RESILIENCE

The 2nd International Workshop on Modelling of Physical, Economic and Social Systems for Resilience Assessment

14-16 December 2017

Ispra

Volume II

Printed by Imprimerie Centrale in Luxembourg

Luxembourg: Publications Office of the European Union, 2018

Print	ISBN 978-92-79-79924-2	doi:10.2760/39325	KJ-04-18-134-EN-C
PDF	ISBN 978-92-79-79923-5	doi:10.2760/727592	KJ-04-18-134-EN-N
EPUB	ISBN 978-92-79-79925-9	doi:10.2760/977709	KJ-04-18-134-EN-E

Contents

Developing an Assessment Methodology for Community Resilience

Maria K. Dillard
Community Resilience Program, National Institute of Standards and Technology (NIST), US Department of Commerce

Abstract

Communities can be characterized as complex systems, with resilience as an emergent property. Complex systems are systems composed of interconnected parts that exhibit emergent properties that arise from the collective and cannot be derived from the individual parts. Communities are composed of dependent social, economic, natural, and physical systems. Understanding how the performance or functionality of these community systems impacts overall resilience can improve planning, policy formation, and decision-making for hazards as well as chronic stressors. The systematic measurement of community resilience requires a coherent methodological approach that depends upon metric development. Meaningful, objective metrics will support systems modeling efforts for resilience and will help communities with long term monitoring and evaluation. The metrics, while enabling assessment of a community's ability to respond to hazards, will be independent of hazard events.

The research aim is to develop a methodology for measuring resilience of social, economic, and physical systems at the community scale. The method draws on a social science based approach to composite indicator development as a means of developing a suite of metrics for the characterization of baseline conditions. Ultimately, the methodology will support the development of the tools necessary for communities to quantitatively assess their resilience over time using community resilience indicators that account for relevant aspects of the overall system.

Keywords: resilience, community, metrics, indicators, complex systems, social science

1. Introduction

Community resilience is a complex, multi-dimensional problem that relies on engineering, social sciences, earth sciences, and other disciplines to improve the way communities[1] prepare for, resist, respond to, and recover from disruptive events, whether those events are due to natural or human-caused hazards. To date, empirical studies have failed to provide a strong methodological foundation for the integration of community systems into a cohesive measurement for resilience. For example, when social dimensions are incorporated, they are often limited to economic factors as opposed to a broader, more complex set of social factors (e.g., factors related to institutions, social demographics, socio-cultural resources). Further, metrics are often designed to either assess baseline conditions or post-event recovery conditions, but not both. Community resilience will be advanced by establishing a more comprehensive, integrated suite of metrics across the systems that remain meaningful, even in the absence of a hazard event.

[1] Communities are defined as "places (such as towns, cities, or counties), designated by geographical boundaries, that function under the jurisdiction of a governance structure" (NIST 2016). Communities include social institutions (e.g., economy, government, education, religion) as well as buildings and physical infrastructure that support the needs of its members.

In the past, communities were encouraged to consider and plan for resilience with little guidance or tools at their disposal. Recently, NIST released the Community Resilience Planning Guide for Buildings and Infrastructure Systems (NIST 2016) to help communities plan and implement prioritized measures for the built environment based on social and economic needs, with the aim of strengthening overall resilience to hazard events. The next phase of NIST's work is focused on providing communities with the tools necessary to evaluate and measure their resilience and to support the exploration of decisions that may enhance their resilience to hazards. A more resilient community will have, among other characteristics, improved functionality of buildings and infrastructure systems, a shorter recovery time of community functions following disruption, good governance, and economic security.

In this paper, the necessary steps of a methodology for assessing community resilience are proposed (see Box 1). These steps are partially adapted from work by the Organisation for Economic Cooperation and Development and the Joint Research Centre (Nardo et al. 2008) and the National Oceanic and Atmospheric Administration (Dillard et al. 2013). A selection of these steps, particularly 1 through 4, will be addressed in subsequent sections.

Box 1. Proposed Steps of Methodology to Assess Community Resilience

1. Development of a theoretical framework
2. Seek consensus among existing resilience methodologies, frameworks, and researchers via a modified Delphi process
3. Selection of a quantitative measurement approach
4. Data and measure selection
5. Imputation of missing data
6. Multivariate analysis
7. Normalization, weighting and aggregation
8. Uncertainty and sensitivity analysis
9. Deconstructing measurement, identifying relationships with other variables
10. Visualization and presentation of measurement
11. Validation studies
12. Finalization of methodology
13. Dissemination of methodology and best practices

1.1. Conceptual foundation

Development of an assessment methodology for measuring community resilience is an essential component of systems modeling efforts, particularly those focused on providing decision support for community resilience. The assessment methodology being developed will be based on several important theoretical propositions. Several of these propositions are based on systems thinking, which refers to the approach to understanding a system through an understanding of its components and their relationships, as well as the properties and behavior of the system as a whole (von Bertalanffy, 1976; Miller and Page, 2007). This approach offers value in both theoretical and methodological terms.

1. Communities can be characterized as complex systems with emergent properties, such as resilience. Complex systems are systems composed of interconnected parts that exhibit emergent properties that arise from the collective and cannot be derived from the individual parts. Communities are composed of dependent social, economic, natural, and physical systems.

2. Community functions are linked to buildings and infrastructure systems. Examples of community functions include the following: housing, economic activity, health, education, public safety, communication, transportation, social connectedness, and recreation. Each function is delivered through interconnected components of the social system (e.g., education system, health care system), the economic system (e.g., businesses), the physical system (e.g., building clusters, transportation networks, communication networks), and the natural system (e.g., natural resources).

3. Resilience is a function of community state. Characteristics of community systems (or their point-in-time state) are assessed over time to measure the resilience of the community. In this way, the characteristics of the community before the hazard event determine, in part, the community response to the event, including the recovery trajectory.

4. To capture the response of the community to a hazard event and more common, chronic stressors, resilience assessment requires tracking the same set of characteristics over time.

5. Resilience is not the only emergent property of integrated community systems; there are other emergent properties. These include, social capital, adaptive capacity, and vulnerability. These properties may influence the response of the community to the hazard event.

Much work has been done on the conceptual clarification of resilience and its associated characteristics (e.g., Holling, 2001; Carpenter et al., 2001; Cumming et al., 2005; Perrings, 2006; Gallopin, 2006; Adger, 2006; Brand and Jax, 2007). This body of work provides an important theoretical basis for the measurement of resilience. The step *Development of a theoretical framework in Box 1* above includes the establishment of the theoretical basis for measurement, including identifying and defining core concepts, selecting composite indicators, and determining essential components of the composites. As part of this step, NIST researchers are beginning with the critical task of identifying characteristics theoretically linked to community resilience.

2. Challenges in the assessment of community resilience

To date, empirical studies have failed to provide a strong methodological foundation for the integration of the social, economic, and physical dimensions of resilience into a cohesive measurement model. These methodologies are often only focused on the resilience of a single system and rarely represent a tight integration of physical and social systems (Lavelle et al., 2015). Further, dependencies among social or physical systems are not taken into account. Finally, metrics are often designed to either assess baseline conditions or post-event recovery conditions, but not both. These methodologies, if fully developed, are rarely validated (Lavelle et al., 2015).

2.1. Measurement challenges

A significant body of literature attempts to address the complexity of interacting systems, while dealing with problems of scale (organizational, spatial, and temporal), causality, and scale mismatches (e.g., Krieger, 2001; Redman et al., 2004; Adger et al., 2005; Anderies, Walker, and Kinzig, 2006; Cumming, Cumming, and Redman, 2006; Gunderson et al., 2006). This work routinely encounters problems associated with empirical measurement. As a result, few researchers in this area have successfully tackled the formidable task of measurement. Thus, much work remains theoretical or conceptual.

Several challenges need to be addressed in the development of a measurement for community resilience (see Lavelle et al., 2015; Kwasinski et al., 2016). These include: interdependencies among the systems, the unbounded nature of communities, the diversity of dimensions that are part of a community's resilience, tradeoffs between simplicity and accuracy, limited validation, and the need for replicability. Further, there is a mismatch of spatial and temporal scales when combining measurement of social and physical systems. Also, there is a need for empirical linkages between the built environment and the social services being supported

A measurement methodology must include indicators that assess and are relevant to both the pre-event state of the community as well as the post-event response (i.e., leading and lagging indicators). These indicators must all be capable of capturing change. Finally, it is critical that the indicators be focused on items that can be altered by community resilience policies and actions.

2.2. Methodology challenges

There remain fundamental decisions related to the methodology itself. It is essential to strike some balance between resource intensive, place and time specific data collections and the efficiency and replicability of methodologies that rely on secondary or existing data. While the main challenge confronting assessment of community resilience is the complexity of the integrated systems, there are methods for simplifying this complexity. These methods can be used to highlight important and useful composite indicators, indicators, and measures to track over time. Though the problem is complex, the assessment must be simple and practical for use in applied settings (Kwasinski et al., 2016). The assessment must also be scientifically grounded so that the outcomes are of value to communities who wish to improve or maintain their resilience.

2.3. Criteria for the methodological approach

Criteria for a robust methodology are proposed in Box 2. These criteria will be sought in the development of the assessment methodology. To advance the field and avoid duplication, NIST researchers are working to enumerate and evaluate existing indicators and accompanying assessment methodologies; these criteria support this process.

Box 2. Criteria for community resilience assessment methodology

- Systems level measurement
- Community scale
- Takes into account empirical relationships between systems (interdependencies)
- Over time measurement, including the baseline and post-event recovery stages
- Can address varying spatio-temporal scales
- Links to resilience policies and actions
- Scientifically grounded
- Practical for decision making
- Specific enough to be meaningful
- Replicable
- Has been validated

3. Approach to measuring community resilience

To address the challenges associated with the development of the measurement of resilience, NIST researchers will use methodologies common to social sciences (e.g., exploratory factor analysis, structural equation modeling) to develop a measurement method for community resilience. The standardized methodology will guide identification, evaluation, selection, and development of composite indicators for community resilience. This approach will be well grounded in theory and will seek to achieve consensus among existing resilience methodologies, frameworks, and researchers via a modified Delphi process. Furthermore, the approach will emphasize validation studies as a means of exploring the types of relationships (e.g., correlation, causal) between resilience metrics and outcomes we would associate with a resilient system (e.g., shorter recovery time, better performance during hazard event).

Resilience metrics will also be developed with attention to their function in the systems model being developed by NIST researchers. Though effort will be made to create a systems model that captures all community systems, including the complexity of social systems, the assessment methodology will include a number of composite indicators that cannot be fully characterized in the systems model. Composite indicators that are not captured by recovery time, reduced probability of failure, and cost, may also be used in post-analysis to support the evaluation of decision alternatives for their resilience benefits.

This work draws heavily on social indicators methods. The use of indicators spans many distinct disciplines and fields. These include international and community development, public health, and education, where they support the tracking of development, outcomes and performance, as well as in environmental sciences and natural resource management to measure and monitor biophysical phenomena (Dillard et al., 2013). This project aims to move the field forward in part through the explicit inclusion of validation studies of the resilience metrics as well as by establishing a more comprehensive, integrated suite of composite indicators across the systems that remain meaningful in the absence of a disruptive event.

3.1. From concept to quantity

A foundational understanding of terms is an essential component of an effective resilience assessment methodology. In Table 1, the definitions for composite indicator, indicator, and measure are provided along with examples for the social system and the physical system. *Composite indicators* are aggregations of multiple measures using mathematical computation to produce a single value (Saisana and Tarantola, 2002).

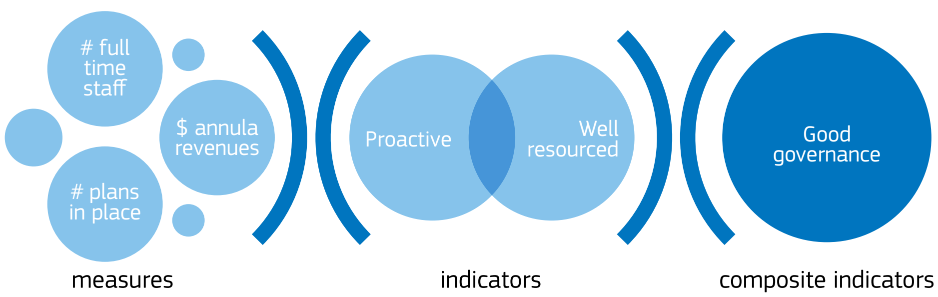
Table 1. Composite Indicators, Indicators, and Measures: Definitions and Examples

COMPOSITE INDICATORS	INDICATORS	MEASURES
An index or composite based upon two or more indicators and generated by mathematical computation	*A quantitative or qualitative measurement that provides reliable means to assess a particular phenomenon or attribute, often indirectly*	*A qualitative or quantitative value*
Example 1: Community health status	Population health	Disease rates in community
	Healthcare access	Hospital beds per capita
	Investment in prevention	Expenditures in public health outreach
Example 2: Structural condition	Age	Year structure built
	Maintenance	Level of maintenance
	Damage state	Level of observed damage

Composite indicators are able to simultaneously simplify complex measurement and communicate the underlying complexity. Most importantly, composite indicators respond to the pragmatic need "to rate individual units… for some assigned purpose" (Paruolo, Saisana, and Saltelli, 2013). *Indicators* are "quantitative or qualitative measures derived from a series of observed facts that can reveal relative position in a given area and, when measured over time, can point out the direction of change" (Freudenberg, 2003). *Measures* are the foundational units by which an indicator is quantified (Nardo, et al. 2008). In this paper, the term metrics is used as a general means of referring to the measurement of resilience and other complex concepts using composite indicators.

Figure 1 depicts the process of moving from the theoretical framework to the data and measure selection steps of the approach. The measure development moves from right to left, as movement from the more abstract, higher level concept gets grounded in measureable phenomena. Beginning with the most abstract, higher level concept, the researcher goes through a process of determining first "what are the essential components of this concept?" and then, "how are these components measured?". Despite the linear presentation, most measure development is highly iterative and requires some flexibility in the starting point and direction of progress.

Figure 1. The relationship between measures, indicators, and composite indicators



3.2. Development of composite indicators

Social science based approaches to composite indicator development typically include several of the steps referenced in Box 1. To complete each of the steps, several underlying activities must take place. For example, the completion of *Development of a theoretical framework* will require the establishment of linkages between building and infrastructure functions and societal functions through the identification of empirical relationships; development of a draft framework of community resilience indicators for physical, social, and economic systems; and, engagement of broader community of researchers to gain consensus around a priority list of resilience indicators (through a modified Delphi methodology). The Delphi method solicits the expert opinions through a series of questionnaires interspersed with information and opinion feedback with the aim of achieving convergence of opinion through the process (Helmer-Hirschberg, 1967).

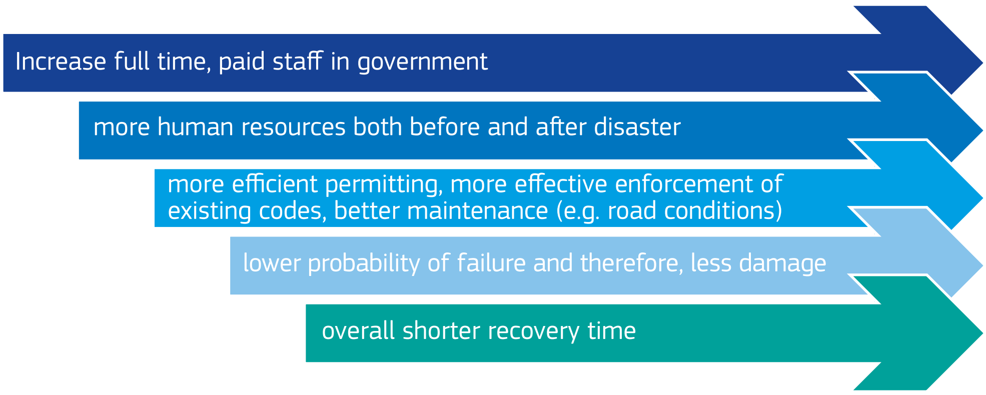
Critical decisions in the development of the methodology include the choice of criteria to apply in the evaluation of indicators. For example, a criterion of including both leading and lagging indicators would require the use of both types of indicators for measuring resilience so as to gain an understanding of community resilience levels before and after hazard events. Likewise, the use of a policy relevance criterion would require that indicators measure, whether directly or indirectly, conditions that can be altered with resilience-related policy and action.

3.2.1. Mapping relationships for community resilience measurement

To identify empirical relationships between building and infrastructure functions and societal functions, the possible dynamics must first be mapped conceptually. Each community resilience metric will ideally be linked to either probability of failure/success, recovery time, or other modeled component to have utility in the systems model. Below, an example of the process of mapping each resilience composite indicator to component indicators that could impact the performance of the physical system is provided.

In Figure 2, an indicator of governance is diagrammed to show its relationship to recovery time.

Figure 2. Example of linking resilience indicators to the performance of the physical system



3.3. Supporting methodology

The final NIST methodology is planned to include the following:

1. selected priority composite indicators, indicators, and measures,
2. the analytical approach(es) for computing each indicator over time for at least one spatial scale,
3. best practices for how the approach can be replicated for different spatial scales,

4. public data sources for all composite indicators, indicators, and measures,
5. data visualization for the composite indicators, indicators, and measures,
6. multivariate analyses to examine relationships between composite indicators, indicators, and measures,
7. sensitivity and uncertainty analysis,
8. and validation studies.

The assessment methodology will ultimately be developed for use by communities and will be science-based, user-friendly, and applicable to communities of varying sizes without requiring extensive technical support to implement. The outcomes of the methodology are envisioned to be presented as a web-based tool for obtaining resilience indicator scores over time for a particular community along with the methodology to support the development of scores for geographic scales not provided by NIST.

4. Conclusion

The systematic measurement of community resilience requires a coherent methodological approach that includes, and often depends upon metric development. Meaningful, objective metrics will support systems modeling efforts for resilience and will help communities with long term monitoring and evaluation. The metrics, while enabling assessment of a community's ability to respond to hazards, will be evaluated in the absence of hazard events. Through the discussion of key issues, this paper aims to provide a shared foundation to facilitate the contributions of a broad community of researchers to the development of metrics that function at varying spatio-temporal scales and reflect resilience and related concepts.

An assessment methodology allows for baseline assessment of the system and for tracking change over time for evaluation of decisions and investments as well as progress towards goals. Several steps of the NIST Community Resilience Planning Guide (CRPG) for Buildings and Infrastructure Systems (2016) would be strengthened by a standardized approach for measuring resilience. For example, the concept of a baseline assessment of the state of the community is central to CRPG Step 2: "Understand the Situation." While this assessment could be conducted using a variety of methods including self-assessments, a standard, quantitative approach would be of great use. In Step 3: "Determine Goals and Objectives, metrics could be used to aid goal setting for community resilience." For example, a goal might be a 20% improvement in 5 years in the community's governance composite indicator. This goal could then be tied to a series of actions that improve components of governance, such as constituent participation, long term planning, and increased financial and human resources. Finally, in Step 6: "Plan Implementation and Maintenance," resilience metrics could be used for evaluation of ongoing investments and activities that are part of plan implementation. Investments in resilience can then be optimized for maximum impact. Each example emphasizes the importance of the steady tracking of resilience metrics as opposed to event specific assessment. It is essential to assess the metrics well before and long after hazard events to understand the community's trajectory and reasonable assumptions for its recovery.

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