as dependent services can only be restored after the systems upon which they depend are brought back into operation. When dependencies occur mutually between two systems, we refer to these as interdependencies. Dependencies and interdependencies, which are discussed in more detailed in Sections 4.f and 4.g, play important roles in resilience assessments because the performance of such systems is interrelated and changes in the resilience of one system or service may cascade into changes in the resilience of other systems and services.

These challenges exemplify some of the most relevant observations made of existing attempts to characterize community resilience. Most of the existing methodologies reviewed in our first report (Lavelle et al. 2015) tend to focus on a particular set of community services with a limited integration of the social and infrastructure systems on which they depend. In addition, many frameworks rely on metrics that are, ultimately, dependent on opinions of subject matter experts or stakeholders, thus reducing the intended benefit of using quantitative metrics. Some of the issues found in existing works originate from a lack of consistent definitions and use of terms. Hence, Section 4 of this report includes terminology and definitions that could be used as the basis for future community resilience assessment methodologies. It was also observed that both the challenges created by the dynamic notion of resilience and the effects of dependencies create potential gaps in existing frameworks and although some attempts to bridge these gaps are made in this report, it is also acknowledged that all of these challenges create future research needs in order to develop community resilience assessment methodologies that can be successfully applied in the real world.

b. Relationship to the NIST Community Resilience Planning Guide and other NIST Efforts

The NIST *Community Resilience Planning Guide for Buildings and Infrastructure Systems* (NIST 2015), henceforth referred to as the NIST Guide, provides a flexible six step process for planning prioritized measures to strengthen resilience and improve a community's abilities to either maintain or more quickly restore vital services in the aftermath of disruptive events and to build back better. It focuses on helping communities integrate resilience plans into their local planning activities that impact their built environment (i.e., buildings, utilities, and other infrastructure systems).

The NIST Guide includes templates for assessing current system performance levels and setting future goals. A hypothetical example from Chapter 9 of the Guide is reproduced below as Figure 1. Tables such as these clearly illustrate gaps between current and desired performance levels; however, in communities where approaches like this have been followed (e.g., San Francisco and Oregon) these tables tend to present opinions of the individuals or groups who prepared those tables and, thus, may be more subjective than a result obtained from a methodology based on a mathematical model.

Another closely related NIST effort is the Community Resilience Center of Excellence (CoE), a five-year cooperative agreement with Colorado State University and ten other universities to "develop computer tools to help local governments decide how each can best invest resources intended to lessen the impact of extreme weather and other hazards on buildings and infrastructure and to recover rapidly in their

aftermath."[1] The CoE's multi-disciplinary team includes experts in engineering, computing, and the social sciences.

Table 9-13: Riverbend, USA energy infrastructure performance goals for design earthquake

Disturbance [1]	
Hazard Type	Earthquake
Hazard Level	Design
Affected Area	Community
Disruption Level	Moderate

Restoration Levels [2,3]	
30%	Function Restored
60%	Function Restored
90%	Function Restored
X	Anticipated Performance

Energy Infrastructure	Support Needed[4]	Design Hazard Performance								
		Phase 1 Short-Term			Phase 2 Intermediate			Phase 3 Long-Term		
		Days			Weeks			Months		
		0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Power - Electric Utilities										
Community Owner or Operated Bulk Generation										
In Place Fueled Generation (Hydro, solar, wind, wave, compressed air)	R/C	90%	X							
Transmission and Distribution (including Substations)										
Critical Response Facilities and Support Systems										
Hospitals, Police and Fire Stations / Emergency Operations Centers	R, C	60%	90%	X						
Disaster debris / recycling centers/ related lifeline systems	R, C	60%	90%	X						
Emergency Housing and Support Systems										
Public Shelters / Nursing Homes / Food Distribution Centers	R, C		60%	90%	X					
Emergency shelter for response / recovery workforce/ Key Commercial and Finance	R, C		60%	90%	X					
Housing and Neighborhood infrastructure										
Essential city services / schools / Medical offices	R, C		60%	90%	X					
Houses of worship/meditation/ exercise	C		60%	90%	X					
Buildings/space for social services (e.g., child services) and prosecution activities	C		60%	90%	X					
Community Recovery Infrastructure										
Commercial and industrial businesses / Non-emergency city services	C			90%	X					
Residential housing restoration	R, S, MS, C			90%	X					

Footnotes:

1 Specify hazard type being considered
Specify hazard level – Routine, Design, Extreme
Specify the anticipated size of the area affected – Local, Community, Regional
Specify anticipated severity of disruption – Minor, Moderate, Severe

2

30%	60%	90%

Desired restoration times for percentage of elements within the cluster

3

X

Anticipated performance for 90% restoration of cluster for existing buildings and infrastructure systems
Cluster recovery times will be shown on the Summary Matrix

4 Indicate levels of support anticipated by plan
R = Regional; S= State; MS=Multi-State; C = Civil (Corporate/Local)

Figure 1. Example of performance goals from the NIST Community Resilience Planning Guide

[1] http://www.nist.gov/el/resilience/research-center-help-communities-increase-resilience-to-disaster.cfm

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4. General Approach

This document provides a framework and an example to help stakeholders in local communities start to think about assessing resilience in their communities. It is not a how-to-guide, but rather a set of ideas and illustrations that can create a starting point for a wide range of community planning activities in support of resilience assessment. This section provides an introduction to several key terms that are important to understand before one can go about assessing resilience. Given the complexity of the concept of resilience, the goal of this section is to help orient the reader to the general approach we will illustrate in Section 5.

a. What is a Community?

In order to assess community resilience, it is important to start with a basic understanding of what "community" means. In this report, as in the NIST Guide (2015), the term community refers to a place designated by geographical boundaries that functions under the jurisdiction of a governance structure, such as a town, city, or county. This definition is useful because it focuses attention on how some set of actions affects the people in that place. In instances where a leader is responsible for a particular geographic area and/or has some power to influence how a part of that location operates, it is common to think of that area or space as the community in which he/she is working. For the purpose of an assessment, it is also important to think about the place and space upon which the community resilience assessment is focused. There are a number of unique realities that exist in any place due to its history, natural environment, culture, and other factors. Part of any assessment is recognizing that general ideas express themselves differently in specific places. Given the variety of community types across our nation, one of the principles any person working to improve resilience needs to consider is what is the physical and social space within which you operate and are mandated, or otherwise are motivated, to change? Further, when looking at that space what concepts can help you consider how resilience might be developed or facilitated in that specific area?

When thinking about the place defined as a community, there is another important element to consider. Within any place or jurisdiction, every person is not equally connected to every other person or organization. We, as people, are different in terms of our family, culture, values, motivations, etc. We often associate and form connections with people who share our views, values, perspectives, and life circumstances. It is important to recognize that membership in this second type of community does not necessarily correspond to jurisdictions, physical, or geographic spaces previously referred to as communities. This second type of community can sometimes be physically concentrated in small places inside the jurisdiction and in other instances can connect people well beyond the physical boundaries of a specific place to those inside it, bringing significant external influence or pressure. In getting to know a community, it is important to work towards understanding the "sub-communities" that are part of the larger jurisdiction. These groups are important and often include diverse stakeholders that, at some point, will be impacted by changes to the community. It is important to consider the intended and unintended consequences of any proposed activities, given the varied values and preferences of the more natural groups within the borders. It is also important to note that significant research has shown that the impacts of disruptive events are not equally shared among these communities. Rather, it has been shown that some groups are disproportionally affected by these events.

Taken together, it is important to understand community in both ways. We must recognize it as the jurisdiction within which resilience will be assessed and enhanced through improvements to specific systems and services, but we must also recognize it as a reminder to consider how changes to the jurisdiction might differentially impact the sub-communities within that place. Understanding both "the good of the

whole" and of the needs and desires of these "other" groups should be a key concern of any resilience assessment. Another key consideration is the involvement of representatives of the various stakeholders within the community. Community support and "buy-in" into resilience planning, project selection, and resource allocation is critical to garnering the political support required for effective selection and prioritization of community needs as well as funding for projects. Past experiences in related disaster preparedness efforts have shown community support to be a fundamental key to achieving program success.

b. Community Dimensions

Community resilience can be evaluated from a variety of different perspectives that emphasize and/or take into consideration any number of different factors. This assessment framework has adopted a set of concepts intended to help orient thinking around community resilience. A central concept is the idea of community dimensions. We assert that the purpose of a community is to facilitate the provision of a set of critical dimensions. Much of the way we structure ourselves, the way we design buildings and infrastructure, and the way we utilize the natural resource are determined by our desire to provide these essential dimensions within a community. They are, in essence, the purpose of communities. Understanding and assessing these fundamental community dimensions, both under normal circumstances and in the wake of disruptive events, are the ultimate goals of any resiliency assessment. By thinking about dimensions first, we can see a broader purpose for communities and can start to assess the degree to which services, resources, infrastructure, policies, and practices help people within a community to achieve and maintain these dimensions over time. Building on our two-part definition of community, it also allows us to see the degree to which these benefits are distributed within a particular place. In doing so, we see that a great deal of existing research, planning, and implementation efforts that, while not formally thought of as "resilience-related" could and we argue should be adapted to serve those who are looking to improve resilience.

We propose the following set of essential community dimensions, developed from the insights of Maslow (1943) and the NIST Guide (2015), as a starting point:

- Sustenance
- Health
- Housing and Shelter
- Security and Safety
- Education and Personal Development
- Culture and Identity
- Belonging and Relationships

While it is recognized that this list is not necessarily exhaustive, these are certainly several of the most fundamental dimensions of a community. The addition of other dimensions to those listed above would need to be done on a case-by-case basis depending on the particular needs and conditions of a community, the threats it faces, and how combinations of these various elements are viewed in terms of their importance.

c. Community Services

It is important to recognize that the essential community dimensions are intentionally broad and abstract. This choice keeps the number of dimensions to a minimum without unduly constraining the types or sizes of communities to which they can be applied. Next, we introduce the idea of community services to serve as an expanded and more tangible set of essential building blocks. Services are the provision of activities,

supplies or goods needed to support the essential community dimensions. A partial listing of typical community services includes:

- Communication services: provision of connectivity between a sender and receiver in order to allow information or a message to be exchanged.
- Transportation services: provision of physical connectivity in order to deliver people and/or resources from one place to another.
- Water services: provision of water suitable for human consumption, fire suppression, irrigation, industrial processes, etc.
- Sewage services: provision of infrastructure to remove and treat wastewater.
- Energy (includes electric power and natural gas) service: provision of electrical energy, natural gas, or liquid fuels to consumers. Electrical energy can be either locally produced or remotely generated.
- Governance: provision of rules and processes for the adjudication of public problems. The services also include collection and administration of public funds.
- Policing: provision of a process for the enforcement of laws.
- Fire protection: provision of emergency firefighting, rescue, and other safety-related services (e.g., education).
- Medical services: provision of medical care to individuals in the community.
- Social services: provision of elder care, child services, housing subsidies, homeless shelters, etc.
- Education: teaching at schools, universities, homes, on-line, etc.
- Religion: services related to spirituality and self-discovery.
- Commerce and exchange: provision of the ability for buying/selling or exchanging resources and services. These services include financial services that are provided to manage money and other fungible assets or assets that are part of individual or collective wealth, such as commodities and real estate. Examples of financial services include investing, lending and saving these assets. Insurance services are also considered part of the commerce and exchange services.
- Construction: services focused on the creation and maintenance of the built environment.
- Entertainment: activities that allow for leisure, relaxation, and enjoyment.

Some of the community services are directly aligned with a single community dimension (e.g., policing and fire protection services support the security and safety dimensions), whereas other community services support multiple community dimensions (e.g., energy, communication, transportation and commerce and exchange services each support multiple community dimensions). Once again, it is recognized that this list of community services is not exhaustive. This list has been developed to represent many of the most fundamental services for communities. The addition of other services to this basic list is encouraged to be conducted on a case-by-case basis based on the needs, characteristics, and conditions of a particular community.

d. Resources and Systems

There are a number of resources and systems within any community that serve to support the delivery of community services. For our purposes, we are distinguishing between resources, systems, and services. Resources are the inputs (e.g., fuel, people, buildings, and equipment) that can be utilized by systems (e.g., electric power generation, transmission, and distribution) to provide services (e.g., electric power at an

outlet). This is an important distinction because many equate systems with services. For example, the provision of power is often equated with the quality of the electric wires, grid, switches, repair crews, etc. The difficulty with equating the two is that if systems are seen as the services, then the only options we have are to repair, replace, and/or strengthen individual systems. If, however, we think about the traditional systems as one important way, but not the only way, of ensuring the delivery of the key services that ultimately allow communities to function, we are able to see a host of alternatives and interdependencies emerge. For example, if the power grid goes down, all available resources can be allocated to repairing power lines to get a hospital up and running, or, instead, resources can be allocated to providing access to fuel that allows the facility to run an on-site generator and continue to provide critical health care. Ultimately, this view emphasizes the delivery of services and the support of essential community dimensions as the goal of any resilience system, plan, or policy alternative.

As discussed above, resources are inputs that are used, and in some instances consumed, in order to deliver services. These resource or assets are also referred to in the social sciences literature as community capitals (e.g., NIST 2015; Ritchie and Gill 2011). Examples include:

- Financial capital/resources (savings, income, investments, and available credit)
- Built capital/resources (infrastructure systems and buildings)
- Political capital/resources (access to resources and the ability to influence their distributions)
- Social capital/resources (social networks, associations and the trust they generate)
- Human capital/resources (knowledge, skills, creativity, health, and physical ability)
- Cultural capital/resources (language, symbols, attitudes, competencies, and orientations)
- Natural capital/resources (air, land, water, minerals, and ecosystems)
- Information
- Time
- Values, policies, regulations

Systems are combinations of resources organized to provide services. For the purposes of this study, it is helpful to distinguish two types of systems: infrastructure systems and social systems. As detailed below, systems comprise three primary domains: physical, human and cybernetic.

Infrastructure systems are specific combinations of resources and processes developed to deliver services primarily through a physical built environment or a cybernetic sub-system. Examples of physical, human, and cybernetic resources utilized in infrastructure systems include:

- Physical domain of infrastructure systems
  - Pipelines and infrastructure
  - Buildings
  - Roads and bridges
  - Information networks
  - Electric power generation, transmission and distribution assets
- Human domain of infrastructure systems
  - System operators
  - Users
  - Policies and procedures
  - Regulation and law

- Cybernetic domain of infrastructure systems
  - Databases
  - Control and operations algorithms

A public transportation is an example of an infrastructure system. Its physical domain includes, for example, buses and garages. Its cybernetic domain includes data about schedules and routes as well as the database of drivers. The human and social domain includes employees, riders, mechanics, and the personnel and processes to hire and train drivers or to conduct inspections and repairs of buses.

Social systems are specific combinations of resources and processes developed to deliver services primarily through human interactions. Like infrastructure systems they are also formed by human, physical, and cybernetic domains. Examples of social systems include public safety, education, health, and religious systems. Examples of resources utilized in social systems include:

- Physical domain of social systems
  - Buildings
  - Supplies
  - Vehicles
- Human domain of social systems
  - Workers (police officers, teachers, doctors, …)
  - Clients (students, patients, …)
  - Policies and procedures
  - Regulations and laws
- Cybernetic domain of social systems
  - Databases
  - Control and operations algorithms

An education system includes school buildings and supplies as part of its physical domain; administrators, teachers, students, curricula, rules, and laws as part of its human and social domain; and school records and payroll systems as part of its cybernetic domain.

Social systems tend to serve people, primarily through human-to-human interactions, whereas infrastructure systems may serve people or other physical systems. These systems use their resources and other elements to provide the services that influence the resilience of the community dimensions that they support. As Figure 2 exemplifies, both social and physical systems (infrastructure) are, actually, a combination of human, physical assets and cybernetic components. For example a power grid could be considered as an example of a physical system, which includes physical assets (lines, towers, transformers, etc.), a cybernetic component (control and management platform, information and data, sensing, etc.), and a human component (utilities personnel, processes, etc.). Another example is a health system, which include physical elements (buildings, such as hospitals and clinics, technology, such as medical imaging devices, etc.), cybernetic components (medical records, information, internal communication network, etc.) and human elements (doctors, nurses, administrative staff, etc.).

This conceptual framework can be used to characterize the methods used in an assessment of community resilience by evaluating which systems are considered in each method, whether each of the three component domains (human, cyber and physical) is considered for each of those systems, and which dependencies between systems are considered. As an example, consider Figure 3, which depicts a reduced set of five interacting community systems. In this figure, the arrows represent the provision of a service from one system to another system. Each system depends on other systems to generate services that, in turn, support

one or more community dimensions. For example, the arrow going from the physical domain of the power grid infrastructure system to the physical domain of the health system represents the need for electric energy in health care facilities in order to deliver health services. The arrow going from the physical domain of the communications systems to the cybernetic domain of the health systems represents the communication services used by health systems in order to coordinate their activities when delivering health services. The arrows going from the human domain of the health system to the human domains of the power grid system and the communication networks systems represent the health care services needed by these infrastructure systems to allow their workers to maintain a level of health that is sufficient to operate their systems and deliver their corresponding services.

Thus, as explained above and as depicted in Figure 3, dependencies between systems can be established through physical links, human links or cybernetic links. However, some services can be provided at least temporarily by "buffers" (i.e., local storage units belonging to the dependent system). For example, a power grid system can reduce its dependency on health services provided by a health system by having additional personnel beyond the absolute minimum needed to deliver its services or cross-trained personnel who can switch to critical positions at least temporarily. Conversely, a health care facility can store energy on-site in the form of diesel which can be used to fuel a generator set or in the form of batteries so it can maintain operations at least temporarily when a power grid outage occurs. These examples also illustrate the existence of mutual dependencies or interdependencies (e.g., health systems depending on electric power and power grids depending on health care services) among community systems.

Finally, we note that Figure 3 depicts services provided by social systems as being provided primarily from the human domain, which is in agreement with the definition of social systems as community systems that deliver services primarily through human interactions.

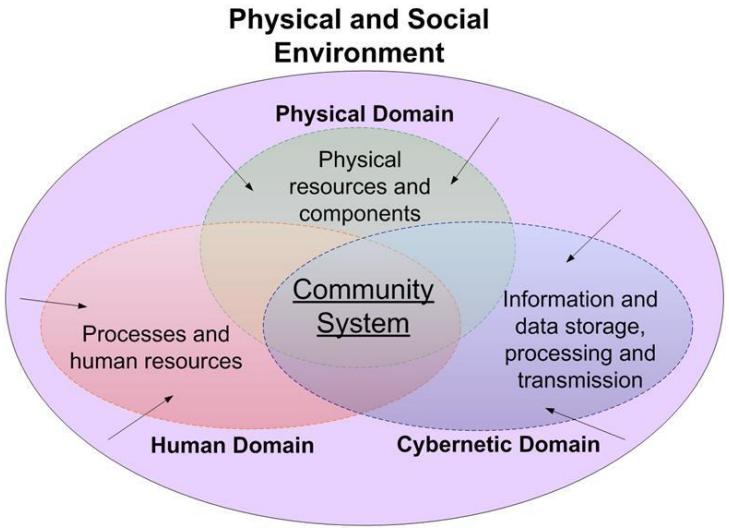


Figure 2. Representation of a community (social or physical) system and its three component domains: physical, human, and cybernetic.

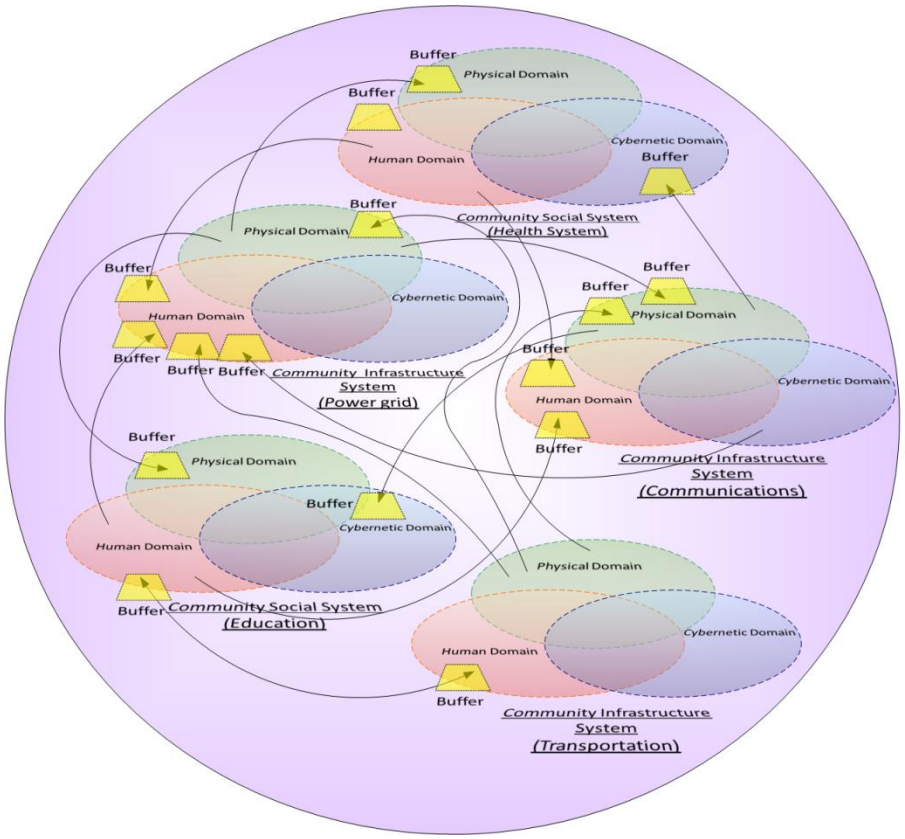
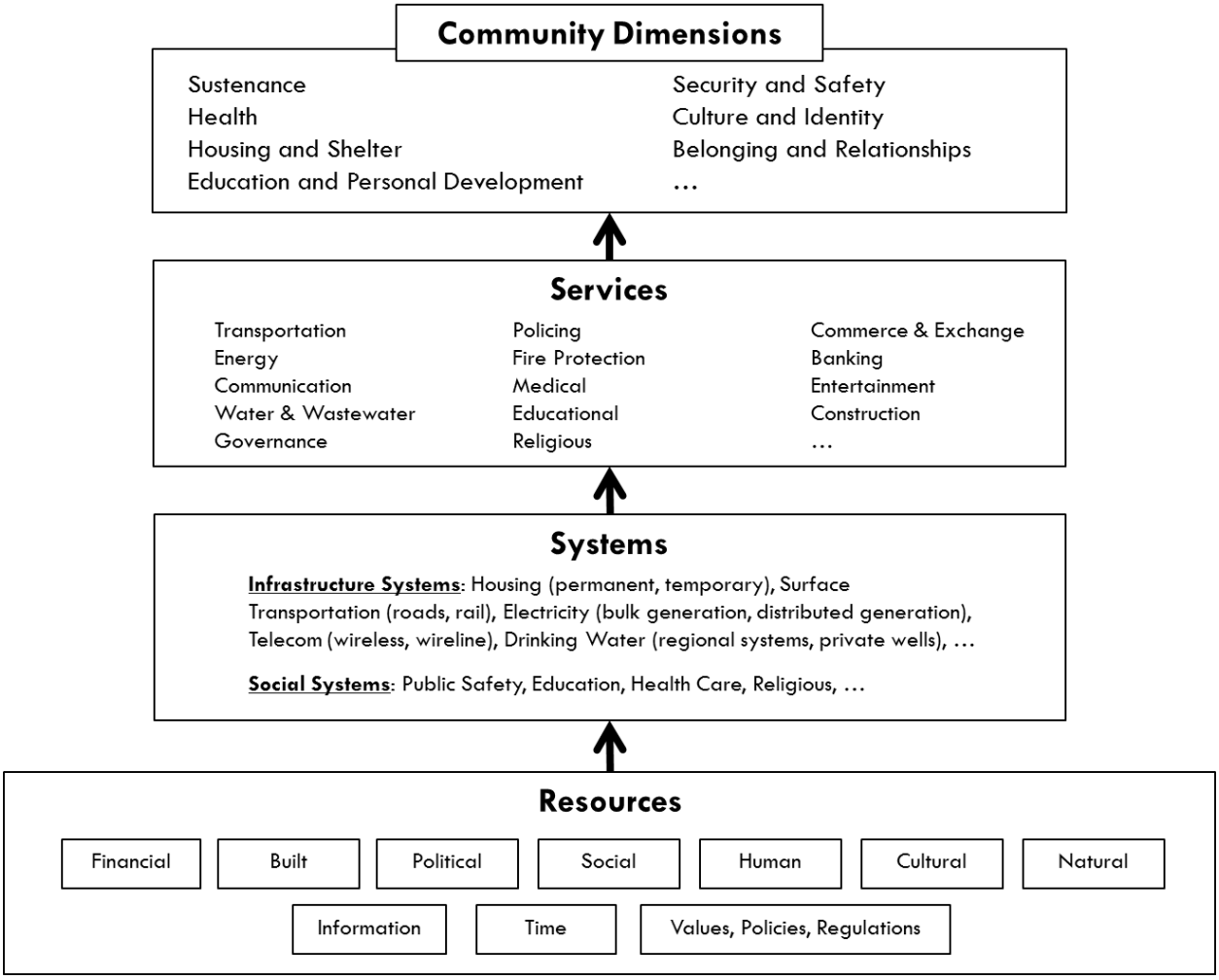


Figure 3. Representation of a community with a reduced number of systems, showing the interactions among these systems.

e. Hierarchy of Community Dimensions, Services, Systems and Resources

Figure 4 illustrates the hierarchy of community dimensions, community services, supporting systems, and resources introduced in the preceding sections. This figure highlights the dependence of community dimensions on community services and their supporting systems and resources. The conceptual framework emphasizes that no single resource, infrastructure system, or social system should be thought of as equivalent to the provision of a service. Further, no service should be seen as fully independent from all other services.



Community Dimensions are the broad purposes or desires of the community.

Services are the provision of specific activities, supplies or goods that support community dimensions.

Infrastructure Systems are specific combinations of resources and human actions organized to deliver services primarily through the built environment and cybernetic sub-systems. Infrastructure systems comprise three primary domains: physical, human, and cybernetic.

Social Systems are specific combinations of resources and human actions organized to deliver services primarily through human interactions. Social systems are formed by the same three primary domains as infrastructure systems, but with an emphasis on the human dimension over the physical and cybernetic dimensions.

Resources are inputs to systems that are used, and in some instances consumed, in order to deliver services.

Figure 4. Conceptual framework of community dimensions, services, systems and resources.

f. Dependencies

At any level in Figure 4, the type or degree of dependency can take different forms. The simplest and least resilient type of dependency occurs when one element is completely reliant on another element in order to perform. For example, communication in a hospital might regularly occur through wireless cell sites, which typically depend on electric power provided by a power grid for their operation. In this example, the cell tower is dependent on the service of power. When we turn to the level of infrastructure systems, however, we can see that the degree of dependency on an element can vary significantly. In our previous example,

the cellular communication would be fully dependent on the power grid. However, these facilities and others could be equipped with energy storage devices, such as batteries or fuel tanks for standby generators, in order to maintain cell operation for a given time after the electric grid tie points of these facilities experience a power outage. In this second instance, the communication service is not fully dependent on the power grid. Instead, it is only partially dependent on the grid, in that some level of service can be supported through these alternative systems. In continuing to explore the example, we see that the capacity (level of stored energy) and the level of demand users place on the system while the power grid is down determine the degree to which this service can be delivered without the grid. As a result, we see that a facility with a standby generator but no stored fuel is not resilient, since a loss of grid-delivered power will lead to an immediate disruption of service at the site. On the other hand, we can imagine an ideal energy storage device that is able to store an infinite amount of energy at the facility. In that case, an electric power grid outage will pass unnoticed and such facilities would be able to provide the needed level of service indefinitely. Similarly, demand could be altered. If a community develops a fallback approach to delivering communications that eliminates the need for cell phones and power for some time or reserves the use of that stored energy for the most critical and time sensitive communications, the need for communication services can be met more resiliently. The framework and examples presented here allow us to consider a range of alternatives.

The types of dependencies discussed in the previous paragraph also allow us to identify different degrees of dependencies. The degree to which one system is dependent on another system to provide a needed service may vary based on the ability to maintain a local reserve or buffer for the needed service (e.g., an energy storage device). This observation suggests that the level of dependency of one system on another system can be regulated and, thus, measured, by evaluating the local storage capacity that is required to prevent disruption of the services produced by the one system when other infrastructure and/or social systems are disrupted. Another option is to put in place processes that recognize a reduced demand during some circumstances. The combination of both a local buffer and reduced demand allow for greater resilience in that service. Similar dependencies can be identified for other services, as well. For example, dependencies on financial services could be theoretically managed in some cases by maintaining a reserve of cash at the site where it is needed, or dependencies on entertainment services could be regulated by having the means of entertainment (e.g., movies or other programs on DVD) stored at the site. Dependencies on community systems can be established through any of the dimensions of the system (physical, human or cybernetic). Hence, the type of storage necessary to regulate the dependency depends on the way in which the service is provided.

g. Interdependencies

Having discussed unidirectional relationships, it is also important to note that, in some instances, two systems depend on each other reciprocally in order to provide their respective services. This type of two-way relationship is exemplified in Figure 5 through Figure 7, where natural gas distribution systems depend on electric power grids to power their compressors and, conversely, electric power grids depend on natural gas distribution systems to fuel some power stations. We refer to these two-way dependencies as interdependencies. In general, interdependencies are much more complex than this simple example. For example, the power plant in Figure 7 can also be fueled by oil, but, as shown in Figure 8, oil production and refining requires electric power. Therefore, even when dependencies on oil production systems are reduced by storing oil at the power station, eventually oil reserves may be exhausted in the aftermath of a disruptive event if natural gas service is interrupted and oil cannot be refined.

Interdependencies are not merely established between infrastructure systems. Important interdependencies also exist between social systems and infrastructure systems. As Figure 9 exemplifies, financial systems require electric power in order to provide their services, and financial services are essential for the operation of electric utilities. With an aging workforce and expectations that a significant portion of the current workforce will retire in the next decade, electric power utilities are extremely dependent on educational systems, which, in turn, need electric power to provide their services. At a community level, interdependencies among systems exist in a very complex meshed structure, in which services provided by one system influence and are influenced by other community services. Thus, changes in the resilience in one of these systems can affect the resilience of the other systems through their interdependencies. Therefore, a community resilience assessment methodology needs to consider how interdependencies affect resilience of each community system in particular and of the community in general.

Figure 5. A natural gas compression site near St. Gabriel, LA after Hurricane Gustav.

Figure 6. Willow Glen power plant in St. Gabriel, LA after Hurricane Gustav.

Figure 7. Little Gypsy power plant in Laplace, LA. This power plant is primarily fueled by natural gas, but it also accepts oil as fuel. Oil storage tanks are seen on the bottom right corner of this photograph.

Figure 8. Shell refinery in Norco, LA. The detail in the box on the bottom left shows the electric substation serving this facility.

Figure 9. A mobile diesel generator powering a bank office south of Baton Rouge, LA after Hurricane Gustav.

h. Importance of Dependencies and Interdependencies over Time

Another important element of an assessment is to evaluate the relative importance of the many connections between dimensions, services, systems, and resources. The example discussed above illustrates this concept. While the electric power plant in Figure 7 is critically dependent on natural gas distribution systems, it is only conditionally dependent on oil production, refining, and distribution systems when natural gas systems are out of service and the on-site oil storage tanks are empty. Likewise, electric utilities are critically dependent on financial systems, but they are only dependent on educational systems in a complementary way because electric power grids could operate for relatively extensive periods of time even when the educational system is not fulfilling the electric utilities' workforce instructional and development needs. Nevertheless, it is important to also point out that this characterization of dependencies may change over time or may also change when considering different resilience time scales. For example, although for short time scales electric power utilities dependence on an educational system may be considered complementary, such dependency may be critical when assessing long term resilience of electric power systems.

i. Cascading Effects

Finally, it must be noted that disruptive events often lead to a necessary reduction in total level of all services available in a community. While the goal is to minimize the magnitude and duration of the net effect, communities will need to prioritize particular interventions as they move toward resilience. One important element to consider when evaluating the importance of dependencies and interdependencies are potential cascading effects between any two elements and the other systems, services, and dimensions. We should not only look at first order impacts, but we should also strive to look at the effects across all of the community elements described here. Part of developing community resilience metrics then, will require somehow identifying dependencies across these levels and categorizing the impacts a disruption will create for other systems, services, and dimensions down the line.

j. Assumptions and Limitations of the General Approach

Resilience is a complex concept. It captures our desire to make the places we live less susceptible to disruptive events by thinking about the services communities need to function and thrive. When considering the spectrum of community dimensions, services, systems, and resources, as discussed in the previous sections, one sees that each of these elements is related to and dependent upon the others; yet, accounting for the full set of dependencies and interdependencies is a difficult task. Therefore, some simplifications will be necessary in order to make a practical and usable resilience assessment tool. One initial way to simplify the analysis is to treat community dimensions as if they are not dependent on each other. This is obviously not true, but approaching the problem this way will allow users to focus on the more tangible elements of the community where change is possible (e.g., systems, policies, etc.). While necessary for this initial articulation of the assessment framework, considering these dependencies could be an important future project.

It is also important to note that community dimensions are not always met with services, systems, and resources originating entirely from within the boundaries of a single community. It is often the case that one community is dependent on or interdependent with those around it. It is important to note that the concepts and examples provided in this report are largely focused on how a community can improve in one or more dimensions through more resilient services and systems located within its community. However, a

community should also consider how improved resource sharing and regional planning efforts might serve as a context for internal decisions.

Another, and perhaps more significant, limitation of the approach is that it is neither comprehensive, nor specific, nor complete. As stated previously, the concept of resilience starts at a local level. In fact, it can be suggested that resilience starts with individual people, individual elements of infrastructure, and so on. For example, the ability of a roadway to withstand the effects of flooding and washouts could be based on the ability of a single culvert to convey surface run-off from one side of the road to the other. As such, to be truly effective, resilience assessments need to take into account as many individual elements as possible and examine the overlaps with and relationships to one another. Next, it is not possible to create a general assessment methodology that explicitly addresses every community dimension, service, system, resource, stakeholder, and threat condition. Thus, individual communities need to assess what they value and what their local budgets and needs are capable of addressing. Finally, assessments should be viewed as an ever-evolving work-in-progress to be reviewed and updated as knowledge, experience, and needs change over time.

k. From Concepts to Assessment – Pulling it all Together

Much of this general discussion has focused on a series of somewhat abstract concepts. In this section, we provide some insights into how these ideas might be brought together in order to perform an actual assessment. For the purposes of this document, we are not attempting to fully articulate the steps and tools one might use. Instead, we examine the following issues and questions in the context of an illustrative example:

- Selection and prioritization of community dimensions:
  - Which dimensions are the most important to a particular community?
  - What is the relative importance of these dimensions within different recovery time frames?
  - What is the level of consensus and/or conflict over the relative importance of these dimensions?
- Identification of the services and systems that are needed to support the selected community dimensions.
- Assessment of how well current services and systems are supporting the selected community dimensions.
  - Although the roles of community services in supporting community dimensions are readily apparent in many cases, the linkages are not always obvious and are often not formally assessed.
  - Consider how these services are delivered on a day-to-day basis by checking to see if and how the community is already delivering these critical services through fundamental activities – then move forward from there.
- Identification of performance indicators that are relevant to the selected community dimensions, such as:
  - High levels of employment
  - Low levels of poverty
  - High levels of educational achievement and workforce skills
  - Housing availability, affordability, and stability
  - Low levels of crime
  - High levels of social connectivity and capital

    - Physical and mental health
    - Happiness
- Development of performance goals – An important part of any assessment is the identification of benchmarks or goals to measure one's community against. For example, resilience could be assessed for an individual community dimension, service or system, or it could be assessed for a group of such dimensions, services or systems. The in Such decisions will influence various choices in the overall resilience evaluation process, such as:
    - Who develops these goals/benchmarks?
        - Community developed/benchmarked
        - External/agency benchmarked
    - How will dimensions be benchmarked?
        - Qualitative
        - Quantitative
    - Consider the importance of how different dimensions vary over time: short-term (days), medium-term (weeks), and long-term (months).
    - What is the level of aggregation that the benchmark is considering? Are the resilience levels of each individual dimension being assessed individually and then aggregated together or is a unique benchmark considered for the entire community?
- Consideration of possible solutions for meeting performance goals
    - How important is each system to maintaining services for that function?
    - How do the levels of demand for that service vary with time?
    - What options are currently available?
    - What creative new alternatives can be imagined?
    - Consider connections between particular systems, services, and the dimension.
    - Benefits and costs
    - Equity of benefits and costs

l. Visual Display of Community Resilience Assessment Results and Goals

To facilitate communicating and understanding of the assessment results, the methodology should include some type of visual display or "dashboard." The output of the assessment could, for example, be represented in a form like the one shown in Figure 10, in which resilience is assessed for each community system, service, or dimension on a scale from 0 to 1 for a specified hazard type and level. Tables, such as those included in the NIST Guide (NIST 2015), could still be used as a tool for what they have been successfully used up to this time (i.e., as a way to indicate resilience goals). That is, a community assessment tool display such as the one in Figure 10 could be used in combination with the tables in the NIST Guide in order to graphically identify the gaps between desired and expected resilience in all categories and, then, use this information to prioritize investments for community resilience improvements. If it is possible to define resilience metrics so that the performance goal tables in the NIST Guide could be translated into desired resilience metrics, then a plot like the one in Figure 11 could be built in which both the existing resilience assessment metric and the desired performance are plotted together and then the severity of the graph is plotted in a color code in order to easily identify the systems, services, or dimensions with the most significant gaps. Similarly, a tool could be developed that asks community stakeholders to provide insights into their preferences and those could be used to develop individualized performance benchmarks. Investment needs could be estimated based on the difference between desired and expected resilience.

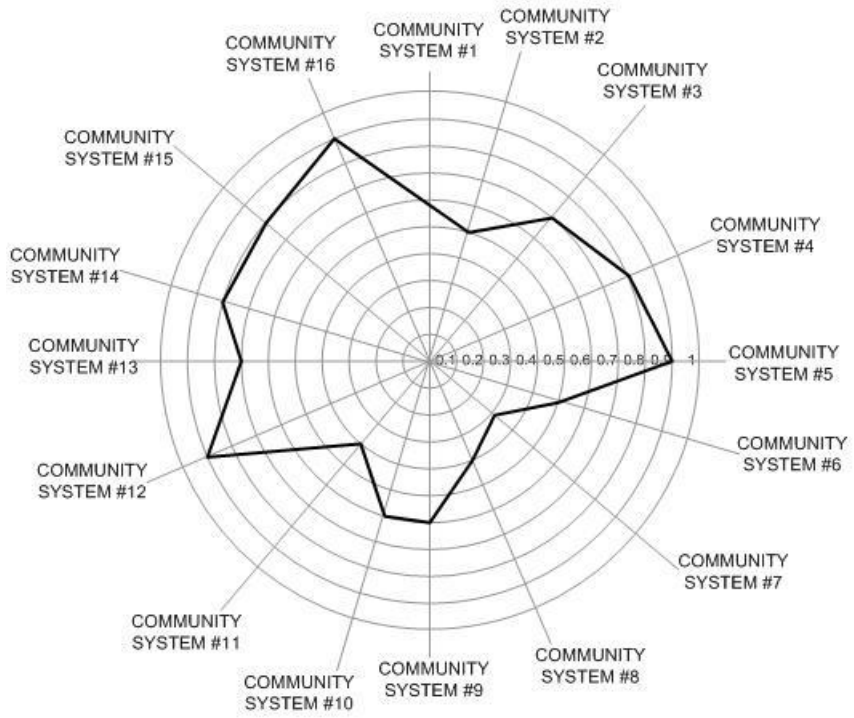


Figure 10. Example of a way to present community resilience (at the systems level) based on a quantitative scale ranging from 0 to 1.

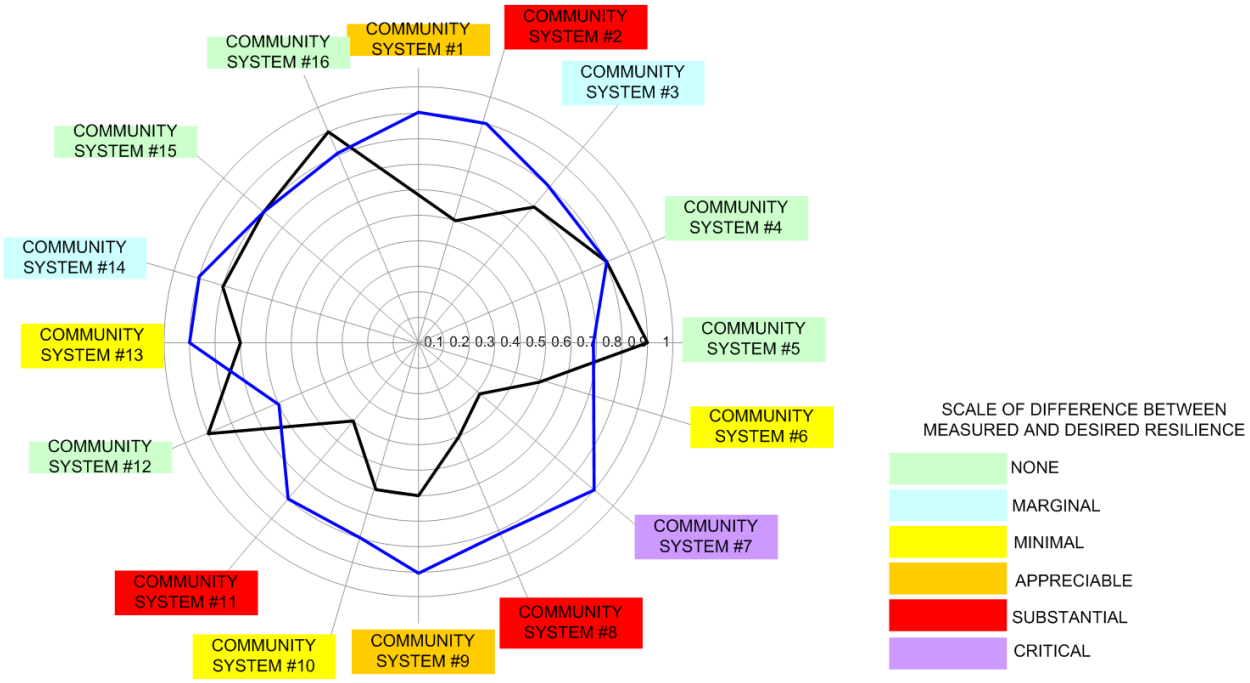


Figure 11. Example of a community resilience assessment tool. The black line shows measured or projected resilience, the blue line shows the performance goals and colors for each system represent the severity of the gap between expected and desired resilience ranging from green (expected resilience is better than its goal) to red and purple (largest gaps between expected resilience and goal).

5. Illustrative Example

In this section, the community dimension of health is used as an illustrative example to explore potential approaches for assessing the resilience of a community dimension and how resilience studies of the services, systems, and resources that support the health dimension can be integrated into an assessment. Although the framework and processes discussed in this illustration emphasize the supporting roles played by buildings, transportation, energy, communication, and water/wastewater systems, it is implicit that the methodological processes could also be applied to other physical systems. In order to support the discussion presented in this section, Figure 12 builds upon Figure 4 to illustrate the services and systems that support the community health dimension. Note that the ten health care services shown under the community health dimension in Figure 12 correspond to the ten health care services identified in Section 10.4.4 of the NIST Guide (2015).

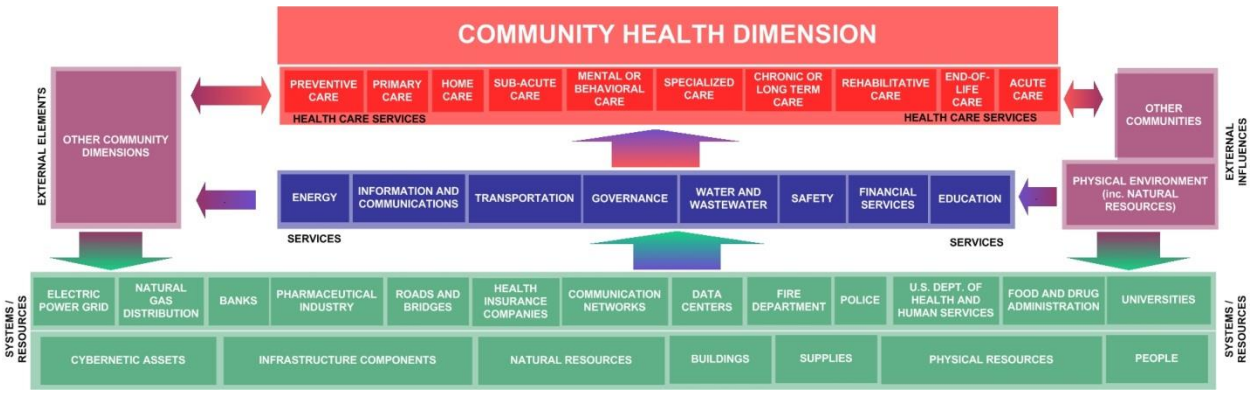


Figure 12. Hierarchy of the community health dimension with supporting services, systems, and resources.

The illustrative example is presented within a temporal framework that is based on the three primary time scales or phases of recovery described in the NIST Guide:

- Short-term period within the first few days of an event, during which the provision of essential emergency response activities is the primary focus;
- Medium-term period of several days to several weeks in which community services are restored to various levels of operation; and
- Long-term recovery period, which may last from months to several years, during which time communities return to pre-event service levels and/or strive to become more resilient to future events.

The NIST Guide also recommends consideration of three hazard classification levels (routine, design, and extreme) to address the range of potential damage, response, and recovery scenarios. Routine events should have limited impacts and recovery should be rapid; whereas extreme events are rare and likely to be accompanied by longer recovery time scales.

The goal of this section is to use the community dimension of health care to illustrate potential approaches for assessing community resilience in the context of these hazard classification levels and recovery time scales.

a. Definition of the Health Dimension and Health Care Services

Health as a community dimension is considered here based on the World Health Organization definition – the need for a "state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO 1948). Health care as a service is considered as the provision of care in order to achieve or maintain an individual in a healthy state. Public health is a related service focused on the collective well-being of the community as a whole or complete unit. While the health dimension includes both, we have focused more on health care here. Hence, in particular, "health care within a community specializes in promoting, monitoring, maintaining, and restoring health" (NIST 2015). As a result, various types of care can be considered as part of the general health care service. From the NIST Guide, the types of care that can be provided as part of the general health care service are: preventive, primary, specialized, chronic or long term, sub-acute, acute, rehabilitative, end-of life, mental or behavioral, and home health care. These types of care span all three primary time scales considered in this assessment methodology, ranging from short-term care, such as acute care, to care, such as mental health care or preventive care, provided in all of the recovery periods, including long-term, after the disrupting actions of the stress event have passed. These types of care also indicate that health care services are necessarily based on a widely distributed and diverse infrastructure, which in some cases even rely on its provision at facilities outside of the domain of health care providers, such as patient homes or other locations that are part of ambulatory-related care.

Based on these types of health care, it is also possible to distinguish a large set of health care activities that are part of the more general health care service. Some examples of these activities include diagnosis, illness treatments (through surgery, medicines and other procedures), dental care, provision of vaccines, and care for the elderly, either in their homes or in specialized facilities, such as nursing homes. It is also worth noting that the delivery of these services can vary significantly across and within communities. For example, some levels of care are typically managed in special facilities such as hospitals, but others are can occur in a wide range of locations, including homes, offices, schools, etc. Different types of facilities within a community may provide the same kinds of care, but to dramatically different standards.

b. Rationale for Selection

Although all community dimensions play an important role when assessing community resilience, the health dimension presents several characteristics that make it a particularly suitable choice for this illustration:

- Health is a critical community dimension that depends on many community services.
- Health care services have strong interdependencies with most, if not all, other community services.
- Health care is a critical need for any community, not only during and after disruptive events but at all other times, as well.
- Community health is a dimension that highlights many of the difficulties in assessing community resilience due to the many factors affecting delivery of services and, ultimately, how it can be measured in a quantitative way.
- Community development and recovery after a disruptive event is significantly influenced by access to quality health care.
- Health care needs are fairly uniform across all types of communities and easily recognized by community members from different stakeholder groups.

- Effective health care provision involves the coordinated participation of both government and private institutions.

Health is a community dimension that provides one of the best illustrations of the key temporal aspects of resilience. From a needs perspective, health care in the aftermath of a major disruptive event is critically important across all temporal scales. From the standpoint of immediate need, health care facilities need to be operational, staffed, powered, and supplied to meet the immediate life-safety needs of those injured or otherwise compromised by the direct effects of the hazard. These types of needs were illustrated in New Orleans during the flooding conditions in the aftermath of Hurricane Katrina when hospitals, nursing homes and other health care facilities did not have electrical power, communications, and ran out of supplies.

From a medium-term perspective, patients and health care workers will also require operational infrastructure systems to support health care services for additional non-immediate life-threatening care for needs associated with treatment of various acute illnesses and treatment of chronic disorders. Similarly, health facilities would need to be resupplied and reliable communications and energy systems would be required. Over the long term, health care is needed for many other health support services ranging from mental health services; elective surgeries and procedures; vision, hearing, and dental services and so on.

While it is clear that the delivery of health care is a fundamental dimension of communities, many of the infrastructure and community systems that support health care support other community dimensions, as well. From a practical standpoint, the infrastructure services, whether transportation-, energy-, communication-, or water/wastewater-related, necessary for health care support most, if not all, of the other community dimensions. For example, if electrical power is restored to an area, it would have a more comprehensive effect beyond health care. This would also be true of most other infrastructure systems. As such, the concepts and ideas presented in the following sections can be generally extended to other dimensions and systems.

c. Pre-Assessment Work – What Should We Measure?

The initial goal of this activity should be to reflect on the level of functioning and the performance goals for whatever dimension the community is working to improve. In the case health care, there are numerous tools and guides available. For example, the Centers for Disease Control (CDC) Essential Public Health Services list (reproduced here as Figure 13) provides an overview of the major public health services and adopts a modified version of the Pan American Health Organization (PAHO) Essential Health Functions List. Building on the approach above, it includes both health care and public health. It is important to take a more general view of health care. While medicine is a critically important element of health, the community health dimension is more general.

Figure 13. CDC essential public health services (CDC 2014).

In other places, more specific frameworks may be preferred. For example, the following list focuses on characterizing specific health services. While the list recognizes that the precise organization and content of health services will differ from one place to another, it contends that the network of service delivery in any well-functioning health system should have the following key characteristics:

- Comprehensiveness: A comprehensive range of health services is provided, appropriate to the needs of the target population, including preventative, curative, palliative and rehabilitative services and health promotion activities.
- Accessibility: Services are directly and permanently accessible with no undue barriers of cost, language, culture, or geography. Health services are close to the people, with a routine point of entry to the service network at primary care level (not at the specialist or hospital level). Services may be provided in the home, the community, the workplace, or health facilities as appropriate.
- Coverage: Service delivery is designed so that all people in a defined target population are covered, i.e. the sick and the healthy, all income groups and all social groups.
- Continuity: Service delivery is organized to provide an individual with continuity of care across the network of services, health conditions, levels of care, and over the life-cycle.
- Quality: Health services are of high quality, i.e. they are effective, safe, centered on the patient's needs and given in a timely fashion.
- Person-centeredness: Services are organized around the person, not the disease or the financing. Users perceive health services to be responsive and acceptable to them. There is participation from the target population in service delivery design and assessment. People are partners in their own health care.
- Coordination: Local area health service networks are actively coordinated, across types of provider, types of care, levels of service delivery, and for both routine and emergency preparedness. The patient's primary care provider facilitates the route through the needed services, and works in collaboration with other levels and types of provider. Coordination also

takes place with other sectors (e.g., social services) and partners (e.g., community organizations).

- Accountability and efficiency: Health services are well managed so as to achieve the core elements described above with a minimum wastage of resources. Managers are allocated the necessary authority to achieve planned objectives and held accountable for overall performance and results. Assessment includes appropriate mechanisms for the participation of the target population and civil society.

In thinking about health as a community dimension, it is important to note that there is a broad range of providers and services that can be categorized in many different ways. For example, the criteria above could be applied to assess delivery of the community health services identified in the NIST Guide:

- Public health-prevention
- Preventative Care
- Primary Care
- Specialized care
- Chronic Care
- Sub-acute Care
- Acute Care
- Rehabilitation
- End of Life
- Mental/ Behavioral Care
- Home Care

It is important to consider if and how these different types of services are being delivered and what level is expected for each. As one progresses from routine to expected to extreme events, the gaps between the desired and projected levels of service can increase significantly.

d. Understanding the "Communities" within the Community

Another important element of measuring the health dimension is to consider issues associated with the distribution of services in the geographic areas and access to those services by a diverse public. Health disparities are differences in health outcomes between groups that reflect social inequities. The research, policy, and public health practice literature report substantial disparities in life expectancy, morbidity, risk factors, and quality of life, as well as persistence of these disparities among segments of the population. No single reason has been found to explain why racial and ethnic disparities exist. At the patient level, factors such as language barriers; socioeconomic status (education and income level); cultural norms and beliefs; and attitudes in the way individuals seek care, make decisions about their care, and adhere to treatments, all contribute to disparities. Within the clinical setting, possible provider bias and stereotyping, in addition to limited time, and a limited understanding, knowledge, and sensitivity about a patient's culture may explain why optimal and equitable care is not always provided. Disparities in health care, specifically, may also stem from organizational barriers, such as the lack of diversity in the health care workforce, lack of access to affordable health care, and the limited availability of culturally and linguistically appropriate services and resources (AHIP 2005). As a result, public health and medical research has long focused on health disparities and social determinates of health. A good assessment tool would need to take these factors into account. As stated by the CDC (2005), "Choices concerning the measurement of disparity should be

made deliberately, recognizing that each choice will affect the results. When results are presented, the choices on which measurements are based should be described clearly and justified appropriately."

e. Assessing Pre-event Service Provision

One of the first tasks in assessing the resilience of a community is to recognize that many of the activities in which individuals currently engage can be thought of as resilience related. It is important to review these activities and consider their impact on a community's state of resilience. The tools described below focus on more specific concerns that can help to assess the level of service provision within the specific dimension and when completed across dimensions can provide a rich view of community resilience:

Several examples of such assessment tools include:

- CDC Community Assessment Tool for Public Health Emergencies (CAT)
  - CAT for Public Health Emergencies was developed using feedback received from several communities that participated in workshops focused on influenza pandemic planning and response from 2008 through 2011.
  - http://www.cdc.gov/phpr/healthcare/documents/cat_cdc.docx
- CDC National Public Health Performance Standards (NPHPS)
  - The National Public Health Performance Standards (NPHPS) provide a framework to assess capacity and performance of public health systems and public health governing bodies. This framework can help identify areas for system improvement, strengthen state and local partnerships, and ensure that a strong system is in place for addressing public health issues.
  - http://www.cdc.gov/nphpsp/
- WHO Service Availability and Readiness Assessment (SARA)
  - The SARA methodology takes into account best practices and lessons learned from the many countries that have implemented health facility assessments of service availability and readiness. It also draws heavily on the work of the International Health Facility Assessment Network (IHFAN) and on experiences from program- and service-specific facility assessment work.
  - http://www.who.int/healthinfo/systems/SARA_Reference_Manual_Full.pdf
- CDC Community Health Assessment and Group Evaluation (CHANGE) tool
  - The CHANGE tool helps community teams (such as coalitions) develop their community action plan. This tool walks community team members through the assessment process and helps define and prioritize possible areas of improvement. Having this information as a guide, community team members can create sustainable, community-based improvements that address the root causes of chronic diseases and related risk factors. It can be used annually to assess current policy, systems, and environmental change strategies and offer new priorities for future efforts.
  - http://www.cdc.gov/nccdphp/dch/programs/healthycommunitiesprogram/tools/change.htm
- Additional Assessment Resources
  - http://www.cdc.gov/nccdphp/dch/programs/healthycommunitiesprogram/tools/change/pdf/additionalresources.pdf

It is important to consider which of these have been applied in a community or could be. It is also important to work with the local facilities, departments, public health entities, etc. that work in the health care sector on a daily basis. While this report highlights national approaches, it is common for state and local agencies to also develop their own tools and concepts of assessment and evaluation.

f. Hazard Assessment

The next element of a health care resilience assessment is to consider what threats a community is likely to face and predict the potential impacts on services, systems, and resources considering three time scales:

1. Short-term period involving immediate life/safety activities and search and rescue operations, often expressed in minutes and hours to a day or two after an event;
2. Medium-term period of several days to several weeks in which community dimensions are restored to various levels of operation; and
3. Long-term recovery period, which may last from months to several years, during which time communities gain full functionality and/or strive to become more resilient to future events.

For each identified hazard scenario, it will be necessary to project the impacts on the services, systems, and resources within each of the three time frames. Questions and considerations to be addressed in the impact assessment include:

1. How are day-to-day services impacted by the event?
   - Loss of capability
   - Increase in demand
2. What are the potential gaps between basic services expected to be available and the needs to meet minimum levels of function?
3. What are the resilience priorities for the different services, systems, and resources in the short-, medium-, and long-term time frames?
4. How do access and demand vary spatially and across sub-communities?

It is also important to consider who in a community will provide care. That care may be provided by government, employers, or by individuals.

g. Attributes of the Community Health Dimension and its Related Services and Systems

Attributes of the community health dimension and related health care services influencing resilience include the following:

- **Vertical structure**: Health care is a widely distributed service that is organized in a vertically hierarchical structure and includes multiple interacting systems. For example, it is possible to identify various levels in terms of the type of services provided at the different health care facilities ranging from a local doctor's office or clinic, where basic preventive medicine and primary care are provided, to community hospitals, where a broader set of services is provided, to regional medical centers, where the most complex health care services are provided. A similar vertical organization is also found in other areas of the health care services. For example, specialization levels in physicians follow a similar structure, ranging from doctors providing general health care to surgeons specialized in procedures concerning one particular human organ, such as neurosurgeons. This organization leads to many dependencies that are

discussed in detail in the next sub-section. Such vertical organization reflects the fact that health needs (i.e., the health dimension) have the same organization.

- **Relationship with other communities**: An important attribute of health care services is that a community's health influences and is influenced by health services of other communities. For example, in anticipation of a hazard event or its immediate aftermath, health care facilities, such as the nursing home in Figure 14, are often evacuated, sometimes for extensive periods of time and/or to relatively distant communities. Such evacuations not only affect the evacuated community by requiring relatives of those under care to travel outside of their communities to visit their loves ones, but also the receiving communities that see their resources stretched and, thus, see their resilience potentially affected. Another example is the frequent reliance on neighboring communities when local capacity is lost or reduced due to damage during a disaster. This is commonly the case, as exemplified in Figure 15 and Figure 16 where the services of local medical offices, dental offices and pharmacies are transferred into neighboring communities. Although such solutions may provide a short-term health resilience improvement, community resilience may be reduced in the long term if the services provided by such local offices cannot be restored, because community members will be forced to continue to travel to neighboring communities in order to have their health care needs satisfied. This long-term resilience reduction is often more noticeable in communities with less economic resources because people may encounter complications when traveling in order to receive assistance for their health care needs. Hence, the vertical structure of community health services, in which more difficult and serious issues are treated at centers of higher complexity, depend on the existence of local built environment in order to provide basic health services, such as dental health or pharmacy services. If these basic health services provided at a local level are disrupted, operations of the centers intended for treatment of relatively few patients with more serious issues could be also affected by having to treat more patients than expected. As previously commented, neighboring communities could also be affected and see their resilience reduced by having more demand on their existing resources. Thus, both long-term and short-term resilience depend not only on local built environment and resources but also on the built environment and resources of neighboring communities in need of assistance after a disaster.

Figure 14. A nursing facility in Pass Christian, MS, after Hurricane Katrina.

Figure 15. A local doctor's office, a pharmacy and a dentist office in the Rockaway Peninsula after Hurricane Sandy.

Figure 16. A medical center in the Rockaway Peninsula destroyed by Hurricane Sandy

- **Time-varying assessment of community health**: An important attribute of community health is that it is a dynamic concept that varies over time as a result of internal influences from the community or external actions, such as those caused by disruptive events. For example, community news could gradually influence its members' mental health, both positively when some important achievement leads to more optimistic views about the general state of well-being, or negatively, if misfortunes leads to anxiety, depression, or a generally pessimistic view of the situation. External actions may also affect community health in a dynamic way. For example, many diseases have an incubation or development time that is key in influencing how community health evolves over time. Moreover, most medical treatments require some time in order to begin being effective. In terms of resilience assessment, this dynamic variation of community health needs to be considered within a context of an event that will evolve with the passing of time in the three phases (i.e., short-, medium-, and long-term). During these phases, a community's health care needs are expected to change and, thus, the health care system should be designed to accommodate both these changing needs and the natural evolution of health conditions. For example, blood banks have to prepare in advance of a disruptive event that may affect the community because building the necessary blood stock demands considerable time. As a result, community health resilience will necessarily need to be considered in a dynamic way with variables that will influence its speed of change. These variables are influenced by a number of factors, such as availability of resources and infrastructure quality.
- **Multiple aspects of community health characterization**: One particular challenging attribute of community health is the multiple aspects in which it can be characterized due to the many types of health care services and the many factors influencing provision of health care services. Fundamentally, this complexity originates in how community health is defined; i.e., the "state of complete physical, mental and social well-being." At an individual level, people may have

different interpretation of what such state of complete well-being is. Moreover, people may consider that they are healthy when they are not actually healthy or vice versa. Furthermore, individual assessments of state of complete well-being may not be directly extended into an overall community state of well-being. Thus, the multiple aspects community health creates a significant challenge when trying to measure community health resilience. This challenge is further discussed in the last portion of this chapter.

- **Influence of individual and group social beliefs and traditions**: The relative notion of well-being and community health in general lead to another broader attribute of community health. Community health and delivery of related services are significantly influenced by individual and group social beliefs and traditions. Typical examples of such influence are delivery of reproductive medicine services or acceptance of blood donations, storage and transfusions. Another example of social beliefs influencing community health has been opposition by parents for their children to receive vaccination. However, although it is intuitively relatively simple to observe that social beliefs and traditions influence community resilience through their effect on health, identifying an objective assessment framework to evaluate how much these factors affect community resilience is less a less straightforward task. Factors such system flexibility and established procedures for serving diverse sub-communities would need to be assessed. A similar complexity is observed when realizing that social interactions are considered part of a complete state of well-being. The level of social interactions varies significantly among individuals in a community and leads to important differences in how individuals would assess their state of health. Hence, assessment of community health resilience has to necessarily balance objective metrics with factors that have a subjective influence on how health care services are delivered and the aggregated effect of how individuals in the community try to maintain or to reach a state of complete well-being while influenced by their beliefs and traditions. It can also be concluded that all members of a community are intrinsic parts of such community health dimension, whether they are experiencing some illness or not.
- **Provision of health care services requires extensive support from infrastructure components and resources:** Health care services are provided by relying (to varying degrees) on an extensive infrastructure (both physical and cybernetic) and by making use of many resources, including human, natural and manufactured. Some of the attributes of community health can be, then, directly related to such need for resources or reliance on health infrastructure systems. For example, in terms of human resources, community health is based on heavily regulated processes, involving extensive certifications and, at some levels, many years of education, preparation and practice. Hence, it is very complex to coordinate activities, which may often require extensive planning. Many processes are organized in a vertical fashion, sometimes requiring complex approval steps. Health care activities often require interactions with people that are not part of the immediate community, either to obtain information or have access to supplies.

Similar attributes to those observed for human resources are found for the built environment, consumable materials, and cybernetic systems. The built environment includes all infrastructure systems and facilities that support the health system, such as:

- Hospitals
- Pharmacies
- Nursing homes
- Local offices and clinics

- Medical equipment
- Associated equipment for transportation, such as ambulances, medical service cars and medical helicopters
- On-site power assets, such as batteries, generator sets and diesel storage
- Dedicated communication networks, such as ham radios
- Health cybernetic systems including data and information that are used to deliver health services, such as information about how to treat health conditions and patients medical records

Health care consumables are physical supplies consumed when providing health care services. Examples of consumables include:

- Medicines
- Vaccines
- Bandages
- Syringes

Attributes related to community health environment include:

- **All aspects of community health are intensively regulated:** Like human resources, community health built environment and cybernetic systems are subject to important regulations and are also administered with a vertically structured hierarchical organization. They are required to be highly reliable and to operate with an ultra-high availability.
- **High cost:** Community health environment components have very high cost of development, procurement, construction, installation and operation.

h. Dependencies

According to the World Health Organization (WHO 2007), all health systems must carry out six basic activities:

- Providing health services
- Developing health workers
- Developing a functioning health information system
- Providing equitable access to essential medical products, vaccines, and technologies
- Mobilizing and allocating finances
- Ensuring leadership and governance

These activities rely not only on the availability of health care facilities, systems, consumable materials, and personnel but also on services provided by infrastructure operators, government agencies and private institutions and enterprises in order to ensure satisfactory delivery of health services. These needs of a community health care system from other community services establish dependencies that are not limited to hospitals or main health care facilities. These dependencies are also established with other health care services, such as services required by pharmacies in order to distribute medicines. These essential services include electric power (e.g., Figure 17), communications in order to receive prescription orders, transportation networks in order to receive supplies and have pharmacists able to travel, financial services, and security. Such an extensive list of dependencies, exemplified with just one of the many facilities supporting health care services, suggests significant vulnerabilities and potential for reduced community

health resilience. This conclusion can be extended in general. That is, dependencies introduce vulnerabilities that may compromise community resilience.

Figure 17. A closed pharmacy in downtown Manhattan after Hurricane Sandy. The electric utility van represents dependencies with respect to electric power.

The following are examples of services that are necessary for effective delivery of health care services and that may affect resilience of community health:

1. ***Energy*** – Energy services are required by health care systems in order to deliver multiple services, such as for cooling of vaccines in preventive care services. Energy as a dependency relates mainly to two infrastructure-based services: electric power and natural gas. Electric power is normally provided to health care facilities by electric power utilities, as exemplified in Figure 18. Large facilities, such as hospitals, are usually also equipped with standby generators that are commonly fueled by diesel stored in tanks at the facility in order to reduce their dependency on power grids. However, in some cases when the on-site generator fails, or at facilities that are not equipped with a permanent generator, portable generators are transported to the site, as exemplified in Figure 19 and Figure 20. Small and more distributed facilities, such as the previously mentioned local offices or pharmacies, are typically not equipped with permanent generators and do not usually receive portable generator sets during long power outages. As a result, community resilience is reduced because these facilities are not able to provide their services until their electric power service is restored. Although standby electric generators can also be fueled by natural gas, natural gas is usually used primarily in large facilities for heating water and for maintaining the facility at a comfortable and healthy temperature. Although dependencies on natural gas infrastructure could be reduced by storing natural gas at the health facility, such solution is rarely implemented due to practical and safety reasons. Hence, the need for natural gas at some health care facilities creates a vulnerability that, contrary to the case of electric power dependency, cannot practically be mitigated through local storage.

2. ***Water and wastewater*** – Water and wastewater services are critical lifelines for health care services. At a basic level, water plays an important role for hygiene, sustenance, and safety (fire suppression). Water can be, and is, stored in order to reduce dependency from a water distribution infrastructure. However, it is difficult to practically store sufficient water in order

to supply all services in large facilities and it is uncommon for individual community members to store water for their needs. The latter issue could be overcome with increased community education for preparedness programs, but it is not unreasonable to expect that a large percentage of a community will not be sufficiently prepared in case of a disaster. Dependence on a sewage system to remove wastewater is avoided in places where there are septic tanks. However, in these cases, there is a dependency on the transportation network so that trucks can reach the location where there is a septic tank in order to service and empty it. Dependencies on transportation networks are also established when portable toilets are deployed in areas where sewage systems are not operational due to damage, such as those in Figure 21(a).

3. ***Information and communications*** – This lifeline includes traditional public communication networks, such as wireless and wireline networks and data centers. It also includes radio and TV broadcasting stations that could be used to transmit news and health-related messages to the community and that may contribute to improved mental health state with the availability of entertainment after a traumatic event. A main function of public communication services is to enable health care activities coordination and transmission of information for a number of reasons, such as instructions to conduct a medical procedure, obtain information from medical records of a patient, request supplies, or ensure an adequate flow of funds. More broadly, social interaction through social media is increasingly influencing community state of well-being. These interactions are supported by public communication services, particularly wireless communication networks. Hence, it is possible to see in recent disasters the deployment of temporary communications infrastructure at community gathering locations, such as the cell on light truck (COLT) in Figure 21(a) after Hurricane Sandy. This temporary communication infrastructure, supported by a mobile electric power generator, provided not only increased communication capacity in the short term when networks may be saturated due to increased data traffic and call volume, but also provided electric power outlets to charge the communication devices. In the long term aftermath of an event, communications plays an even more important role in supporting community health resilience by facilitating social interactions and expanding access to information through the Internet. Data centers are also important for other health care services because they are used to store electronic medical records. Dependencies on communication services to access and transmit these records could be reduced if medical records and other data, such as information about medicines, illnesses and procedures are stored locally at the medical facility where they are needed. However, this solution is only practical in large facilities, such as medical centers.

4. ***Transportation*** –Transportation services are a key lifeline for health care services not only to transport patients to health care professionals but also to transport health care professionals to patients so they can receive attention locally, as exemplified in Figure 22 and Figure 23. These temporary health care solutions serve to alleviate potential losses in health care capacity, such as the previously commented examples in the Rockaway Peninsula. Transportation services are also needed in order to deliver medical supplies or food to health care facilities. These dependencies may be reduced by storing supplies, such as medicine or bandages or even blood for transfusions in blood banks, locally at the health care facility needing such resources.

5. ***Governance*** – Health care services depend on government administrative actions, such as regulation, inspections, certifications, and support to health insurance services. Health services also depend on a variety of government health programs ranging from insurance programs such

as Medicare and Medicaid to research support by National Institutes of Health and other agencies.

6. ***Financial services*** – Financial services are essential for health care operations in order to enable execution of a broad set of processes, such as medical supplies procurement and medical facilities infrastructure construction and maintenance. Financial services also support insurance programs, including those required for doctors and medical facilities and those needed by individuals. Complex dependencies of health care systems also include governance and financial services. For example, although Figure 18 seems to represent dependency of the former Peninsula Hospital Center on electric power supply, it was a combination of dependencies on financial and governance services that reduced the resilience of the Rockaway Peninsula community prior to the arrival of Hurricane Sandy. News reports (Nir 2012) dating from about 6 months before Hurricane Sandy made landfall described how the neighboring St. John Episcopal Hospital was left as the only moderately large medical facility in a community of more than 100,000 people after the Peninsula Hospital Center, which was providing acute care, long-term care and rehabilitation services, was forced to close due to financial shortages compounded by failed certification of a lab. This closure significantly reduced community resilience as demonstrated by the fact that St. John Episcopal Hospital experienced a 40 percent increase in inpatient volume and had full occupancy with medical surgical units at 100 percent capacity even several weeks after the storm. Moreover, a few months later, St. John Episcopal Hospital experienced financial difficulties after the State of New York delayed some reimbursements needed to cover the losses that the hospital had from the additional demand due to the closing of the Peninsula Health Center and sheltering Hurricane Sandy victims. Dependencies on financial services can be reduced by creating policies that encourage essential service providers to build and maintain a cash reserve for such purposes.

7. ***Education*** – Education is a fundamental service supporting health care services. Although education is needed for effective health care, education may be interrupted for some time without interrupting health care services. In many communities health care and education are linked with health care systems tied to higher-education institutions.

8. ***Security*** – Emergency and security services are closely tied with health services. Safety services are needed under all conditions in order to ensure security and support operations at medical facilities. Additionally, safety services contribute to community health emergency services by hosting the 9-1-1 phone number service and by conducting rescue and disaster relief operations, as exemplified in Figure 24. As illustrated in Figure 21(b), safety systems also provide direct resources to health care services.

9. ***Natural environment*** – Community health has obvious dependencies on the natural environment in terms of air quality, water availability/quality, and food availability/safety. In addition, some community health services also make direct use of natural resources, such as eggs to produce vaccines.

Figure 18. A damaged electric power substation in the Rockaway Peninsula. The building in the background on the left is part of the Peninsula Health Center.

Figure 19. A portable electric power generator in front of Tulane University Health Science Center after Hurricane Katrina.

Figure 20. A portable generator in front of Tulane University School of Medicine after Hurricane Katrina. The building is equipped with a permanent generator that was not operational.

Figure 21 [(a) Left and (b) Right]. Equipment associated with the provision of several community services, such as electric power, communications, medical care, security, and sewage, outside Long Beach City Hall after Hurricane Sandy.

Figure 22. A health care professional providing services locally in the town of Yscloskey, LA, approximately 6 weeks after Hurricane Katrina.

Figure 23. A mobile health care unit in Union Beach after Hurricane Sandy.

Figure 24. A U.S. Army helicopter in Crystal Beach, TX after Hurricane Ike.

i. Relationships between Health Care and other Community Dimensions

All community dimensions are interrelated and influence resilience. In particular, health influences all other community dimensions because people's needs change based on their state of well-being. Conversely, community health is also influenced by needs represented by other community dimensions. In particular:

1. *Sustenance* – An obvious relationship exists between the need for food and water (sustenance) and the community health dimension. This relationship should not be interpreted merely in the context of immediate survival needs after a disaster, such as the emergency disaster relief operation exemplified in Figure 25 and Figure 26. The relationship between sustenance and health should also be understood in a broader context that includes long-term effects on community resilience. Hence, although in the immediate phase after a disaster the relationship between sustenance and health focuses on surviving the disaster, in the long-term attention shifts to the quality of sustenance and its influence on individual and collective health.

2. *Belonging and Relationships* – Social interactions have an important influence on community resilience due to their relationship with mental health. Increased direct social interactions tend to be beneficial to the health of the vast majority of community members. Although it is possible to find diverse places where community members tend to meet, most of these locations have some other purpose, such as grocery stores or schools. In many communities religious centers are a main gathering point. For this reason, these centers are frequently used as relief locations in the immediate aftermath of a disaster, as shown in Figure 25 and Figure 26. Religious groups and charities are also among the most active parties providing assistance to communities after a disaster. All these activities have a direct impact on short-term community resilience after a disaster. Religious centers and groups have also a significant importance for long-term mental health in providing spiritual comfort and a place to meet other community members during the long-term recovery phase. For this reason, losses like the church in Figure 27 could have a significant impact to community health and affect overall resilience by reducing recovery speed. Moreover, as discussed above, in some communities, health care and religion are significantly tied together as community members may make their decisions based on their religious beliefs. In some communities, religious organizations also administer medical facilities, such as hospitals. Still, other social interactions besides religious activities are important for community health. For example, programs that provide counseling or that keep families together in the long aftermath of a disaster help to increase community resilience.

3. *Housing* – An obvious relationship also exists between housing and health. As with the previous dimensions, this relationship needs to be understood in the broader context of long-term health defined above and not just the short term sheltering need that community members may have immediately after a disaster.

4. *Culture/identity* – Cultural activities and entertainment also relate to community health, primarily due to their effect on mental and physical health. This relationship is observed both in the short term when, for example, sporting events help communities to cope with a traumatic event and in the long term as cultural activities and entertainment help community members to achieve or maintain a "complete" state of well-being.

Figure 25. A Red Cross disaster relief site outside a church in New Jersey coast after Hurricane Sandy.

Figure 26. A religious center providing disaster relief in Long Beach, NY, after Hurricane Sandy

Figure 27. First Baptist Church in Gulfport, MS, after Hurricane Katrina.

j. Resilience Assessment of the Community Health Dimension

An assessment of community health resilience can be structured around the four main characteristics identified in Presidential Policy Directive 21 (PPD-21 2013):

1. **Withstanding capability:** Will the community be able to maintain a state of well-being following a disruptive event?
2. **Recovery speed:** How quickly will the community be able to overcome any reduction in the state of well-being caused by a disruptive event?
3. **Preparation:** How much of the potential reduction in the state of well-being is the community able to prevent through actions taken before the disruptive event happens?
4. **Adaptation capability:** Are health care services being modified in response to changing conditions, including, but not limited to, a new economic situation or potential changes in weather patterns?

Such an assessment represents an important challenge because, in general, a community health resilience assessment needs also to evaluate how individual and collective states of *complete physical, mental and social well-being* relate to the four aforementioned characteristics of resilience. Hence, two important decisions when evaluating community health resilience include determining whether such resilience is indicated in a qualitative or a quantitative manner and whether it should include a single metric or various indicators. Such decisions may depend on a number of factors, including the desired level of accuracy, availability of resources to conduct the assessment, and the level of expertise of the people conducting the evaluations and making community health care services planning decisions. It should be noted that an assessment of the community health dimension should begin with the expectation that a complete state of well-being is attainable – imperfections will exist in all practical evaluations. The fact that a perfect state of reliability in physical components or availability in physical systems is also impossible to achieve has not prevented the development of an entire field in engineering intended for the assessment of reliability and availability of physical components and systems.

One challenging aspect of evaluating community health resilience is the subjective nature of how individuals may assess their own health. Some individuals may not be able to provide accurate reports on their own state of physical well-being. This suggests an intrinsic relationship among all three components—physical, social and mental—of well-being. This relationship adds another complexity to the analysis, not only because of the difficulties in assessing the influence level of one aspect over another but also because of the difficulties in measuring social well-being in particular. As noted above, social well-being can influence mental health and, this influence on mental health could lead in some cases to real effects on physical health. But social well-being is a particularly challenging aspect to evaluate because of the subjective nature of what "social well-being" means for each individual. For example, social well-being could be assessed based on number of social interactions. However, the quantity of social interactions is not indicative of the quality of such interactions and, more importantly, how those interactions affect an individual's state of mind. That is, the underlying question is, eventually, whether social well-being equates to happiness and, if so, how can it be assessed? The answer to this question is expected to be the focus of future research. This research should necessarily consider practical aspects of how well-being and, eventually, resilience are assessed. Some of these practical aspects include limitations originating in privacy laws and on potential medical tests required and how to administer them to a sufficiently large sample of the community population. The dynamically changing nature of community health resilience yields additional complexities that may need to be considered as part of future research. One alternative, in order to consider dynamic aspects of a health resilience assessment, is to identify the most significant attributes

that affect how health resilience change over time, such as availability of resources or influence of human interactions for mental health. However, such assessment may be also of impractical implementation due to its complexity.

Similar difficulties are found when assessing individual health care services because some indicators, like survival rate after a medical procedure or life expectancy, may not provide an indication of quality of life and, thus, state of well-being after those procedures. Moreover, it may not be possible to aggregate assessments of individual health care services in order to find a broader community health resilience indication. Issues when aggregating health conditions are found when trying to extend assessment for individual persons of a community into a collective indication of the community's state of well-being. The related challenge for this problem is not only the aforementioned difficulties in considering individual personal assessments of the state of well-being but also questions about how to combine all the individual assessments into a collective indicator. For example, one of these questions is how to consider the aforementioned multidimensional nature of community health? Is it possible to weight and combine assessment factors in a manner that accurately reflects their complex interactions and their relative importance to a particular community?

The dependency of health care services on other services is an important aspect that also needs to be included in a community health assessment. Fortunately, contrary to the other factors discussed in this section, assessing the degree of dependencies and their effect on community health could be an aspect that is simpler to approach and evaluate. Such assessment requires an evaluation, at each health care site of interest, of the other services that are needed to provide health care services, the inherent resilience of such other services—i.e., it will be necessary to develop a resilience assessment framework for those other services—and the level of local storage associated with transferred services that is necessary to provide health care services at the facility. For example, at a pharmacy it will be necessary to assess resilience of the transportation network reaching the pharmacy and how many medicines, vaccines and other supplies need to be stored at such pharmacy so delivery of those supplies can be maintained for a given time in case of disruptions with their delivery process. Likewise, a hospital may also need to assess how much blood needs to be stored in its blood bank. Additionally, a hospital may need to assess the resilience of its power grid tie and how much diesel fuel needs to be stored locally in order to supply its backup generators and maintain operations for a required time during long power outages.

The aforementioned factors are some of the most important issues to consider when assessing community health resilience. However, these are not intended to be a description of the only factors to be included in such assessments. Other factors could be of importance, such as relationships with other communities or the effect of pets on community health due to their influence on mental health. Considering these and other factors could lead to questions, such as whether an evaluation of veterinary hospitals, such as the one in Figure 28, should also be included in a community resilience health assessment. Eventually, the search for a balance among practicality, simplicity and assessment accuracy will necessarily have to limit the factors considered in an evaluation. Such prioritization of factors is in itself a complex problem which will likely require extensive future research.

Figure 28. A veterinary hospital in Long Beach, NY, after Hurricane Sandy.

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6. Conclusions and Recommendations

The first and most important insight from this project is a conceptual framework for assessing resilience at the community level. The framework, depicted in Figure 4, is represented through community dimensions and their relationships with community services, systems, and resources. These components are defined in this study as follows:

- **Dimensions** are the broad purposes or desires of the community.
- **Services** are the provision of specific activities, supplies or goods that support community dimensions.
- **Infrastructure systems** are specific combinations of resources and human actions organized to deliver services primarily through the built environment and cybernetic sub-systems. As illustrated in Figure 2, infrastructure systems comprise three primary domains: physical, human, and cybernetic.
- **Social systems** are specific combinations of resources and human actions organized to deliver services primarily through human interactions. Social systems are formed by the same three primary domains as infrastructure systems, but with an emphasis on the human dimension over the physical and cybernetic dimensions.
- **Resources** are inputs to systems that are used, and in some instances consumed, in order to deliver services.

This hierarchical structure of the framework is illustrated in Figure 4 and is intended to bridge a significant gap found in some previously suggested community resilience assessment frameworks by more explicitly considering the integration of social systems and infrastructure systems and by differentiating these systems from the services that they provide. In essence, the proposed framework treats people, buildings, infrastructure, and information systems as the pieces that communities organize in order to produce services that support essential community dimensions. Natural resources can also be very important in the resilience planning process, but these are beyond the scope of this study.

Next, the development of this report has revealed a number of important difficulties in developing an approach that is universal. When one considers the concepts of community dimensions and services in the abstract, they help make sense of crucial components of a community. That being said, when one attempts to consider benchmarks for these dimensions and services, there is an inherent tension between community empowerment and the idea of universal comparability. On one hand, we wish to recognize that different places will make different assessments of how important one service or dimension is or what level of service is required at one time or another. This will necessarily lead to different benchmarks or performance goals in different communities. The desire for comparability, on the other hand, calls for the establishment of a more universal standard. Further, the idea of measuring the potential benefits of particular resilience enhancing activities may be more complex than initially envisioned due to the complex relationships between services and the community dimensions they support. One can envision scenarios in which a particular activity greatly enhanced the resilience of one place, but in another, the same activity may not have the intended effect due to the configuration of other related systems, services, or components.

This study has also identified several challenges that will influence the further development of a comprehensive and practical community assessment resilience methodology. These challenges include:

- **Selecting metrics or indicators** for evaluating resilience (whether these indicators are quantitative or qualitative) and determining how to evaluate them.
- **Projecting social benefits** or impacts under different planning scenarios. These include benefits or impacts that cannot be expressed in monetary terms or that the community may not wish to express in monetary terms, such as: deaths, injuries or illnesses avoided; community disruptions avoided; or any other net negative social effects that are reduced or avoided through the implementation of community resilience measures. This could also include less tangible effects that can be difficult to measure, such as loss of community cohesion or culture. The assessment of social factors should also consider how social impacts and benefits are distributed within the community.
- **Dealing with multiple metrics** or indicators. In general, some combination of social indicators and economic metrics will be required. These, in turn, will depend on system performance levels and associated recovery times. Figure 11 presents one possible approach for displaying multiple disparate measures without aggregating them into a single combined score.
- **Developing a focused set of dynamic resilience metrics** that are applicable to the short-term (days), medium-term (weeks), and long-term (months) assessment time frames that are recommended in the NIST Guide (NIST 2015).
- **Representing and accurately accounting for external effects** on the community. It is quite uncommon for a community to be internally self-sufficient or self-contained. Activities of one community can have serious and significant impacts on another. This relationship can also work in a positive way. For example, in our health care example we focused on the provision of services within the community; however, in modern medicine, it is common for providers to be part of large and complex networks that dictate policy, but also bring significant negotiating power and connectivity to resources. In the current effort, we have not fully explored the potential of mutual aid agreements and other external influences, both direct and indirect, on resilience.
- **Allowing resilience assessments to be performed at different levels** in the framework. Depending on the time and resources available, one could target individual dimensions, services or systems, certain combinations of these, or the entire community. This decision will clearly influence the scope of the resilience planning decisions that can be assessed and the metrics selected.
- **Treating the effects of dependencies and interdependencies** within community systems and services. Community systems typically depend on services that are provided by other community systems. As illustrated in Figure 3 some dependencies can be mitigated through buffers (i.e., local storage). The buffer capacity required to achieve a given level of resilience can serve to characterize the degree of dependence. It is also possible to identify different levels of dependencies, some more critical than others, although this can change depending on the recovery time frame being considered. In this report, two-way dependencies are referred to as interdependencies. Through dependencies and interdependencies, all community dimensions are interrelated. Therefore, resilience improvements focused on one community dimension are likely to affect all other dimensions to varying degrees. As a result of such complex interactions, characterization of dependencies may need to be simplified or considered on a limited basis in order to simplify the analysis to a practical level.
- **Balancing assessment accuracy and comprehensiveness with implementation practicality and simplicity**. This challenge encapsulates the more specific challenges described above and is perhaps the most significant challenge we encountered.

Some lessons have also been identified by exploring a specific example of the community health dimension and related health care systems and services. Community health clearly demonstrates the dynamic notion of resilience as it changes over time and the many dependencies and interdependencies that can be found among systems and services and the community dimensions they support. One of the lessons learned though the discussion of community health is that it is difficult, if not impossible, to treat resilience of a given community in isolation because of the influence and interactions with neighboring analogous communities and the broader political and social environment. Still, it is important to identify local resources as well as resources that may be available from outside of the community.

A practical community resilience assessment methodology must be adaptable to communities of different types and sizes. Through the study of the community health dimension, it was possible to describe a general structure for a community resilience assessment, beginning with a pre-assessment with the goal of determining what to measure and what approach to follow. The pre-assessment is then followed by the proper assessment, in which it is recommended that service performance be evaluated in terms of the four resilience components described in the PPD-21: (1) withstanding capability, (2) restoration speed, (3) planning capacity, and (4) adaptation. The assessment should provide an understanding of the sub-groups within the community and project the expected levels of service provision under each of the relevant hazard scenarios. In many cases, it will be important to assess not only whether a service can be provided but also the quality of service delivery. Definitions of the community dimensions and services may also lead to additional challenges. For example, the definition of community health with respect to social well-being may introduce a subjective component to the assessment.

Many research needs are, thus, identified from the discussion presented in this report. One important research objective relates to the need for measuring resilience by identifying attributes, dependences and other influencing factors and integrating these notions in a simple to understand output. Such an evaluation is a complex task because it is likely to be affected by limitations, such as laws, beliefs and implementation practicality. Since dependencies and interdependencies play a critical role, their characterization and identification also represent important research needs. Analysis of scaling approaches to determine resilience by considering assessments at an individual level and aggregating them into a community indicator is a complex problem that also needs to be further explored. All these studies need to be made within a context of resilience as a dynamic indicator that may change for different time scales. Ultimately, it is important to accept that any assessment will require significant simplifications in order to find a balance between practicality and comprehensiveness. Hence, every assessment methodology will include tradeoffs and need to accept certain margins of error.

As a next step, it is recommended that the analysis of the community health dimension be extended to other essential community dimensions, including: sustenance, housing and shelter, education and personal development, security and safety, culture and identity, and belonging and relationships. This process will lead to a richer and more complete understanding of the dependencies and interdependencies of community dimensions and services with the built environment. The infrastructure systems that support essential community dimensions are fundamentally linked, and their dependencies and interdependencies extend beyond community boundaries. This is certainly the case over longer time scales where it is necessary to have educational, health, and financial systems that support the people that are responsible for the operation of infrastructure systems. It is critical that future community resilience evaluation methodologies include guidance for assessment and evaluation teams by:

- Identifying common dependency and interdependency linkages;

- Encouraging planners to look for and identify other important linkages; and
- Providing guidance on evaluating the resilience of the linkages between systems and community dimensions in addition to the systems themselves.

Resilience must be evaluated not only in terms of the physical components of infrastructure systems, but also in terms of the resilience of plans, policies, and people. Evaluation methods must include mechanisms to assess whether those elements are also resilient.

A simultaneous objective should be to begin building a catalog of tools and methodologies for estimating recovery times, economic impacts, and social impacts that is applicable to a broad range of possible hazard scenarios, community types, and recovery time scales. The selection and/or development of these tools and methods should focus on the needs and capabilities of end-users. Any guidance, methods, information, and expectations should encompass a range of experience, expertise, staff availability, and budgetary resources and should allow for localized and location-specific practices and customs. For example, the assessment methodology should provide enough flexibility so that it could be adapted for use by a municipality as large as New York or a small rural community whose challenges, manpower, experience, and budgetary constraints are completely different.

Finally, it is recommended that a set of pilot community resilience assessments be conducted and documented for a broad range of real-world case studies. A key focus of the pilot studies should be the selection of metrics or indicators that are appropriate to the pilot communities and the development and evaluation of methods for displaying multiple disparate measures or meaningfully aggregating them into a single combined score.

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