NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**MEASURING STATE RESILIENCE:
WHAT ACTUALLY MAKES A DIFFERENCE?**

by

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September 2018

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2018	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE MEASURING STATE RESILIENCE: WHAT ACTUALLY MAKES A DIFFERENCE?	**5. FUNDING NUMBERS**
6. AUTHOR(S) Jasper V. Cooke	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

What drives resilience for states in the United States? This thesis seeks to answer this question and addresses the absence of quantitative metrics for efforts to increase resilience. We used a literature review to create a framework of indicators, a Delphi review to validate the framework, and statistical techniques to create a composite indicator from the framework. Knowing that all models are false but some are useful, the intent was not to perfectly predict resilience, but simply to create a tool to help practitioners understand which programs most affect resilience. Our results showed that even programs assumed to have a strong link with resilience—such as strong building codes—actually had little relation with increased resilience, as measured by weather-related fatalities and economic losses. Some conclusions are that state-level measurement masks granular differences that are important in understanding weather-related deaths. In most states, for instance, weather-related deaths happen infrequently, yet most federal and state programs aim to increase resilience in catastrophic events, which makes it challenging to validate resilience measurement tools using data on day-to-day deaths. Recommendations include that FEMA should continue to build on improvements to the Threat and Hazard Identification and Risk Assessment and that agencies should determine and consistently measure the dependent variable (i.e., deaths and damage or other measures of well-being).

14. SUBJECT TERMS homeland security, preparedness, resilience, measurement, social capital, state, federal, risk management, mitigation, policy, DHS, partnerships, statistics, composite index, quantitative, Delphi, THIRA, SPR, Threat and Hazard Identification and Risk Assessment, stakeholder preparedness report	**15. NUMBER OF PAGES** 163
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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MEASURING STATE RESILIENCE:
WHAT ACTUALLY MAKES A DIFFERENCE?

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS IN SECURITY STUDIES
(HOMELAND SECURITY AND DEFENSE)

from the

NAVAL POSTGRADUATE SCHOOL
September 2018

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ABSTRACT

What drives resilience for states in the United States? This thesis seeks to answer this question and addresses the absence of quantitative metrics for efforts to increase resilience. We used a literature review to create a framework of indicators, a Delphi review to validate the framework, and statistical techniques to create a composite indicator from the framework. Knowing that all models are false but some are useful, the intent was not to perfectly predict resilience, but simply to create a tool to help practitioners understand which programs most affect resilience. Our results showed that even programs assumed to have a strong link with resilience—such as strong building codes—actually had little relation with increased resilience, as measured by weather-related fatalities and economic losses. Some conclusions are that state-level measurement masks granular differences that are important in understanding weather-related deaths. In most states, for instance, weather-related deaths happen infrequently, yet most federal and state programs aim to increase resilience in catastrophic events, which makes it challenging to validate resilience measurement tools using data on day-to-day deaths. Recommendations include that FEMA should continue to build on improvements to the Threat and Hazard Identification and Risk Assessment and that agencies should determine and consistently measure the dependent variable (i.e., deaths and damage or other measures of well-being).

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LIST OF ACRONYMS AND ABBREVIATIONS

ANDRI	Australian Natural Disaster Resilience Index
BCEGS	Building Code Effectiveness Grading Schedule
BRIC	Baseline Resilience Indicators for Communities
CCRAM	Conjoint Community Resilience Assessment Measure
CRI	City Resilience Index
DHS	Department of Homeland Security
DROP	Disaster Resilience of Place
EMPG	Emergency Management Performance Grant
FA	factor analysis
FEMA	Federal Emergency Management Agency
GDP	gross domestic product
IBHS	Insurance Institute for Business and Home Safety
ISO	Insurance Services Office
LEPC	local emergency planning committee
minres	minimum residual
NEMA	National Emergency Management Association
NHSPI	National Health Security Preparedness Index
NIST	National Institute of Standards and Technology
NPG	National Preparedness Goal
OECD	Organisation for Economic Co-operation and Development
PCA	principal components analysis
PPD8	Presidential Policy Directive 8
RMSEA	root mean square error of approximation
SoVI	Social Vulnerability Index
THIRA	Threat and Hazard Identification and Risk Assessment
TLI	Tucker-Lewis Index

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EXECUTIVE SUMMARY

This thesis aims to answer the question: What drives resilience at the state level in the United States? Specifically, we have tried to address the lack of a clear success metric for broad goals of increasing security or resilience. Further, within the broad range of activities that states can engage in to achieve these goals, some must be more effective than others. It would be beneficial to know, for instance, whether a county emergency manager would save more lives by spending $100,000 on a community preparedness campaign or by spending the same amount on a full-scale exercise. Without a clear measure of resilience or security, however, we cannot know if we are more resilient and we cannot know which actions more effectively achieve that goal.

To answer this question, we conducted a literature review and determined that a composite indicator, also known as an index, is the most quantitatively rigorous way to measure complex idea such as resilience. Additionally, we followed existing precedent and used weather-related deaths and economic damage as external proxies for resilience. We decided to measure resilience at the state level in the United States because of federalism; if Department of Homeland Security grants for improving resilience and security are provided to the states, then it is important to measure resilience at the state level. There were a number of notable forerunners using composite indicators to measure resilience as well, including the Baseline Resilience Indicators for Communities (BRIC) model, which measures county-level resilience in the United States; the Australian Natural Disaster Resilience Index (ANDRI), which measures province- and national-level resilience in Australia; and the National Health Security Preparedness Index (NHSPI), which measures health security at the state level in the United States.

As outlined in the Organisation for Economic Co-operation and Development's *Handbook on Constructing Composite Indicators*, the first step in creating a composite indicator is to create a theoretical framework and list of specific indicators.[1]

[1] Organisation for Economic Co-operation and Development, and European Commission, *Handbook on Constructing Composite Indicators: Methodology and User Guide* (Paris: OECD, 2008).

We used existing research to pull together this framework and then validated it with a two-round Delphi method. We also spoke to a group of professional data analysts at the Federal Emergency Management Agency (FEMA) called the Analytics Community Brownbag to gain further insight into existing measures and efforts. We made edits to the framework based on feedback from these groups, then gathered available data and aggregated it into an index. Recognizing the truth of George Box's remark, "all models are false but some are useful," our goal was not to create a perfectly accurate model but instead to create a model that would help actual practitioners better evaluate program success.[2]

However, we did not want to leave accuracy out altogether, so used two methods to assess the index: factor analysis and regression analysis. Factor analysis uses a correlation matrix to assess and pull out a handful of "factors," underlying unobservable trends that can be said to drive the overall concept—resilience in our case. Though our analysis clearly showed five factors in our dataset, when we "extracted" them and looked at the indicators with which they were most strongly correlated, there were no clear labels for these drivers. Moreover, measures of index reliability all showed that the index was not statistically sound.

The regressions were simpler. We compared data for each indicator for which data was available to the total two-year average of per capita weather-related injuries and fatalities, and also to the average economic loss. In short, we used scatter plots to see if any indicators in the framework were correlated with deaths and damage (stand-in proxies for resilience). The answer was no. None of the indicators we used—from building code ratings to emergency management budgets—showed a strong relation to deaths and damage.

While the factor analysis was somewhat inconclusive, the regressions were fairly black and white. Either it is true, as the data show, that better building codes do *not* save lives or prevent property damage, or there is a problem with the analysis. We believe the

[2] George E. P. Box, "Robustness in the Strategy of Scientific Model Building," in *Robustness in Statistics*, ed. Robert L. Launer and Graham N. Wilkinson (New York: Academic Press, 1979), 201–36.

latter option—specifically, that analyzing resilience on the state level masks granularity in the data that is necessary for truly understanding resilience.

In the end, the tool we used, a composite indicator measuring resilience at the state level in the United States, did not answer the question, What drives state resilience? If anything, the analysis showed most clearly that the state is too large an area to accurately measure resilience when the output is very local, such as for weather-related deaths.

Taking all this into account, we provide some recommendations for improving resilience measurement. Because the Threat and Hazard Identification and Risk Assessment (THIRA) is the most commonly used assessment of resilience nationally, and it is used at all levels of government, most recommendations focus on improvements to the THIRA. Specifically, emergency managers and security practitioners should use resilience to break down silos and unify effort, add nuance and quantitative measurements where possible, focus on data quality, control for the hazard, and use common sense.

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ACKNOWLEDGMENTS

Many people have made this effort possible—the love I have and continue to receive buoys me in all parts of my life. First and foremost, I would like to thank my wife and family for their support, not only throughout this program but continually. This thesis is as much a product of their support as it is my own effort. Additionally, without my colleague Deana Platt's support, I would simply not have been able to complete the program.

I would also like to thank my advisors for their support and guidance, even as I ran out the clock, pushing to maximize the available time to work and, consequently, asking for their review with very short turnarounds. Their guidance and input was invaluable. Many others inside and outside academia made this possible, including all those who participated in the Delphi review, the FEMA Analytics Community Brownbag, and all those who have researched resilience and measurement before me.

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I. INTRODUCTION

Although the literature on measuring resilience has advanced significantly in the past decade, there is still no common model for measuring how resilient we are, either nationally, locally, or at the state level.[1] Specifically, the federal government has spent tens of billions of dollars over the past decade in homeland security and preparedness grants to make our country more secure and resilient. Though many practitioners may intuitively see progress in this area or feel that we are more resilient, it is not possible to say definitively whether we are more resilient, and by how much. Without a baseline, states and the federal government cannot effectively measure improvements and, further, without knowing which efforts drive the largest improvements in resilience, decision-makers cannot target investments to achieve better safety and security.

For example, it is plausible that regular exercises would make a state more resilient. It is also plausible that community preparedness campaigns or effective alert and warning authorities would make a state more resilient. However, without a baseline and common metrics, it is impossible to know definitively which activities increase resilience most.

In an era of constrained resources, all investments involve tradeoffs. If an emergency manager has $100,000 and can use it either for a large exercise or a preparedness campaign, which would should the manager choose? Which will save the most lives or prevent the most economic damage? This paper aims to address these questions.

Given the problem described here, this thesis aims to answer a number of questions:

- What drives state resilience?
- What are the best indicators for measuring a state's resilience?

[1] For the purposes of this thesis, a state is defined broadly as a state within the United States. It is not specific to emergency management or even state government, but includes all sectors, levels of government in the state, individuals, and communities.

- Which federal programs and policies affect a state's resilience and how (increase, decrease, no impact)?
- What is the simplest way to represent the different components of critical infrastructure, social capital, and other aspects that create a resilient system?

A. METHODOLOGY

To answer these questions, we conducted a literature review and determined that a framework and composite indicator (or index) was the best approach to measure resilience. Building on this review, we created a framework and, using the Delphi method, sent it to a range of experts in academia and state, local, and federal government to validate whether it was potentially useful, whether it accurately described resilience, and what changes might make it more useful and accurate. After consolidating these edits, we sent it to the same group for a second round of feedback.

At this point, we had a hierarchical framework of four dimensions and around 100 individual indicators with a strong theoretical foundation. As we gathered data to begin creating a composite indicator, we spoke with an employee group at the Federal Emergency Management Agency (FEMA) called the Analytics Community Brownbag, which provided additional insight on data sources and existing federal efforts to measure resilience.

After gathering available data, we used regression analysis and factor analysis to assess how accurate the composite indicator was and validate whether specific factors did actually correlate with observable indicators of resilience (e.g., weather-related fatalities, injuries, and property damage). We then used weighted arithmetic mean (with equal weighting) to aggregate the indicators, resulting in a resilience index and single resilience score between one and ten for each of the fifty United States and the District of Columbia.

Finally, based on the results from the analysis to this point, we developed recommendations and next steps. The following section describes the first step, the literature review.

B. LITERATURE REVIEW

The purpose of this literature review is to explore the range of definitions around the concept of resilience, as well as criticisms of the concept and reasons both for and against measuring it.

1. What Is Resilience?

Different disciplines offer a range of definitions, which we discuss in this section. One important point for our purposes is that the idea of resilience can be broken down into a number of discrete components, which is ultimately necessary for measurement, and which can also help to understand the idea.[2]

Given that this thesis focuses on measuring resilience, these discussions of a resilience definition look primarily through this lens—not only what resilience is but also how practitioners can measure it. In this section, we discuss whether resilience is a process or an outcome, how it relates to vulnerability, what the components of resilience are and how they might combine in a formula, what resilience looks like practically, and some criticisms of the idea.

a. Overview

Resilience is a broad term with a long history. In much of the current literature, resilience is complex; it is expansive enough to be almost a complete catch-all status that all government should aim to achieve.[3] Although ecology is commonly cited as the first field to use the term, as Peter Rogers points out, it was first used by Francis Bacon in 1659 to describe sound waves, well before ecology was an independent field of study.[4] It appears to have then moved to the physical sciences, where it was used by Thomas Tredgold in 1824, who referred to resilience as "the number which represents the power of a material

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[2] Fran H. Norris et al., "Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness," *American Journal of Community Psychology* 41, no. 1–2 (2008): 130.

[3] The Rockefeller Foundation and Arup International Development, *Research Report Volume 1 Desk Study* (New York: The Rockefeller Foundation, 2014).

[4] Peter Rogers, "The Etymology and Genealogy of a Contested Concept," in *The Routledge Handbook of International Resilience*, ed. David Chandler and Jon Coaffee (New York: Routledge, 2016), 14.

to resist an impulsive force."[5] It continued to be used in literature and other fields during the 1800s before becoming more common in the second half of the twentieth century, when it was used in fields as diverse as engineering, psychology, and management.[6]

David Chandler and Jon Coaffee build on Rogers's account of singular definitions by summarizing three overall themes in the current debate. The first definition of resilience, called the "homeostatic approach," is about regaining or returning to normal as quickly as possible.[7] They term their second definition the "autopoietic approach." In this approach, "bouncing back is not the aim but rather growth and development through an increased awareness of interconnections and processes."[8] The third approach, unnamed by the authors, is somewhat more abstract. The key differences are a focus on the local-individual level and a shift from viewing shocks and stresses as problems to viewing them as opportunities for growth. Rather than focusing on major changes, resilience in this third view focuses on continual growth through frequent small improvements drawn from a high degree of civic interaction.[9]

Fran H. Norris and her co-authors provide another voice in the debate, summarizing and synthesizing over twenty definitions from six different disciplines. Their analysis shows that "resilience is better conceptualized as adaptability than as stability," thus aligning with Chandler and Coaffee's second and third definitions, which focuses on growth.[10] Susan L. Cutter et al. also supports the idea that resilience involves growth, saying that "resilience … includes not only a system's capacity to return to the state (or multiple states) that existed before the disturbance, but also to advance the state through learning and adaptation."[11]

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[5] Rogers, 14.

[6] Rogers, 14.

[7] David Chandler and Jon Coaffee, "Introduction: Contested Paradigms of International Resilience," in *The Routledge Handbook of International Resilience* (New York: Routledge, 2016), 5–7.

[8] Chandler and Coaffee, 5–7.

[9] Chandler and Coaffee, 6–7.

[10] Norris et al., "Community Resilience as a Metaphor," 129–30.

[11] Susan L. Cutter et al., "A Place-Based Model for Understanding Community Resilience to Natural Disasters," *Global Environmental Change* 18 (July 2008): 599–600.

Given that the ultimate audience for this paper is government decision-makers, including the most prominent government definition helps fill out the discussion. Presidential Policy Directive 8, *National Preparedness* (PPD8), for example, lays out the requirements for the National Preparedness System and the National Preparedness Goal (NPG). It defines resilience as "the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies."[12] After PPD8, the Obama administration published the NPG itself: "A secure and resilient Nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk."[13] The NPG follows the capacity development approach, describing (in the final sentence) the five different capacities which, if developed strongly, will lead to a resilient nation. Ultimately, the Threat and Hazard Identification and Risk Assessment (THIRA) makes this definition real by providing a framework for stakeholders at all levels of government to assess their own capabilities in thirty-two core capabilities within these five mission areas.[14]

This section has outlined a number of ideas that we will continue to build on, in particular the idea that resilience is made up of discrete components. It is important first, however, to discuss whether resilience is a process or an outcome.

b. Process or Outcome

Many experts discuss whether resilience is a process or an outcome. One major catalyst in the overall discussion around resilience has been the Rockefeller Foundation, which launched the 100 Resilient Cities initiative in 2013. To support defining the term and measuring success, they created the City Resilience Framework, which defines resilience as "the capacity of cities to function, so that the people living and working in cities—particularly the poor and vulnerable—survive and thrive no matter what stresses or

[12] Barack Obama, *Presidential Policy Directive/PPD-8: National Preparedness* (Washington, DC: The White House, 2011), 8.

[13] The White House, *National Preparedness Goal* (Washington, DC: The White House, 2015), 1.

[14] Department of Homeland Security (DHS), *The Threat and Hazard Identification and Risk Assessment Guide: Comprehensive Preparedness Guide 201*, second edition (Washington, DC: DHS, 2013), 2.

shocks they encounter."[15] In their *City Resilience Index*, the Rockefeller Foundation and independent design firm Arup declare that "resilience is understood as an outcome (i.e., a scenario that could be achieved), rather than a process (i.e., a continuous series of actions)."[16]

Norris et al., on the other hand, posit that "community resilience is a process linking a network of adaptive capacities (resources with dynamic attributes) to adaptation after a disturbance or adversity."[17] Cutter et al. agree, stating that "we view inherent community disaster resilience as a complex process of interactions between various social systems, each with their own form and function, but working in tandem to provide for the betterment of the whole community."[18] Ultimately, however, for our purposes of measurement, academic discussions like these must link to real outcome measures that highlight the difference between a resilient community and a community that is not resilient, as we discuss in Section I.B.1.e on a practical definition of resilience. Another important part of the definition for resilience that overlaps with theory and practicality is the relationship between resilience and vulnerability.

c. Resilience and Vulnerability

Before discussing the components of resilience directly, one debate is important to highlight: that between resilience and vulnerability. Cutter et al. address this directly with the Social Vulnerability Index (SoVI), one of the first efforts to measure resilience

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[15] Rockefeller Foundation and Arup, *City Resilience Framework*, 2nd ed. (New York: Rockefeller Foundation, 2015), 3.

[16] Rockefeller Foundation and Arup, *Research Report Volume 1*, 11.

[17] Norris et al., "Community Resilience as a Metaphor," 127.

[18] Susan L. Cutter, Kevin D. Ash, and Christopher T. Emrich, "The Geographies of Community Disaster Resilience," *Global Environmental Change* 29 (2014): 66.

numerically.[19] There, they define resilience as “the potential for loss.”[20] As Figure 1 shows, that potential is driven by a number of other components, including hazard potential (e.g., exposure).

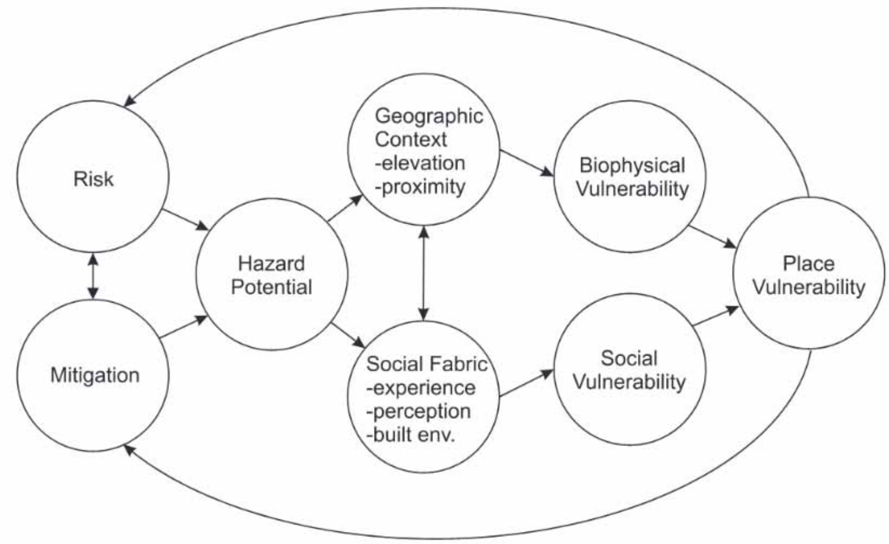

Figure 1. Hazards-of-Place Model of Vulnerability[21]

Norris et al., on the other hand, view vulnerability more as the opposite of resilience. This seems to imply that a community is either resilient, in which case it gets stronger, or vulnerable, in which case it gets weaker, as shown in Figure 2, which equates vulnerability with persistent dysfunction.[22] As Cutter mentions, however, just because an area is vulnerable does not immediately mean that it will not be resilient, highlighting the

[19] Benjamin Beccari, “A Comparative Analysis of Disaster Risk, Vulnerability and Resilience Composite Indicators,” *PLoS Currents* 8 (March 2016): 2, https://doi.org/10.1371/currents.dis.453df025e34b682e9737f95070f9b970.

[20] Susan L. Cutter, Bryan J. Boruff, and W. Lynn Shirley, “Social Vulnerability to Environmental Hazards*,” *Social Science Quarterly* 84, no. 2 (2003): 242, https://doi.org/10.1111/1540-6237.8402002.

[21] Source: Cutter, Boruff, and Shirley, 244.

[22] Norris et al., “Community Resilience as a Metaphor,” 131.

Vietnamese community in New Orleans East, which recovered relatively quickly after Hurricane Katrina despite originally being rated as vulnerable.[23]

In this light, the idea that resilience and vulnerability are opposites is misleading at best. The point Cutter makes in "Resilience to What? Resilience for Whom?" is that the relationship is more nuanced than simply arranging the two concepts as polar opposites.[24] Indeed, the key idea that these models share is a view of resilience through its individual components. Understanding each component individually can help better explain the concept as a whole, which is the idea we explore in the next section.

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[23] Cutter, "Resilience to What? Resilience for Whom?," *The Geographical Journal* 182, no. 2 (June 2016): 112.

[24] Cutter, 112.

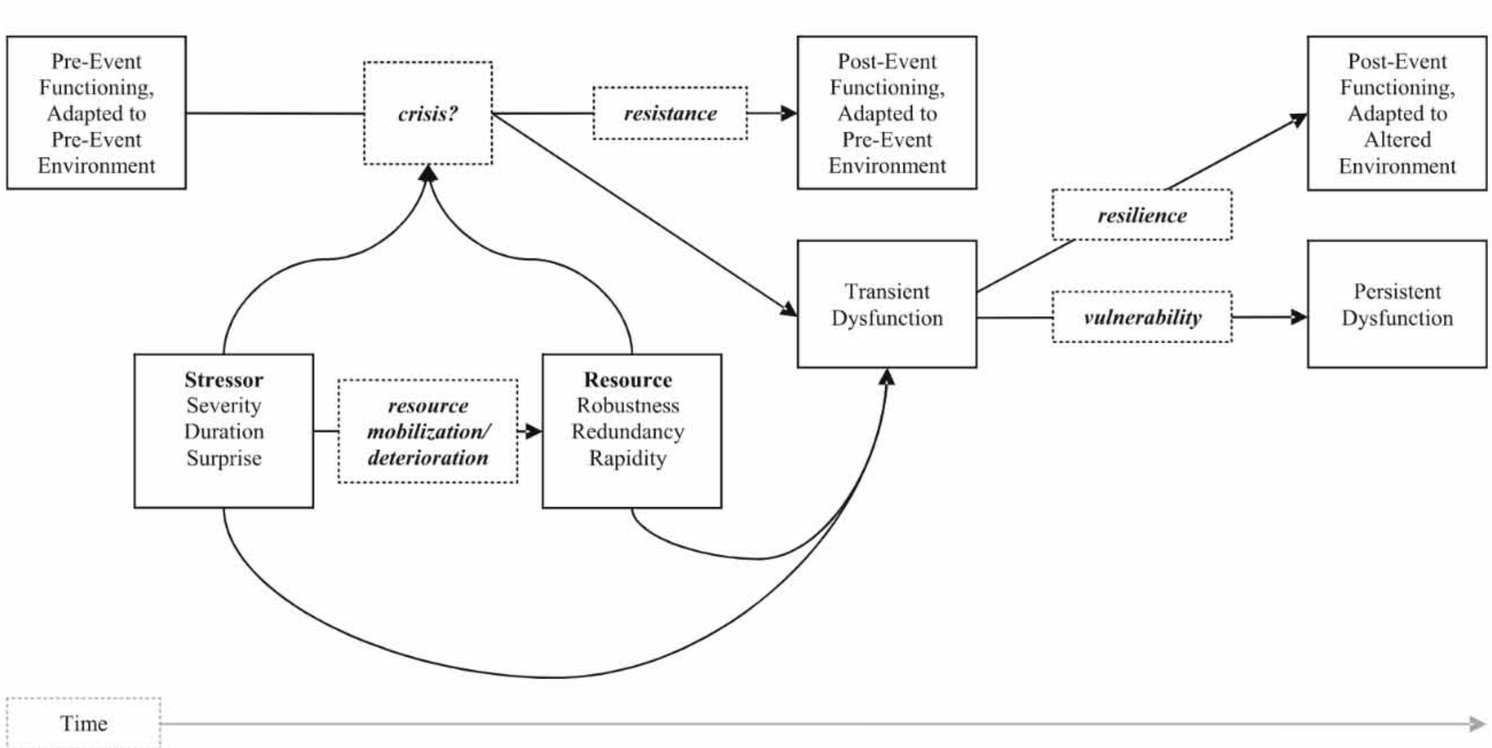

Figure 2. Model of Resistance and Resilience[25]

25 Source: Norris et al., "Community Resilience as a Metaphor," 131.

d. Formulaic Definition of Resilience

Continuing the idea of understanding resilience by looking at its components, it can be helpful to think about a formula for resilience. Norris et al. help, describing how "resilience's scientific value lies not in whether it can be easily captured and quantified but in whether it leads to novel hypotheses about the characteristics of—and relations between—stressors, various adaptive capacities, and wellness over time."[26] Arup goes on to create an actual formula, shown in Figure 3.

Figure 3. Theoretical Resilience Formula[27]

Cutter et al. also use a formula of sorts to conceptualize their Disaster Resilience of Place framework, displayed in Figure 4. This captures more elements of resilience and so offers a more nuanced approach to understanding the idea.

[26] Norris et al., 146.

[27] Source: Rockefeller Foundation and Arup, *Research Report Volume 1*, 13.

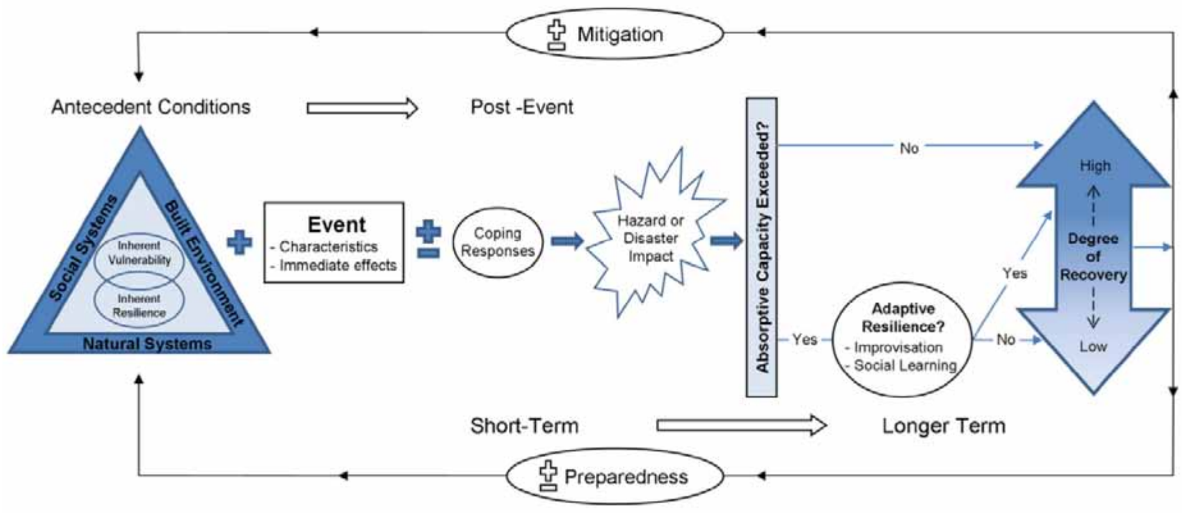

Figure 4. Formulaic Representation of the DROP Model[28]

Building on the previous section, both "formulas" treat vulnerability and resilience differently. While Arup does not explicitly define each term in Figure 3, exposure seems to most closely mirror vulnerability, or the susceptibility to harm. Figure 4, on the other hand, simply lists "antecedent conditions" and the "inherent vulnerability" that is part of them.[29]

Another important commonality between these models, including also the depictions in Figure 1 and Figure 2, is the idea that the disaster or shock is part of the formula. This is important because it means that a community's resilience is dependent, to some degree, on the severity of the hazard. While this may seem obvious (a bigger storm is going to do more damage and be more difficult to recover from), in trying to scientifically isolate variables to understand how much each contributes to the outcome (speed of recovery, for example), researchers must control for the hazard just like economists control for the dollar to compare values across years.

[28] Source: Cutter et al., "A Place-Based Model," 602.

[29] Cutter et al., 602.

Time is another point to include in a resilience formula, as Figures 2 and 4 both show. The National Institute for Standards and Technology and PPD8 both include time as a key part of their definition, highlighting that communities that recover more quickly are more resilient.[30]

For clarity, we will summarize these "formulas" in writing. An area exists, including certain weaknesses and certain strengths. An event happens and the area responds, with the immediate goal of simply dealing with the disaster ("coping responses") and the subsequent goal to address any major vulnerabilities that the disaster highlighted ("adaptive capacity"). Understanding these specific pieces of resilience can help explain the whole. Additionally, thinking about what resilience looks like in the real world outside academic spheres can provide another enlightening perspective.

e. Practical Definition

At a practical level, attempts to measure resilience provide a view of the concept as well. More grounded than the theoretical definitions above, any author who has published a list of indicators as part of a resilience framework is saying that those items represent resilience. Melissa Parsons et al., for example, describe seventy-eight indicators, from the population age to the number of hospital beds.[31] Beyond a simple, one-sentence definition, these data points spell out the concept of resilience in a more nuanced way.

Efforts to externally validate resilience frameworks by testing them against outcomes in the real world provide another view into the real experienced concept of resilience. Laura A. Bakkensen et al., for example, use deaths, economic damage, and FEMA disaster declarations to determine how accurately five different frameworks represent resilience. By using these variables, the authors are saying that the real observable

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[30] National Institute of Standards and Technology (NIST), *Community Resilience Planning Guide for Buildings and Infrastructure Systems*, Volume I, NIST Special Publication 1190 (Washington, DC: U.S. Department of Commerce, 2016), 13, http://dx.doi.org/10.6028/NIST.SP.1190v1; Obama, *PPD-8*, 6.

[31] Melissa Parsons et al., "Top-Down Assessment of Disaster Resilience: A Conceptual Framework Using Coping and Adaptive Capacities," *International Journal of Disaster Risk Reduction* 19 (October 2016): 8–9, https://doi.org/10.1016/j.ijdrr.2016.07.005.

action of being resilient is the deaths, economic losses, and federal disaster declarations.[32] Put another way, according to these authors, a jurisdiction is more resilient when disasters harm fewer people and cause less damage. This perspective provides a healthy balance to somewhat more abstract academic discussions of the term. To complete these discussions of the definition of resilience, we must discuss some criticisms of the concept.

f. Criticisms of Resilience

One criticism of this concept is that as emergency managers spread responsibility for resilience across agencies and society, this may also change how citizens interact with government, potentially being "relegated to a largely passive role."[33] Claudia Aradau also addresses these issues, focusing on the shift implied by the language of shocks in resilience. Calling an event that stresses the system a "shock" makes it seem like a surprise.[34] Implying that an event is unforeseen distracts, however, from the fact that multiple clear instances of communities not being resilient may be examples not of the power of the shock to disrupt but of the failure of normal government and development. For example, "the rendition of economic crisis as 'shocks' does not question the conditions of possibility for the crisis or the policies that might have led to the crisis."[35] Put another way, calling something a "shock" makes it seem outside governments' control while, in reality, the event may have been caused by government actions.

Charlotte Heath-Kelly takes these criticisms one step further, calling resilience a nightmare and arguing that it sells the false hope that society can erase future disasters—if they are just resilient enough, even when things happen, it won't affect them.[36] "And

[32] Laura A Bakkensen et al., "Validating Resilience and Vulnerability Indices in the Context of Natural Disasters," *Risk Analysis* 37, no. 5 (2017): 990.

[33] Rogers, "Etymology and Genealogy," 20–21.

[34] Claudia Aradau, "The Promise of Security: Resilience, Surprise, and Epistemic Politics," in *The Routledge Handbook of International Resilience*, ed. David Chandler and Jon Coaffee (New York: Routledge, 2016), 84–85.

[35] Aradau, 84.

[36] Charlotte Heath-Kelly, "Resilience and Disaster Sites: The Disastrous Temporality of the 'Recovery-to-Come,'" in *The Routledge Handbook of International Resilience*, ed. David Chandler and Jon Coaffee (New York: Routledge, 2016), 307.

should we be suspicious," she adds, "of a concept that can supposedly be applied in equal measure to disaster management, security, psychological treatment and economy? Is resilience actually an empty promise?"[37]

Another criticism is that larger questions remain about who benefits from resilience efforts. As Cutter highlights,

> By not asking the obvious questions of to what and for whom, governments or agencies can maintain the status quo and the existing power structure of elites, and perpetuate the disenfranchisement of selected groups and/or communities, as they undertake actions to codify and implement actions ostensibly intended to make them become more resilient.[38]

The key point, made not only by Cutter but also by Norris et al., is that emergency management resources are not deployed equally and the most vulnerable parts of society are the ones that get fewer resources.[39] From this perspective, the goal of resilience should be to "develop economic resources, reduce risk and resource inequities, and attend conscientiously to their areas of greatest social vulnerability."[40]

Viewing resilience as a simple evolution of policy, however, addresses these concerns somewhat. The idea that security is the most important role of government has a long history.[41] Governments can no longer guarantee security, though, so resilience has now started to replace security, not promising perfect freedom from harm but promising adaptation and recovery. In this light, resilience is an acknowledgement that undesirable events will happen and a focus on how best to deal with them.[42]

Continuing this evolution, resilience is fundamentally a broader concept than almost any other in emergency management or homeland security. When the term broadens

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[37] Heath-Kelly, 309.

[38] Cutter, "Resilience to What," 110.

[39] Norris et al., "Community Resilience as a Metaphor," 137.

[40] Norris et al., 145.

[41] Thomas Hobbes, *Thomas Hobbes: Leviathan,* in *Longman Library of Primary Sources in Philosophy* (New York: Routledge, 2016), 89.

[42] Aradau, "The Promise of Security," 84–85.

the focus to a full picture of all systems involved in response, notes Rogers, it also begins to involve more and more agencies of government.[43] Jonathan Clarke touches on the issue as well, noting that true resilience planning will have to include a much broader group of interested parties, and that "resilience represents the environmental, social and technical science of persistence and adaptation."[44] Delf Rothe, on the other hand, asserts that resilience benefits from the ambiguity assigned to it. In other words, rather than viewing the multiple definitions as a detraction, they should be viewed as part of the value that the term brings to discussions around emergency management. Being able to bring different concepts together makes ambiguity one of the key elements of the definition of resilience.[45]

Even if resilience can serve as a bridging discipline to bring people together, it is still challenging to define because the concepts it describes are complex. It may seem best to pick a definition and move on but, as Rogers outlines,

> Complexity becomes a prerequisite of any attempt to map patterns of resilience.… Perhaps the biggest challenge for those seeking to use the resilience concept is to avoid becoming trapped in the effort to establish one particular dominant meaning, and allowing the flexibility of polysemy to continue creating opportunities for thinking, doing, and acting differently as we stumble on through an age of uncertainty.[46]

In short, taking a broad definition of resilience allows for stakeholders across government and society to work toward the same goal from their own perspective. Each group may have a different definition, but they are all working toward the same outcome. As Rogers explains, "resilience operates to frame discussions of a quite fundamental nature, of how we might rethink forms of social, political and economic organization."[47]

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[43] Rogers, "Etymology and Genealogy," 18–19.

[44] Jonathan Clarke, "From Maladaptation to Adaptation: Towards a Resilient Urban Planning Paradigm," in *The Routledge Handbook of International Resilience*, ed. David Chandler and Jon Coaffee (New York: Routledge, 2016), 216.

[45] Delf Rothe, "Climate Change and Security: From Paradigmatic Resilience to Resilience Multiple," in *The Routledge Handbook of International Resilience*, ed. David Chandler and Jon Coaffee (New York: Routledge, 2016), 181.

[46] Rogers, "Etymology and Genealogy," 22.

[47] Rogers, 7.

g. Defining Resilience: In Conclusion

There are a few key points around the definition of resilience. It is the evolution from traditional concepts of security that prevent all harm to a recognition that, to varying degrees, perfect safety is impossible.[48] It includes prevention and mitigation efforts, known as coping capacity, but also places a large emphasis on post-event growth, called adaptive capacity.[49] Resilience is also a very broad term which, while potentially confusing, ultimately helps bring a range of stakeholders together, working toward the same goal.[50] In this way it is a process that allows government agencies to come closer to overcoming traditional siloes.[51]

Further, resilience can be broken down into specific pieces (e.g., incident, vulnerability/current situation, coping capacity, and adaptive capacity).[52] Practical applications and measurement efforts can provide another window into understanding the true meaning of resilience—for example, that areas with fewer deaths and damage display more resilience.[53]

For accurate quantitative measurement, we found that a framework and composite indicator can provide the most precise definition of resilience through the specific list of domains and indicators they require. We discuss this at length in Chapter III.

2. Why—or Why Not—to Measure Resilience

Though we argue throughout this thesis that measuring resilience is valuable, we do want to spend some time acknowledging concerns in this approach and in resilience measurement overall. We discuss a number of reasons, including that it is too broad, too expensive, already done, or redundant.

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48 Aradau, "The Promise of Security," 84–85.

49 Norris et al., "Community Resilience as a Metaphor," 129–30.

50 Rogers, "Etymology and Genealogy," 18–19.

51 Rothe, "Climate Change and Security," 181.

52 Norris et al., "Community Resilience as a Metaphor," 130.

53 Bakkensen et al., "Validating Resilience and Vulnerability Indices," 990; Rockefeller Foundation and Arup, *Research Report Volume 1*, 13.

a. It Is Too Broad or Complicated

As discussed in Chapter I.B.1, definitions of resilience describe a very broad concept. In addition to the justification outlined there (that a broad definition allows a range of organizations to work together toward the same goal while still working in their own areas of expertise) resilience is also not actually too broad to measure. As an example, the United Nations Development Programme has published the Human Development Index since 1990, continuing to build the conversation around what development looks like globally. Development, like resilience, is a broad concept but one that is still measureable using specific tools.[54] Gross domestic product provides another example of a complex phenomenon that practitioners, despite challenges, still measure. The Bureau of Economic Analysis breaks economic activity into dimensions and then into individual indicators.[55] Both examples highlight that, while complex topics are also complex to measure, accurate measurements are possible. Moreover, by measuring human development and gross domestic product, these organizations help create a dialogue around these ideas, including what they are and how best to improve them.

Not only is measurement possible, the alternative (i.e., continuing an unclear and siloed approach to measurement) does not serve decision–makers. The Rockefeller Foundation has shown this with its approach to the City Resilience Index, which measures a range of variables across sectors with the explicit goal of understanding the full picture of the city.[56] The foundation is directly addressing uncertainty in outcome by coming up with a range of both qualitative and quantitative measures to determine specifically whether the cities have achieved the stated outcome—resilience.[57] By measuring aspects

[54] Selim Jahan, *Overview Human Development Report 2016* (New York: United Nations Development Programme, 2016), 2.

[55] Stephanie H. McCulla and Shelly Smith, *Measuring the Economy: A Primer on GDP and the National Income and Product Accounts*, ed. Brent R. Moulton and Carol E. Moylan (Washington, DC: Bureau of Economic Analysis, U.S. Department of Commerce, 2015), 4–5.

[56] Rockefeller Foundation and Arup, *Research Report Volume 4 Measuring City Resilience* (New York: Rockefeller Foundation, 2016), 46.

[57] Rockefeller Foundation and Arup, "City Resilience Index: Understanding and Measuring City Resilience," Arup, accessed September 8, 2018, 11, https://www.arup.com/perspectives/publications/research/section/city-resilience-index.

of resilience independently, analysts only create an illusion. Truly accurate measurements must take a systems approach to fully determine how the multiple parts of resilience interact.[58]

Heeding George Box's remark, "all models are false but some are useful," it is important to note that early efforts to measure resilience as a system will also create an illusion of understanding.[59] They will not immediately depict the concept accurately.[60] However, by iterating over time—like the National Health Security Preparedness Index—we can come much closer to an accurate model than with alternative approaches that do not span disciplines or do not use quantitative methods.[61] Cutter et al. support this as well, saying "the usefulness of quantitative indicators for reducing complexity, measuring progress, mapping, and setting priorities makes them an important tool for decision makers."[62] To reiterate, the goal of this thesis, discussed further in Chapter III.A.1, is not perfect accuracy but simply enough accuracy to be useful.

b. It Is Too Expensive

Measuring resilience costs both time and money. However, consider how much *not* measuring resilience costs. How much is wasted because decision–makers do not have an accurate understanding of the true return on various investments? Practitioners at all levels of government and in the private sector spend money every year to increase their security or resilience. Without a way to see the outcome, however, they cannot help but miss some of their goals and lose some of their investments. As Sandra Knight et al. highlight,

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[58] Norris et al., "Community Resilience as a Metaphor," 130.

[59] Box, "Robustness," 201–36.

[60] OECD and European Commission, *Handbook on Constructing Composite Indicators: Methodology and User Guide* (Paris: OECD, 2008), 13–14.

[61] "Methodology for the 2018 Release," National Health Security Preparedness Index (NHSPI), April 2018, 1–2, https://nhspi.org/wp-content/uploads/2018/04/2018-Index-Methodology.pdf.

[62] Cutter et al., "A Place-Based Model," 603.

measuring resilience "should drive conversations between a diverse set of stakeholders that inform the trade-offs between alternatives."[63]

c. *We Already Measure Resilience*

Jurisdictions across the country, from counties to states, currently complete a Threat and Hazard Identification and Risk Assessment (THIRA) every year. Despite being called a risk assessment, the THIRA is better described as a capabilities assessment since it focuses on determining relative ability in thirty-two core areas, grouped within five main mission areas.[64] The overall assumption seems to be, however, that if a jurisdiction closes all its capability gaps in order to achieve a perfect score in each core capability, then it will be prepared, or resilient.

While it is not explicitly termed a resilience assessment, we believe the THIRA is the most commonly used tool for measuring resilience in the United States. In this light, it is true that we (as an emergency management community) do already measure resilience. However, as with everything, there is room for growth. Many of our recommendations in Chapter IV.C focus on the THIRA, such as including more quantitative metrics and to focusing on data quality.

d. *It Is Redundant*

One criticism of other composite indices that applies to a possible resilience index is that it may recreate existing indices. As Wojciech Nasierowski, outlines, many indices, such as the Human Development Index or the Global Innovation Index, are "correlated at a statistically significant level," despite measuring seemingly disparate phenomena.[65] If

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63 Sandra K. Knight et al., *Building Blocks for a National Resilience Assessment* (Chapel Hill: The University of North Carolina at Chapel Hill, 2015), 38.

64 James Featherstone, "Recommendations from March 2015 NAC Meeting" (memorandum, FEMA National Advisory Council, 2015), 2–3, https://www.fema.gov/media-library/assets/documents/103964; DHS, *THIRA Guide*, 2.

65 Wojciech Nasierowski, "Composite Indexes Economic and Social Performance: Do They Provide Valuable Information?," *Foundations of Management* 8, no. 1 (2016): 172–73, https://doi.org/10.1515/fman-2016-0013.

this applies to these indices, would it not also apply to a resilience index? Benjamin Beccari seconds this point in his review of 106 composite indicators:

> Even though the intent may be to develop a disaster focussed [sic] index, the choice of variables may make the index indistinguishable from generic development and welfare indices, as found with the Predictive Indicators of Vulnerability, and thus offer very limited insight into disaster specific resilience and vulnerability.[66]

Both Nasierowski and Beccari make valid points. However, rather than highlight the need to cease all measurements of complex ideas, they highlight the need to continue refining existing approaches. The Organisation for Economic Co-operation and Development (OECD) *Handbook on Constructing Composite Indicators* addresses this, describing how "composite indicators must be seen as a means of initiating discussion and stimulating public interest."[67] Knight et al. further the point as well, mentioning that "a credible and transparent assessment can be an effective tool for engaging in a dialogue about the state of the nation's resilience and the actions needed to improve that resilience."[68] Finally, it helps to again reiterate Box's comment that "all models are false but some are useful" and to highlight that the goal is not perfect accuracy but simply utility.[69]

Nasierowski also adds that "the preceding discussion does not negate the usefulness of composite indexes. Rather, the results question the need for yet other indexes, which replicates the ranking of alternate or better established measures."[70] If a resilience index does not provide any additional predictive value beyond what existing indices provide, then practitioners should continue revising it until it does, or eventually stop using it.

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[66] Beccari, "Comparative Analysis," 5.

[67] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 13.

[68] Knight et al., *Building Blocks*, 33.

[69] Box, "Robustness."

[70] Nasierowski, "Composite Indexes," 173.

e. Measuring Resilience Is Worth the Investment

To conclude this section, the key point is that for any effort at all to succeed, a reliable and accurate method to measure success is fundamental. To gauge the success of efforts to enhance resilience or security, therefore, a reliable and accurate method to measure resilience is again fundamental. The value, just like with planning, is in the process. As Knight et al. point out, "the process to build a national scorecard can take decades, but the process itself generates important dialogue. If done right, it can be a catalyst for changing behavior."[71]

The authors of the Conjoint Community Resilience Assessment mention another approach. Measuring resilience over time "is important for two reasons: (1) In order to assess the effectiveness of interventions for increasing emergency preparedness, and (2) to measure the effect of the crisis on the community. The gaps identified will provide decision makers with the information needed to intervene in an evidence-based focused manner in order to strengthen the community."[72]

Ultimately, as this paper's title suggests, in order to know whether investments in security and resilience have accomplished their goal, decision–makers must have effective measurement tools. The following section outlines some approaches to measure resilience, including a composite indicator, the method we chose; they are described in more detail in Chapter III.

[71] Knight et al., *Building Blocks*, 37.

[72] Odeya Cohen et al., "The Conjoint Community Resiliency Assessment Measure as a Baseline for Profiling and Predicting Community Resilience for Emergencies," *Technological Forecasting and Social Change* 80, no. 9 (2013): 1733.

3. How to Actually Measure Resilience

As resilience measurements have become more common, a number of authors have published meta-analyses of the tools; these analyses provide a useful beginning.[73] Efforts to measure resilience frequently take the same approach. Cutter, in her 2016 article "The Landscape of Disaster Resilience Indicators in the USA," describes how three approaches summarize these efforts: "indices, scorecards, and tools."[74] Scorecards are generally the simplest and can often be just a checklist. An index, on the other hand, involves gathering relevant indicators and combining them into one number, while the tools group includes mathematical models and similar instruments.[75] Thomas Winderl, writing for the United Nations Development Programme, lays out some approaches from international development and disaster risk reduction in "Disaster Resilience Measurements: Stocktaking of Ongoing Efforts in Developing Systems for measuring Resilience." The document describes approaches to measure six different parts of resilience: well-being, vulnerability, capacities, shocks/losses/stresses, reaction to disasters, and program results.[76]

Domestically, Knight et al. summarize current approaches to develop a national resilience assessment in the United States, as well as recommendations to effectively realize this type of assessment. Their recommendations include developing a common framework, using expert groups and partnerships, using existing outputs as resilience proxies, adopting a hierarchical approach, and starting the effort now.[77]

[73] Thomas Winderl, "Disaster Resilience Measurements: Stocktaking of Ongoing Efforts in Developing Systems for Measuring Resilience" (report, United Nations Development Programme, February 2014); Beccari, "Comparative Analysis"; Susan L. Cutter, "The Landscape of Disaster Resilience Indicators in the USA," *Natural Hazards* 80, no. 1 (2016): 741–58, https://doi.org/10.1007/s11069-015-1993-2; Eric Tate, "Social Vulnerability Indices: A Comparative Assessment Using Uncertainty and Sensitivity Analysis," *Natural Hazards* 63, no. 2 (2012): 325–47.

[74] Cutter, "Landscape of Disaster Resilience," 744–45.

[75] Cutter, 745.

[76] Winderl, "Disaster Resilience Measurements," 6.

[77] Knight et al., *Building Blocks*, 37–38.

Building on the results of these meta-analyses, as well as the concept of defining and measuring resilience discussed in Chapter I.B.1, we have chosen to use a composite indicator (also known as an index) to measure resilience because of its demonstrated ability to measure complex ideas across a range of fields, and because of the range of resources available in describing the process. Indeed, practitioners and academics have used composite indices to measure complex phenomena since at least 1990, when the United Nations first published the Human Development Index.[78] To provided clarity and standardization as the use of composite indices became more common, the OECD published the previously mentioned *Handbook on Constructing Composite Indicators* in 2008.[79]

While it is a comprehensive approach, using a composite index does not resolve all measurement challenges. As the Rockefeller Foundation points out, resilience

> cannot be measured directly, until after a shock occurs or stresses accumulate and reach a tipping point. Lagging indicators in this context would reveal something about the ability of the city to cope, and can be useful to better understand how the recovery process unfolds, in order to inform post-disaster recovery plans. But, they would not necessarily provide an indication of future performance, even in similar circumstances. Instead, future resilience has to be determined based on present-day proxy indicators.[80]

Put another way, it is challenging to measure resilience without an actual event. Instead of measuring resilience itself, efforts to understand the idea measure proxies, such as the capacities of a jurisdiction.[81]

Though a number of frameworks have been developed, fewer have compiled real data to create an index for measuring resilience. As Cutter explains, “Most of the resilience assessment literature measures assets (infrastructure, livelihoods) or characteristics of systems, including capacities (community trust, social capital, governance). Few integrate

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[78] Jahan, *Human Development Report*, 2.

[79] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 34.

[80] Rockefeller Foundation and Arup, *Research Report Volume 4,* 38.

[81] Winderl, “Disaster Resilience Measurements,” 7.

across all systems or sectors, nor do they acknowledge the complexity of communities or systems."[82] RAND echoed this at its 2016 Resilience Roundtable, calling for "capturing resilience data longitudinally from individuals and communities to support the development of complex systems modeling, and pilot test interventions based on that systems modeling."[83]

Chapter II outlines a number of relevant efforts and indices that currently measure resilience in some way. Next, Chapter III describes the state resilience framework we created and the steps we took to build a composite indicator, including the choices we made for each section. We then discuss the validity of the index, including factor analysis and regression analysis. Finally, Chapter IV offers our findings, conclusions, and recommendations.

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82 Cutter, "Resilience to What," 111.

83 Joie D. Acosta, Anita Chandra, and Jaime Madrigano, "An Agenda to Advance Integrative Resilience Research and Practice: Key Themes from a Resilience Roundtable," *RAND Health Quarterly* 7, no. 1 (2017): 19.

II. MEASURING RESILIENCE: EXAMPLES

We have referenced a number of indices in the discussion so far and throughout this thesis; this chapter describes relevant measurement efforts in greater detail, simply to serve as a reference for other approaches to measuring resilience quantitatively.

1. National Health Security Preparedness Index

The National Health Security Preparedness Index (NHSPI) provides the clearest example of the resilience index that we sought to create. First published in 2013, it was created by the Centers for Disease Control and Prevention and a range of other stakeholders to help them better understand health security. It is now managed by the University of Kentucky and supported by the Robert Wood Johnson Foundation.[84] The chart in Figure 5 describes the NHSPI's domains, and the weights ascribed to them.

One notable aspect of the NHSPI is that both the measures and the statistical techniques it uses are continually refined. Supported by a National Advisory Committee of fourteen experts in public health and resilience, as well as by extensive public engagement through a Delphi process and multiple working groups, the NHSPI continues to improve each year; it is one of the few indices, to our knowledge, that is able to do so.[85]

The main difference between the NHSPI and our proposed state resilience index, outlined in Chapter III, is the subject. Rather than our focus on resilience to natural hazards, the NHSPI focuses on health security. It does, however, use a top-down hierarchical structure with min-max normalization and a weighted arithmetic mean, as we did with our index. Additionally, the program management office for the NHSPI used a multi-stage Delphi process with 148 experts to come up with the most accurate weights possible for each indicator.[86]

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[84] NHSPI, "Methodology for the 2018 Release," 1–3.

[85] NHSPI, 1–3.

[86] NHSPI, 3–8.

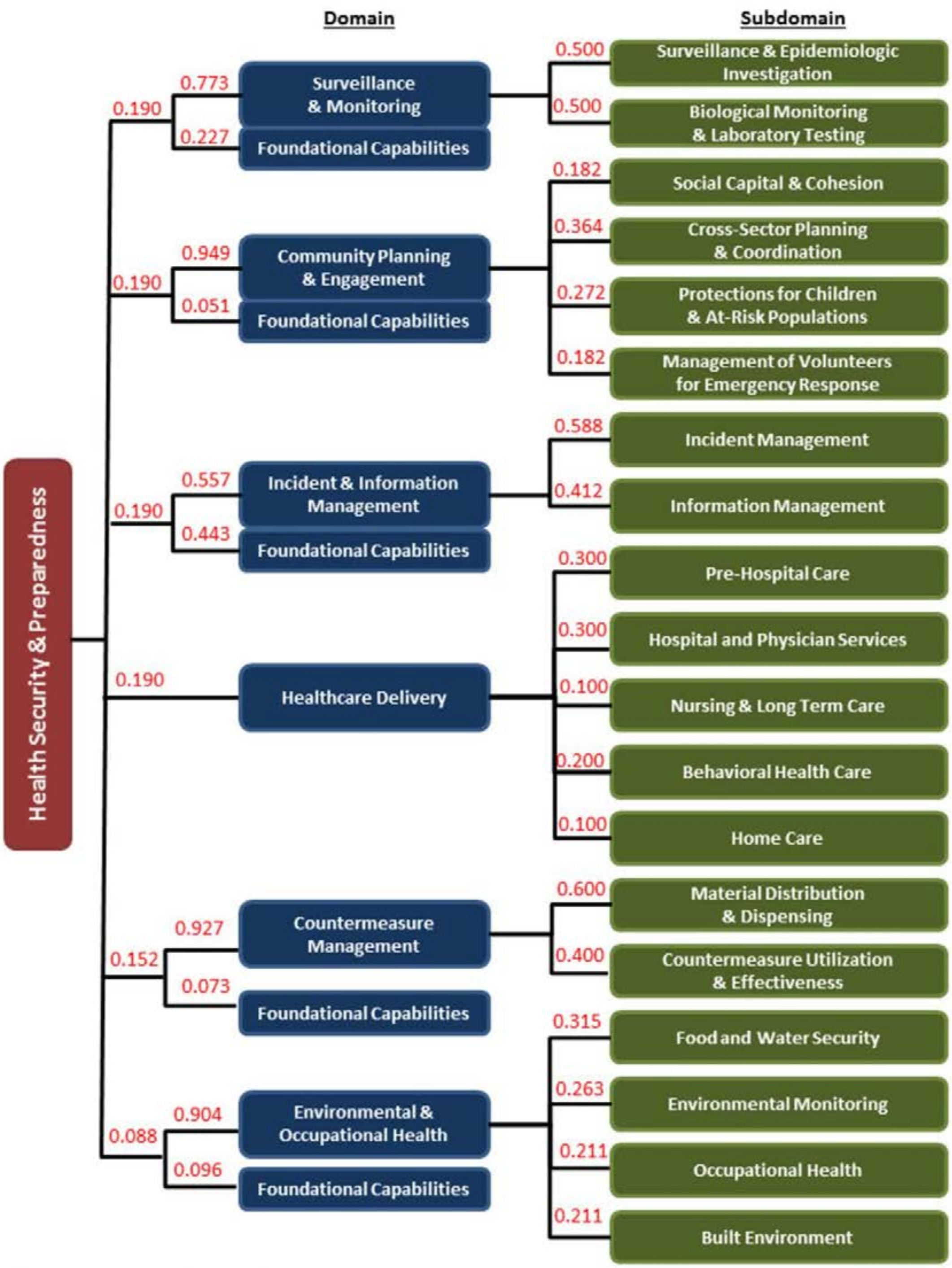

Figure 5. National Health Security Preparedness Index Domains, Sub-domains, and Weights[87]

[87] Source: NHSPI, 12.

Finally, the NHSPI has proven practical and valuable. Because it iterates yearly, the index now provides five years of data for each state, giving researchers and practitioners alike insight into progress over time and successful health security strategies.[88]

Though a useful tool, the index could be improved by potentially conducting external validation to see whether states with high health security ratings do indeed have better outcomes (i.e., fewer injuries and deaths).

2. Australian Natural Disaster Resilience Index

The Australian Natural Disaster Resilience Index (ANDRI) is also a top-down hierarchical framework that aims to provide planning and decision support.[89] Given this, the biggest difference between the ANDRI and the state resilience index described in this thesis is simply the smaller number of territories compared to the number of U.S. states. One notable approach the ANDRI researchers took was to measure adaptive capacity. As Melissa Parsons et al. discuss, "Although it has been a core theme of the theoretical literature on disaster resilience, adaptive capacity and the agency of societies to transform and learn in the face of natural hazards is a newer concept in resilience assessment."[90] The difference between adaptive and coping capacity is that the former focuses on growth and how to facilitate it, while the latter only addresses current response and recovery.[91]

To measure coping capacity, the ANDRI includes eight specific areas: social character, economic capital, infrastructure and planning, emergency services, community capital, and information and engagement. To measure adaptive capacity, on the other hand, the ANDRI includes two areas: governance, policy, and leadership; and social and community engagement.[92] The ANDRI also includes a spatial element—the ultimate goal is to create maps of resilience and compare those to existing maps of hazards and risks, thus creating a better understanding of the most vulnerable areas. These areas would

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[88] National Health Security Preparedness Index, accessed July 19, 2018, https://nhspi.org/.

[89] Parsons et al., "Top-Down Assessment," 5–7.

[90] Parsons et al., 6.

[91] Parsons et al., 6.

[92] Parsons et al., 8.

theoretically then be the focus of effort and investment to increase resilience.[93] Figure 6 displays this structure. Another notable factor of the ANDRI is that, like the NHSPI, it iterates over time; three reports have been published since 2015.[94] Accurately modeling a complex idea like resilience is extremely challenging on the first attempt, so iteration provides a key to an accurate understanding of the factors that drive resilience.

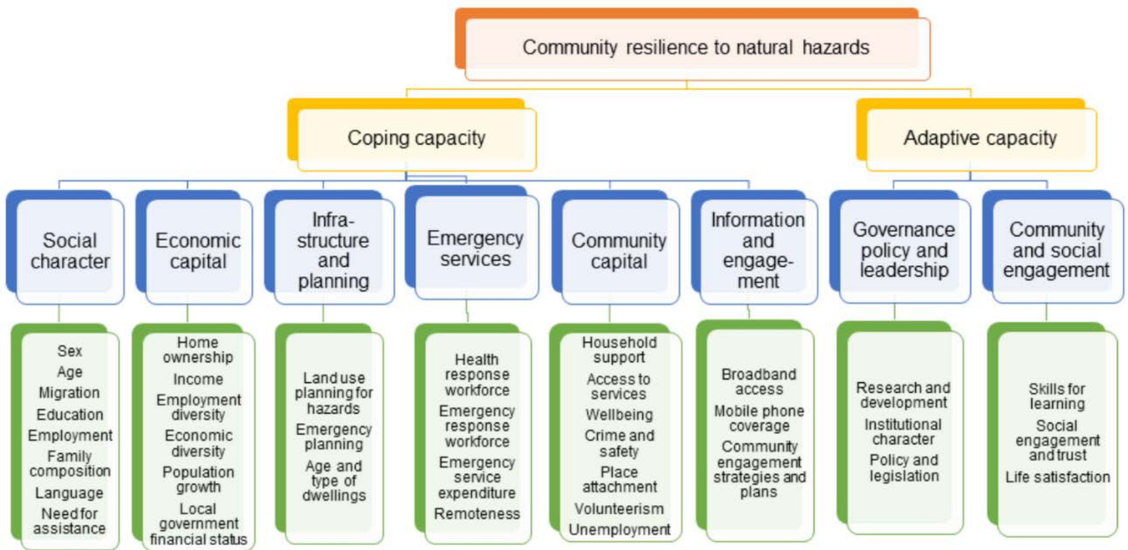

Figure 6. ANDRI Structure[95]

93 Parsons et al., 7.

94 "The Australian Natural Disaster Resilience Index: A System for Assessing the Resilience of Australian Communities to Natural Hazards," Bushfire and Natural Hazards CRC, accessed August 4, 2018, https://www.bnhcrc.com.au/research/hazard-resilience/251.

95 Source: Melissa Parsons et al., *The Australian Natural Disaster Resilience Index: Assessing Australia's Disaster Resilience at a National Scale*, Report No. 290.2017 (Melbourne, Australia: Bushfire and Natural Hazards CRC, 2017), 5.

3. Rockefeller Foundation’s 100 Resilient Cities Framework

The Rockefeller Foundation, with support from Arup, created the 100 Resilient Cities Initiative and, as a measurement tool, the City Resilience Framework and the City Resilience Index (CRI).[96] A number of relevant features stand out for this effort, including its global focus on cities, the substantial research effort, and the breadth of the tool.

The first relevant aspect of the CRI is its global focus on cities. The Rockefeller Foundation created this tool explicitly to address the growing proportion of the world’s population that lives in cities. Additionally, the focus is global rather than only on one country or region. Cities share many of the same threats as the global community, from rising sea levels to economic shocks. Although, as discussed in Chapter III.A.4, we focus on the state level because the federal government legally works to build capability through the states, understanding resilience at the city level complements state measurements. Indeed, one reviewer in our Delphi study noted that measuring resilience at the state level should simply be an aggregation of community-level measurements. This is a valid perspective and is echoed by Cutter et al.[97] It is also why we have included the CRI here as a reference.

The second relevant factor of the CRI is the breadth of the research effort that the Rockefeller Foundation and Arup undertook—including a literature review, resilient city case studies, and fieldwork—to understand what truly drives city resilience.[98] From the literature review, Rockefeller and Arup created a hypothesis of resilience and then tested it using the case studies by looking at the functions cities provide and whether they are able to provide them after an incident. The final step of the research, the fieldwork, looked at six cities globally that had recently experienced some type of incident. From this, the

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[96] Rockefeller Foundation and Arup, “City Resilience Index,” 11.

[97] Susan L. Cutter, Christopher G. Burton, and Christopher T. Emrich, “Disaster Resilience Indicators for Benchmarking Baseline Conditions,” *Journal of Homeland Security and Emergency Management* 7, no. 1 (2010): 17, https://doi.org/10.2202/1547-7355.1732.

[98] Rockefeller Foundation and Arup, “City Resilience Index,” 4.

researchers discerned 1,546 factors, or items that likely influenced resilience. These were then distilled into the more limited final framework.[99]

The final relevant factor is the breadth of the CRI. The Rockefeller Foundation defines resilience simply as "the capacity of cities to function, so that the people living and working in cities—particularly the poor and vulnerable—survive and thrive no matter what stresses or shocks they encounter."[100] This definition explicitly encompasses all aspects and functions of a city, so is broader than many definitions that only seek to describe "disaster-specific resilience."[101] Further, the dimensions and indicators that the Rockefeller Foundation uses to measure resilience in the CRI reflect this breadth as well. Finally, the CRI also describes eight "qualities" of resilience, or traits that apply to all goals and indicators in the framework.[102] This idea of specifically delineating qualities of resilience is relatively unique to the CRI and is one of the ways it has added to the discussion of resilience. Figure 3 depicts the framework.

[99] Rockefeller Foundation and Arup, 4–5.

[100] Rockefeller Foundation and Arup, 3.

[101] Beccari, "Comparative Analysis," 5.

[102] Rockefeller Foundation and Arup, "City Resilience Index," 8.

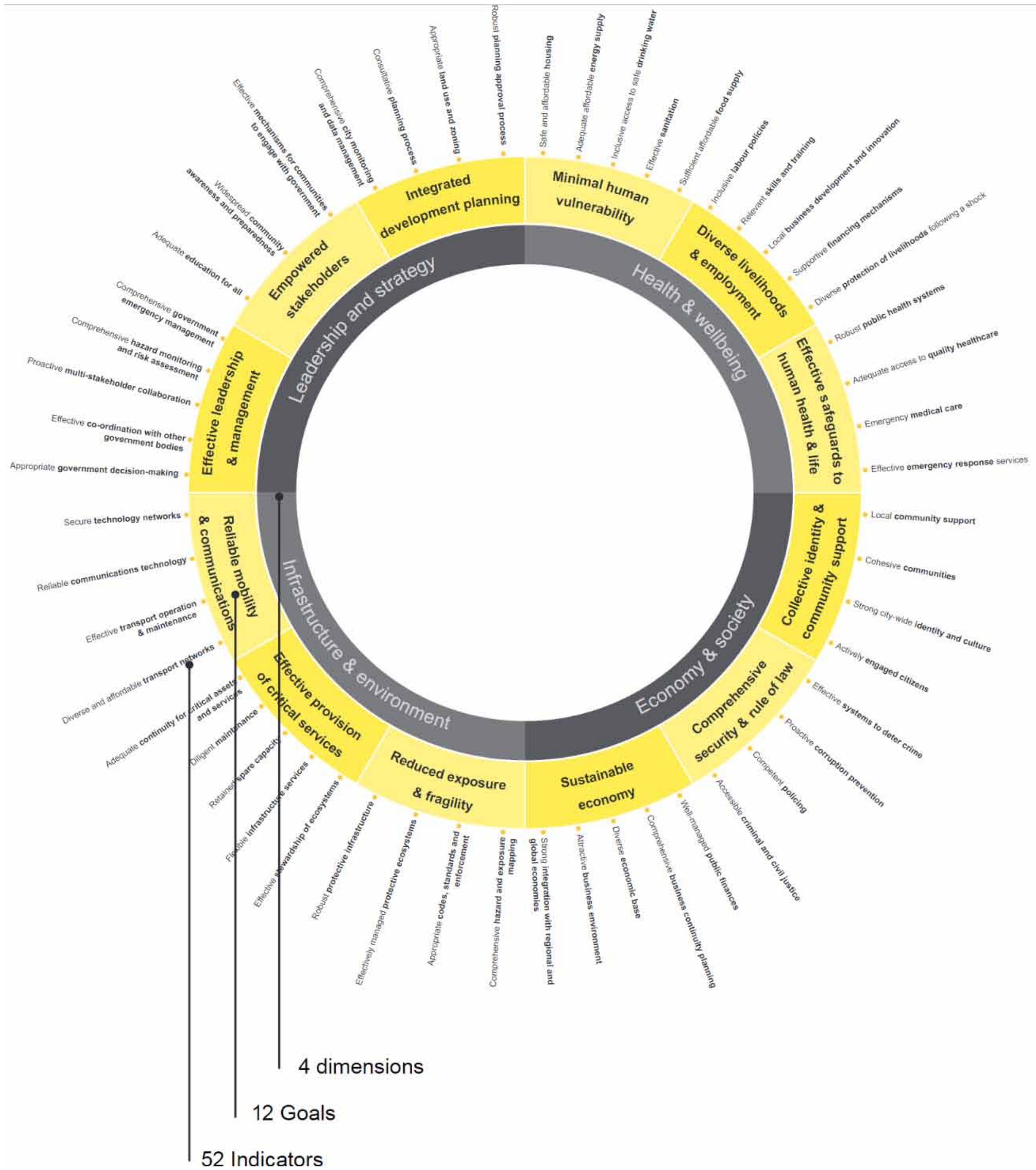

Figure 7. City Resilience Framework [103]

[103] Source: Rockefeller Foundation and Arup, *Research Report Volume 1*, 3.

4. Baseline Resilience Indicators for Communities

In the United States, Susan Cutter has contributed as much as anyone to the study and measurement of resilience through the 2003 Social Vulnerability Index (SoVI), the 2008 Disaster Resilience of Place (DROP) model, and the 2010 Baseline Resilience Indicators for Communities (BRIC).[104] Cutter et al. have pushed the conversation on resilience forward in a number of important ways through these efforts. For instance, they have discussed the relationship between resilience and vulnerability, included a geospatial aspect in resilience measurement, and have employed advanced mathematical and statistical methods such as factor analysis to determine key drivers in both vulnerability and resilience.

The SoVI narrowed 250 original variables to forty-two relevant ones, then used principal components analysis to find the eleven factors that accounted for the majority of the overall variance.[105] Based on this, Cutter et al. used even weights to aggregate these factors into the SoVI, not only creating a tool for understanding vulnerability to natural hazards but also paving the way for many future researchers in resilience and vulnerability to follow the same approach, including this paper's author.[106] Cutter et al. also mapped the SoVI by county, highlighting how location can affect vulnerability.[107]

Following the SoVI, the DROP paper outlines a framework and set of specific variables for measuring resilience, and the BRIC uses actual data to create a composite index from the DROP framework. In their 2008 paper, "Disaster Resilience Indicators for Benchmarking Baseline Conditions," Cutter et al. discuss the process of transitioning from a simple framework and outline of resilience to a composite index.[108] To create the BRIC index for states in FEMA Region IV, Cutter et al. analyzed correlation and internal consistency of the selected variables. The final index used only thirty-six variables, which

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104 Cutter, Boruff, and Shirley, "Social Vulnerability"; Cutter et al., "A Place-Based Model"; Cutter, Burton, and Emrich, "Disaster Resilience Indicators."

105 Cutter, Boruff, and Shirley, "Social Vulnerability," 249–51.

106 Cutter, Boruff, and Shirley, 254; Tate, "Social Vulnerability Indices," 328.

107 Cutter, Boruff, and Shirley, "Social Vulnerability," 255.

108 Cutter, Burton, and Emrich, "Disaster Resilience Indicators," 5–6.

were then normalized with min-max normalization (discussed in more detail in Chapter III.C), and finally applied even weighting to aggregate the indicators into a full index.[109] The researchers then mapped the results to the county level, showing which areas were more or less resilient than the average.[110] Cutter et al. also published a second, iterative paper on the topic in 2014, "The Geographies of Community Disaster Resilience," using the same index and variables but expanding the measurements to all counties in the continental United States.[111]

5. Conjoint Community Resilience Assessment Measure

We have included the Conjoint Community Resilience Assessment Measure (CCRAM) as a notable example of a bottom-up framework, and of the value this approach can provide. Rather than using existing national statistical data—like the top-down frameworks outlined previously did—researchers for the CCRAM surveyed a handful of towns in Israel to better understand key drivers of resilience and complemented this survey with a more objective assessment of infrastructure and other support.[112] Next, the team used hierarchical logistic regression and receiver operating characteristic analysis to look at the relationships in the data and determine which factors most strongly drove resilience.

The survey gathers information on "social ties and sense of community, attachment to place, faith, trust in local elected leaders and their ability to lead change" while the checklist is focused less on opinion and more on fact, such as the existence of infrastructure and the availability and accessibility of services in routine and emergency situations.[113]

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[109] Cutter, Burton, and Emrich, 6–10.

[110] Cutter, Burton, and Emrich, 11.

[111] Cutter, Ash, and Emrich, "Geographies."

[112] Cohen et al., "Conjoint Community Resiliency Assessment," 1733.

[113] Cohen et al., 1733, 1736.

The team found five important resilience drivers: leadership, collective efficacy, preparedness, place attachment, and social trust.[114]

Though we did not use this type of data, it does highlight some of the more challenging aspects of individual determination in resilience that appear in anecdotal accounts of neighbor-helping-neighbor and rural self-reliance. However, in overall theory the CCRAM follows other frameworks. The researchers' goal was to provide decision–makers a baseline to gauge success for specific resilience efforts.[115]

6. Community Resilience Planning Guide for Buildings and Infrastructure Systems

The U.S. Department of Commerce National Institute of Standards and Technology (NIST) *Community Resilience Planning Guide for Buildings and Infrastructure Systems* (referred to simply as "the Guide") provides another relevant element in the discussion about resilience.[116] Though the document is overall a planning guide, not a measurement rubric, there are a number of relevant aspects. Volume II, in particular, outlines different sectors relevant for measuring resilience, and also includes an entire chapter on community resilience metrics. One unique quality of the Guide is its focus on time as an aspect of resilience measurement. However, because much of the data we found are often updated only annually, it would be challenging to use time to recovery as an effective metric for communities.[117]

7. Threat and Hazard Identification and Risk Assessment

The final framework that has some insight for measuring resilience is the Threat Hazard Identification and Risk Assessment (THIRA). As outlined in the 2018 Homeland

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[114] Dmitry Leykin et al., "Conjoint Community Resiliency Assessment Measure-28/10 Items (CCRAM28 and CCRAM10): A Self-Report Tool for Assessing Community Resilience," *American Journal of Community Psychology* 52, no. 3–4 (December 2013): 316–21, https://doi.org/10.1007/s10464-013-9596-0.

[115] Cohen et al., "Conjoint Community Resiliency Assessment," 1734.

[116] NIST, *Community Resilience*, Volume I; NIST, *Community Resilience Planning Guide for Buildings and Infrastructure Systems*, Volume II (Washington, DC: U.S. Department of Commerce, 2016).

[117] NIST, *Community Resilience*, Volume II, 230–31.

Security Grant Program Notice of Funding Opportunity, states are required, along with other jurisdictions, to complete a THIRA and use it to allocate their grant funding with the overall goal of increasing capabilities.[118] Given this close link to funding, the THIRA has become the most commonly used measurement tool for preparedness in the United States insofar as it is used by every state and major urban area in the country.

The THIRA is a hierarchical framework that divides first into the five mission areas from the National Preparedness Goal: prevention, protection, mitigation, response, and recovery. There are then thirty-two core capabilities that jurisdictions evaluate themselves on each year.[119] A jurisdiction then maps these capabilities to its main threats and hazards, resulting in capability gaps, which jurisdictions can use federal grant funding to address. The idea is that if states and other jurisdictions perfect each capability, then they will be able to meet all the needs an incident might create and would thus minimize the loss of life and property (i.e., to be more resilient).[120]

We have adopted some conventions from the THIRA, such as using response and recovery capacity as subdomains in the proposed state resilience framework (see Appendix A). In other areas, however, we found the THIRA somewhat limited. For example, the ANDRI, CRI, and BRIC all follow the idea of major domains—social, economic, infrastructure, etc.[121] However, because the goal of the THIRA is to assess emergency management, it looks only at emergency management. We felt that this approach does not fully include the whole community and, given our goal of understanding the resilience of society at the state level, we adopted the broader approach outlined in the academic literature. Chapter IV outlines other comments on the THIRA.

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[118] "The U.S. Department of Homeland Security (DHS) Notice of Funding Opportunity (NOFO) Fiscal Year (FY) 2018 Homeland Security Grant Program (HSGP)," FEMA, accessed September 8, 2018, 3, https://www.fema.gov/media-library-data/1526578809767-7f08f471f36d22b2c0d8afb848048c96/FY_2018_HSGP_NOFO_FINAL_508.pdf.

[119] DHS, *THIRA*, 2–3.

[120] DHS, 20.

[121] Parsons et al., "Top-Down Assessment"; Rockefeller Foundation and Arup, *Research Report Volume 1*; Cutter, Burton, and Emrich, "Disaster Resilience Indicators."

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III. A STATE RESILIENCE FRAMEWORK AND INDEX

To answer the research questions outlined in Chapter I, we created a composite indicator. A number of resources guided the process, especially the OECD's *Handbook on Constructing Composite Indicators*.[122] This chapter describes our process, the specific decisions we made, and why. By being clear about the options, assumptions, and rationale for each choice, we hope to set the stage for further iteration of resilience measurement tools. Throughout the process we outline, there are a range of choices; however, there is not necessarily one final, true answer. Again, the goal was to create a useful tool, so we have documented each decision to provide clarity, given that there are a range of possibly valuable choices.[123]

We ordered this chapter based generally on the process the OECD prescribes and the process Eric Tate outlines in "Uncertainty Analysis for a Social Vulnerability Index," shown in Figure 8.[124] We discuss the other steps of our own research process, including the Delphi review and the conversation with the FEMA Analytics Community Brownbag, when relevant.

[122] OECD and European Commission, *Handbook on Constructing Composite Indicators*.

[123] Tate, "Social Vulnerability Indices," 327.

[124] OECD and European Commission, 20–21; Eric Tate, "Uncertainty Analysis for a Social Vulnerability Index," *Annals of the Association of American Geographers* 103, no. 3 (2013): 528, https://doi.org/10.1080/00045608.2012.700616.

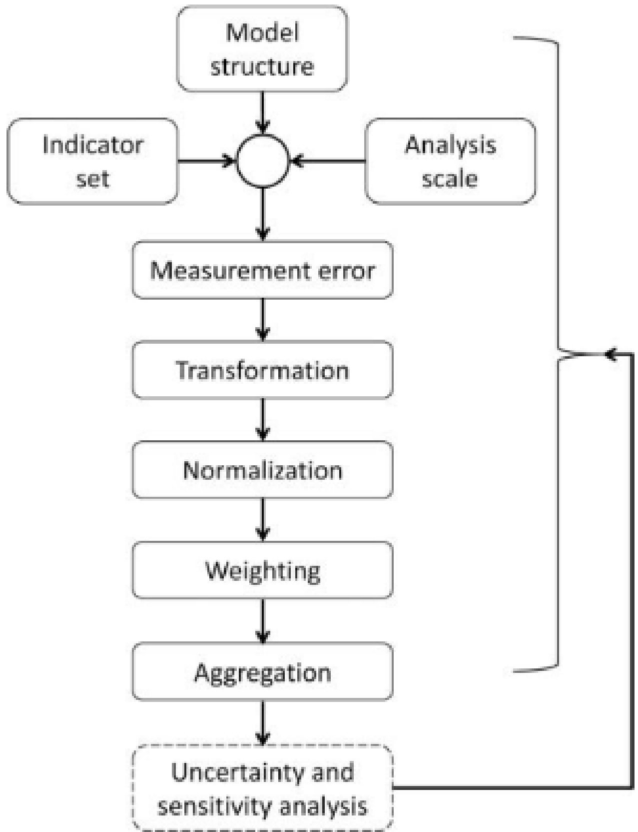

Figure 8. Index Construction Flowchart[125]

A. THEORETICAL FRAMEWORK

The first step in creating a composite indicator is to lay out the theory that supports it. To clarify the discussion, we must first define some terms: A framework is a list of dimensions and indicators that describe a concept, while an index is the mathematical extension of the framework with data added, analyzed, and compiled. A composite indicator and an index are the same.[126] Because the term resilience—and how it can be measured—is discussed in Chapter I.D.1, we only summarize the relevant points here. Resilience as an idea emphasizes the ability to recover and prosper after a disaster.[127] It

[125] Source: Tate, "Uncertainty Analysis," 528.

[126] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 20–21; Cutter, "Landscape of Disaster Resilience," 745.

[127] Norris et al., "Community Resilience as a Metaphor," 129–30.

also represents a system-of-systems approach, measuring the capacity of multiple overlapping domains.[128] Further, by breaking down the concept into its different systems and capacities, researchers and practitioners can view resilience formulaically, as Figure 2 shows (see Chapter I.B.1.c). Based on these general principles, the first step in creating a framework is to clarify the purpose.

1. Purpose

The goal of this framework is to improve state resilience, and we hope to accomplish that by 1) providing a tool to understand which actions really improve resilience (and corresponding decreases in deaths and damage), and by 2) encouraging a process like planning that builds relationships among relevant stakeholders and breaks down silos to facilitate more effective response and recovery. As the OECD handbook highlights, "quality is usually defined as "fitness for use" in terms of user needs."[129] Our goal is to create a tool that is fit for use and that can guide actual investments.

Further, in a budget-constrained environment, it can be challenging to know which investments best build resilience. This framework should provide a baseline for each state to potentially measure its own resilience and to document progress over time. As Knight et al. note, "by identifying relative changes in resilience, decision makers can set targets, prioritize approaches and investment decisions. This should include measuring learning and specific changes in behavior over time, an important, but often underemphasized element of resilience."[130] Building on this, because this index aims to be a useful tool, the final judge must be the end user, which in this case is emergency managers at all levels of government.[131]

[128] Rockefeller Foundation and Arup, *City Resilience Framework*, 3.

[129] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 44.

[130] Knight et al., *Building Blocks*, 33.

[131] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 22.

2. Indicators

Tate, in his overview of composite indices, defines indicators as “quantitative variables intended to represent a characteristic of a system of interest.”[132] Tate further describes qualities that indicators should have: “Choices among indicators are generally guided by factors such as data availability, desired number of indicators, statistical properties, and most importantly validity—how representative is the indicator of the underlying vulnerability dimension?”[133] Indicators should also be relevant and valuable, meaning that they meet the needs of the final customers, and should cover the defined geographic area.[134] Last but not least, indicators should consistently include the appropriate type of variable, whether input, output, or process.[135] Figure 9 outlines additional traits to consider when selecting indicators.

[132] Tate, “Social Vulnerability Indices,” 327.

[133] Tate, 329.

[134] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 46, 100.

[135] OECD and European Commission, 23.

Criteria for indictor selection	Requirements
1. The indicator reflects a justifiable element of natural hazard resilience	• The relationship between the indicator and natural hazard resilience has been verified in the academic/ professional literature
2. The indicator can track change and variability in natural hazard resilience	• Change in the indicator can be determined and associated with change in resilience spatially and temporally
3. The indicator is relevant to the scale(s) of assessment	• The indicator aligns with the scale at which the assessment is undertaken. There may be a requirement for an indicator to remain valid across scales (e.g. local to national).
4. The indicator is measurable and readily interpretable	• The indicator is specific and precisely defined. • The indicator is quantifiable and spatially referenced • The indicator is easy to define, understand and communicate
5. The measurement method for the indicator is robust	• Measurement is reliable (and verifiable) and representative of reality • Measurement occurs regularly enough for the purpose • Measurement is methodologically sound
6. The indicator is achievable – data are available, accessible and cost effective	• Data are available at the required scales across most of the study area • Data are readily available from secondary sources • Data can be accessed within the cost and resource framework

Figure 9. Generalized Criteria for Indicator Selection[136]

[136] Source: Parsons et al., "Top-Down Assessment," 5.

At this stage in the development, the theoretical validity is more important than data availability, so we chose the indicators because of their support in the literature and because of our understanding, based on a general knowledge of emergency management, of their theoretical relationship to resilience.[137] We also added a number of indicators specific to state emergency management, such as Emergency Management Performance Grants.

Eventually, however, the realities of data availability drive some sacrifices. The OECD handbook explains, "compromises need to be done when constructing a composite. What we deem essential is the transparency of these compromises."[138] To that end, we have included further discussion about the decisions on what to include and why in Appendix A, which outlines all indicators included in the final framework.

Additionally, it is important to note that we did not include any component of time in this framework, even though it is a component of many resilience definitions discussed in Section I.B.1. At this point, most data are simply not updated rapidly enough to be useful for a comparison to evaluate the recovery of an area at anything more rapid than the one-year interval. With the available data, it would be difficult to evaluate a jurisdiction weekly after a disaster hit to assess its recovery, for example, though this could be a valuable goal eventually.

3. Structure

Generally speaking, frameworks can be hierarchical, inductive, or deductive.[139] Figure 10 illustrates the different options and provides a basic description about how each works. The data collection format provides another choice in framework construction—either top-down or bottom-up.[140] We chose to use a top-down hierarchical framework because it is most accurate and, as Knight et al. note, "top-down tools tend to provide a more strategic perspective of the resilience of an area or region based on information mined

[137] Tate, "Social Vulnerability Indices," 341.

[138] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 23.

[139] Tate, "Social Vulnerability Indices," 328.

[140] Parsons et al., "Top-Down Assessment," 3.

from available data bases (local, state and national)."[141] The alternative would be a bottom-up structure, so called because rather than using existing national or state data, researchers draw conclusions from local surveys.[142] An ideal framework could potentially combine top-down data with bottom-up survey information to create a more complete picture of resilience.[143]

All three methods, deductive, inductive, and hierarchical, result in a single score.[144] Deductive is, in some ways, the simplest; a small number of indicators are aggregated to create the index. Inductive takes it one step further, starting with a large number of indicators and using a factor analytic method such as principal components analysis (PCA) to identify the key drivers (known as factors), and eventually removing or giving less weight to measures that do not represent the core concept (e.g., resilience).[145]

Hierarchical indices, on the other hand, create the index by domain, as illustrated in Figure 10.[146] Each domain measures one aspect of the issue and aggregates all relevant indicators into a number, which is itself then aggregated with the other domains to create the final index score.[147] While it does not explicitly mention these structural considerations, the OECD handbook seems to assume a combination approach using the hierarchical structure overall and inductive methods, such as PCA, to construct each domain.[148]

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141 Tate, "Social Vulnerability Indices," 337; Knight et al., *Building Blocks*, 5.

142 Parsons et al., "Top-Down Assessment," 4.

143 Knight et al., *Building Blocks*, 14.

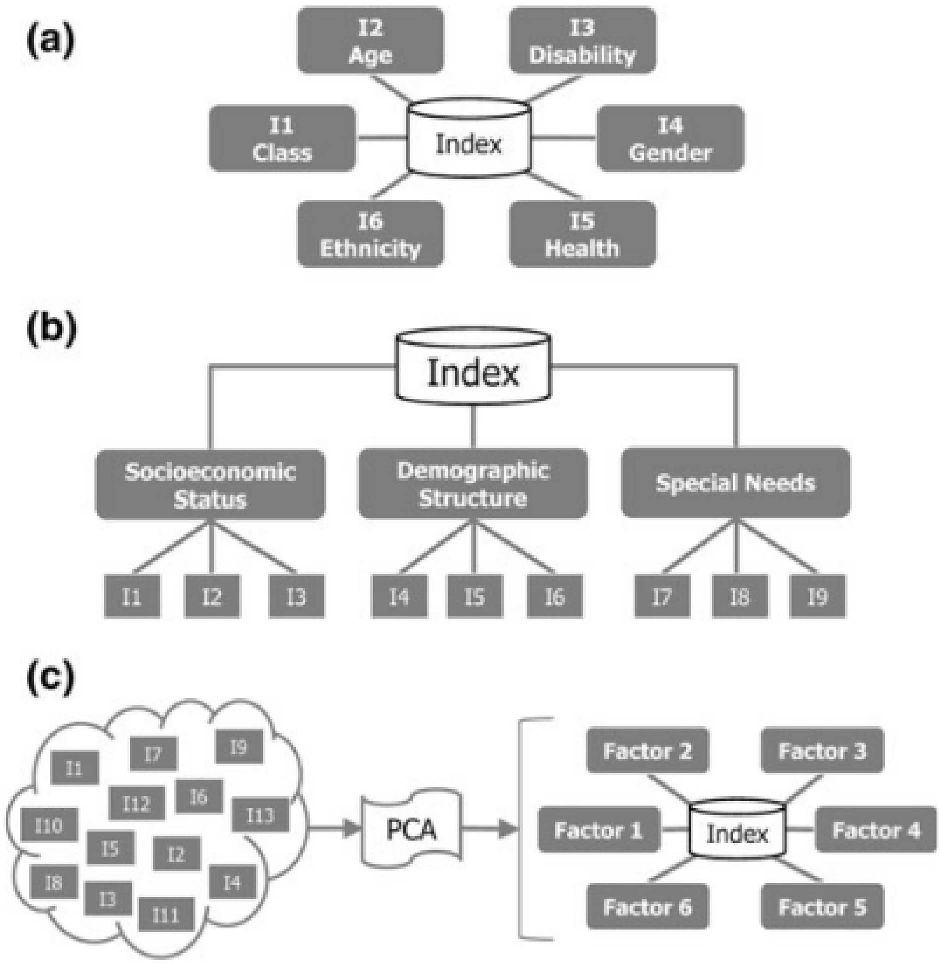
144 Tate, "Social Vulnerability Indices," 324.

145 Tate, 328.

146 Tate, 329.

147 NHSPI, "Methodology for the 2018 Release," 5.

148 OECD and European Commission, *Handbook on Constructing Composite Indicators*, 22–26.



(a) deductive, (b) hierarchical, (c) inductive

Figure 10. Framework/Index Structural Design Methods [149]

149 Source: Tate, "Social Vulnerability Indices," 329.

The key point is that hierarchical methods provide a helpful way to measure aspects of a complex topic in discrete intervals, or domains.[150] Top-down methods provide the necessary data more easily, though perhaps ideally in combination with bottom-up methods.[151] Statistical techniques such as multivariate regression and PCA, discussed more in Section III.E, help to ensure the chosen variables do actually represent the issue under scrutiny.

For our purposes, we synthesized a number of existing frameworks including the ANDRI, CRI, BRIC, and the NIST *Community Resilience Planning Guide*; and the PEOPLES framework.[152] Based on this review, we compiled a framework that originally included four domains, twenty-five sub-domains, and 133 individual measures. Figure 11 outlines the final domains and sub-domains. Readers can see the complete final framework in Appendix A and earlier drafts in Appendix B. Chapter II outlines relevant indices for comparison.

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[150] Knight et al., *Building Blocks*, 37.

[151] Knight et al., 14.

[152] Parsons et al., "Top-Down Assessment"; Rockefeller Foundation and Arup, *Research Report Volume 4*; Cutter, Burton, and Emrich, "Disaster Resilience Indicators"; NIST, "Community Resilience," Volume I."

PEOPLES stands for "Population and Demographics, Environmental/Ecosystem, Organized Governmental Services, Physical Infrastructure, Lifestyle and Community Competence, Economic Development, and Social-Cultural Capital. Chris S. Renschler et al., *A Framework for Defining and Measuring Resilience at the Community Scale: The PEOPLES Resilience Framework* (Buffalo, NY: University of Buffalo, 2010).

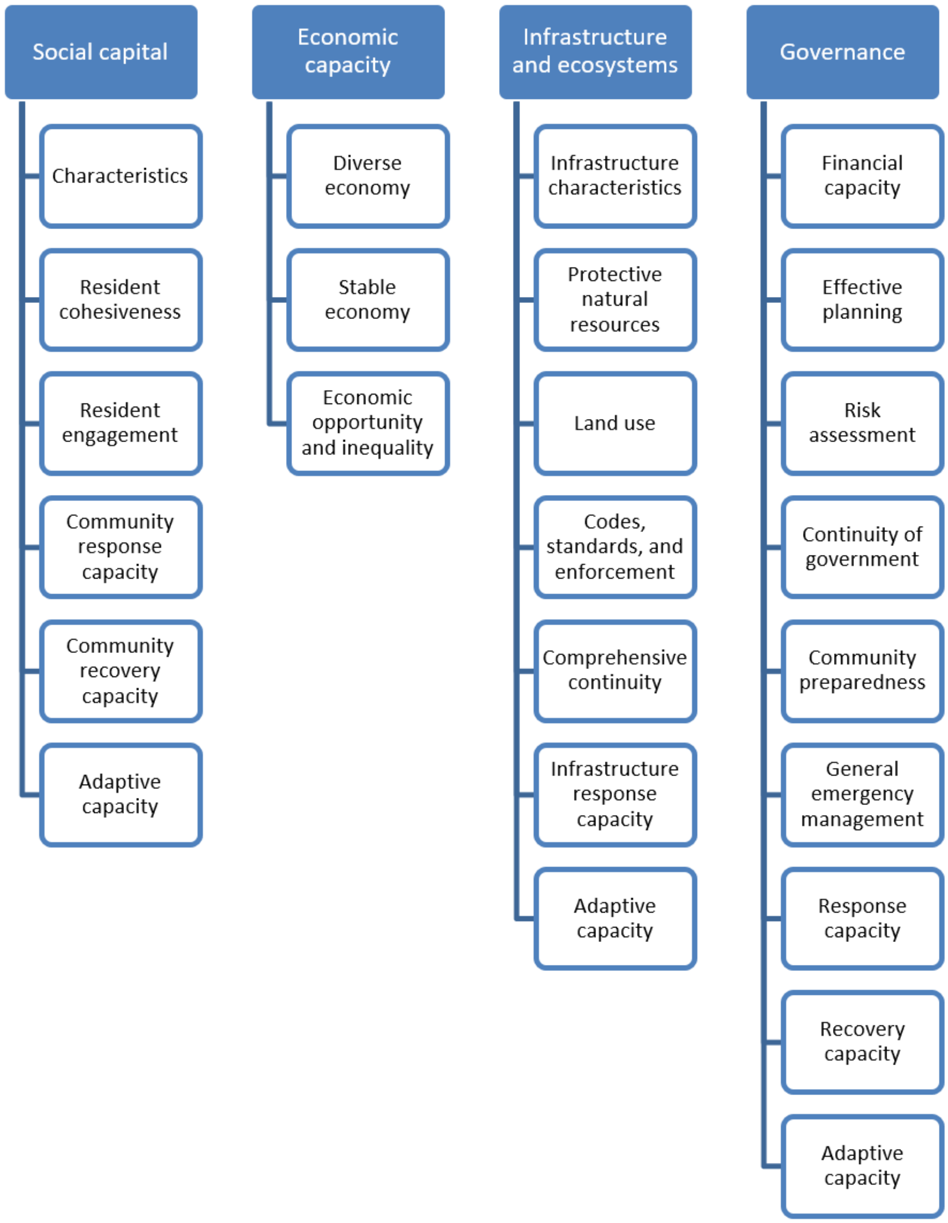

Figure 11. State Resilience Framework Domains and Sub-domains[153]

[153] Adapted from Parsons et al., "Top-Down Assessment"; Rockefeller Foundation and Arup, *Research Report Volume 4*; Cutter, Burton, and Emrich, "Disaster Resilience Indicators"; NIST, "Community Resilience," Volume I; Renschler et al., *PEOPLES Resilience Framework*.

4. Scale

Tate helpfully outlines the need to clarify the scale of the index. “The choice of scale is important because statistical relationships between social indicators often vary across scales, meaning that the same index produced at different scales may yield distinct patterns of vulnerability.”[154] To answer the research question, we focus on the state level in the United States. Additionally, we have backgrounds in state and federal government, including FEMA. Because FEMA legally supports the states in emergency management, we thought it would be valuable to focus on measuring state-level resilience.[155]

5. Delphi Feedback and FEMA Analytics Community Brownbag

We shared this framework with the Delphi group and, based on their feedback, made a number of changes. Notably, we reorganized the sub-domains and indicators to reduce redundancy and to group indicators according to the basic formulas mentioned in Section I.B.1.d (i.e., by current situation, response and recovery capacity, and adaptive capacity). We also renamed the domain originally called *leadership and management* to *governance*.

A number of responses highlighted the need to prioritize indicators—which are most important? To address this, the second Delphi round asked for feedback on weighting, starting with even weights by domain. However, as is further discussed in Section IV.C.2.e, our sample size was limited by the Paperwork Reduction Act to less than ten people, meaning that our Delphi group was not large enough to get statistically significant feedback. We did not adjust weights based on the feedback, but it is interesting to note that all respondents encouraged less weight on the economic capacity section.

One reviewer noted that we should differentiate between measures of resilience, identified as “things the state is doing or can do to reduce impacts,” and measures of vulnerability. This drove some of our thinking on resilience formulas and the subsequent reorganization. Based on this, as well as other feedback highlighting that “It is more

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[154] Tate, “Social Vulnerability Indices,” 329.

[155] Stafford Act, 25.

important to work from first principles of disaster resilience and its dimensions," we significantly modified the sub-domains after the first Delphi round. Many of the sub-domains in the first round were pulled from other indices and so formed a somewhat eclectic mix. Based on the feedback mentioned, however, we focused the sub-domains to align with the formulaic version of resilience outlined in Chapter I.B.1.d, specifically focusing on current characteristics and on capacities for each domain, along with some domain-specific ideas that aligned with core ideas of emergency management (e.g., effective planning in the *governance* domain).

After reworking the sub-domains, we also went through carefully to ensure that all indicators were in the appropriate sub-domain and that there were no redundancies. Based on this general effort, and feedback to remove some specific indicators, we reduced the number of individual indicators from 133 to 105 in the final framework. We made additional edits after the second round of Delphi feedback, though they were mostly focused on the individual indicator level, so were less significant. We detail indicator-specific changes in Appendix A, which lays out the final framework.

After completing the second round of Delphi feedback, we spoke to a professional group of data analysts at FEMA called the Analytics Community Brownbag to not only discuss and bolster the theoretical foundation for the framework but also to learn of any previous similar efforts and any other data sources. Indeed, FEMA, through the Mitigation Framework Leadership Group, had begun a similar effort in 2016, publishing the "Draft Interagency Concept for Community Resilience Indicators and National-Level Measures" for stakeholder feedback.[156] While the discussion did highlight other resources and factors, this tool alone was valuable, especially since it included a number of federal data sources.[157]

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[156] Mitigation Framework Federal Leadership Group, *Draft Interagency Concept for Community Resilience Indicators and National-Level Measures* (Washington, DC: DHS, 2016).

[157] "Community Resilience Indicators and National-Level Measures: A Draft Interagency Concept," FEMA, last updated April 16, 2018, https://www.fema.gov/community-resilience-indicators.

B. DATA SELECTION AND IMPUTATION

As mentioned in Section III.A.2, researchers base initial indicator selection on the quality of the indicator and its theoretical relation to the issue. Having discussed the theoretical framework and specific indicators, two key points arise: data imputation and quality. Data imputation covers a range of mathematical techniques to add missing values into the dataset.[158]

The vast majority of data for states was available for all fifty and the District of Columbia. However, some data were missing from some states and, for other data points like federal grant monies, not all states (and DC) receive them, which created additional gaps. In total, we imputed data for 12 cells out of 2,601, or 0.4 percent. To create a complete dataset, we used the NORMINV function in Excel, which combines the mean and standard deviation of the data with a random variable.[159] We did this simply because of time constraints. For future iterations, we recommend using the multiple regression method that the OECD handbook and NHSPI “2018 Methodology” outline, which allows for prediction of the missing data for a jurisdiction based on its relative position for other indicators that have the full data set available.[160]

In addition to imputation, it is important to select good quality data. The OECD handbook, for example, outlines six traits of good quality data: accuracy, relevance, timeliness, accessibility, interpretability, and coherence.[161] In one example of using these factors, the NHSPI decided to only use data if it meets certain criteria, including an update interval of no fewer than three years.[162]

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[158] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 24–25.

[159] Charles Zaiontz, “Fully Conditional Specification (FCS),” *Real Statistics Using Excel* (blog), accessed August 4, 2018, http://www.real-statistics.com/handling-missing-data/multiple-imputation-mi/fully-conditional-specification-fcs/.

[160] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 56–57; NHSPI, “Methodology for the 2018 Release,” 13.

[161] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 47–48.

[162] NHSPI, “Methodology for the 2018 Release,” 2.

We took these considerations into account when selecting data for this framework. We declined to use some data because it did not meet one or more of these quality criteria. However, in other instances, we did include some data that may not be updated regularly, as it was needed to help construct the index. We tended toward the "done is better than perfect" maxim. However, because transparency about decisions and rationale is paramount, we did note all these data as such in Appendix A.[163]

We used 2016 as the year for analysis because it was a common year for which data was available, including from the American Community Survey, which provided many individual indicators. However, because some data were not available yearly, some indicators not available for 2016 were still included in order to test their relationship to resilience. To the degree possible, researchers should use more regularly updated data for future calculations.

Finally, some sources included a confidence interval. For simplicity of calculation in the initial index, we did not include these. However, as noted by the NHSPI, it is more analytically credible to report a confidence interval with the data so, again, to the degree possible, it is important to include confidence intervals in future resilience indices.[164]

C. NORMALIZATION

Normalization is the process of putting data on the same scale. For instance, per capita gross domestic product (GDP) has, theoretically, no maximum value, while percent of the population over age sixty-five is, obviously, a number between 1 and 100. The different scales make it hard to compare the data. A number of techniques allow researchers to put the data on a common scale and thus maintain the relationships in the data. These include ranking, standardization, min-max, categorical scale, above/below mean, and

[163] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 23.

[164] NHSPI, "Methodology for the 2018 Release," 13–14.

distance to a reference, among others.[165] We chose min-max normalization because it is accurate, simple, and used by the NHSPI.[166] Figure 12 shows the normalization formula.

$$Standardized\ Value = \frac{(Original\ Value - Minimum\ Value)}{(Maximum\ Value - Minimum\ Value)}$$

Figure 12. Min-Max Normalization Formula[167]

Most indicators started on the scale for which a higher number generally indicated better resilience, such as per capita GDP (i.e., if a state has a higher per capita GDP, it will be more resilient, in theory). However, for other indicators where lower is better (e.g., the unemployment rate), we reversed the scale where possible—so, instead, we included the "negative" indicator in the index (e.g., employment rate). We only did this for indicators that were easily reversible, such as those generated as percentages.

D. WEIGHTING AND AGGREGATION

We used a weighted arithmetic mean to aggregate the indicators for each state by sub-domain and domain.[168] Figure 13 shows the weighting formula.

$$\bar{x} = \sum_{i=1}^{n} w_i' \, x_i$$

"w_i is the weight, x_i is the score for measure, subdomain, or domain *i*, and *n* is the number of measures, subdomains, or domains."

Figure 13. Aggregation Formula[169]

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[165] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 27–29.

[166] Tate, "Social Vulnerability Indices," 329; NHSPI, "Methodology for the 2018 Release," 7.

[167] Source: NHSPI, "Methodology for the 2018 Release," 7.

[168] NHSPI, 5.

[169] Source: NHSPI, 13.

The OECD handbook highlights considerations for weighting: "Indicators should be aggregated and weighted according to the underlying theoretical framework. Correlation and compensability issues among indicators need to be considered and either be corrected for or treated as features of the phenomenon that need to retained in the analysis."[170] Many reviewers in the first round of Delphi feedback highlighted the importance of prioritization; to that end, we included a survey on weights in the second Delphi round. However, group size limitations from the Paperwork Reduction Act meant that the survey results on weights were, while helpful, not significant enough to justify adjusting from equal weights. We recommend in Chapter IV to use a larger sample size (e.g., 150–200) in future Delphi work to get a better understanding of likely weights, not only at the domain level (i.e., does social capital or economic capacity drive resilience more?) but also at the sub-domain and indicator levels (i.e., do building codes or land use plans drive resilience more?).[171]

While strong Delphic agreement on weights would have been helpful, we had originally planned to use equal weights in the final measure—not because we believe this to be the most sound structure based on theory but because we were unable to rigorously determine a more sound approach.[172] When aggregating the actual data, however, data limitations imposed a new weighting structure. Specifically, because data were not available for all indicators, using the original weights for each indicator in the final index would result in overall lower scores across domains and states. For example, if a subdomain originally had three indicators, each would have been weighted .33 in the original even-weight structure. If we were only able to find data for one of the three indicators and still used the .33 weight, the overall score would be lower since the other .66 of that subdomain would have been zero due to missing data. It would have been zero for all indicators so, in theory, would have a smaller effect on the relative positions of states, but it would affect the output. Indeed, we tested different weights and state-specific scores did vary between aggregation options.

[170] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 15.

[171] NHSPI, "Methodology for the 2018 Release," 8; Tate, "Social Vulnerability Indices," 336.

[172] Tate, "Social Vulnerability Indices," 329.

The other alternative was to evenly weight all the data that was available. Rather than underscoring the entire index—as with the first option—this would give greater weight to some variables simply because they were available. Though there are merits to both approaches, we used the original weighting system because we presented the data based on whether the state was average, above average, or below average. In addition to following the BRIC and NHSPI precedent, presenting the index this way makes the overall index, whether high or low (the downside in the first weighting choice), irrelevant. Figure 14 shows the full state resilience index.

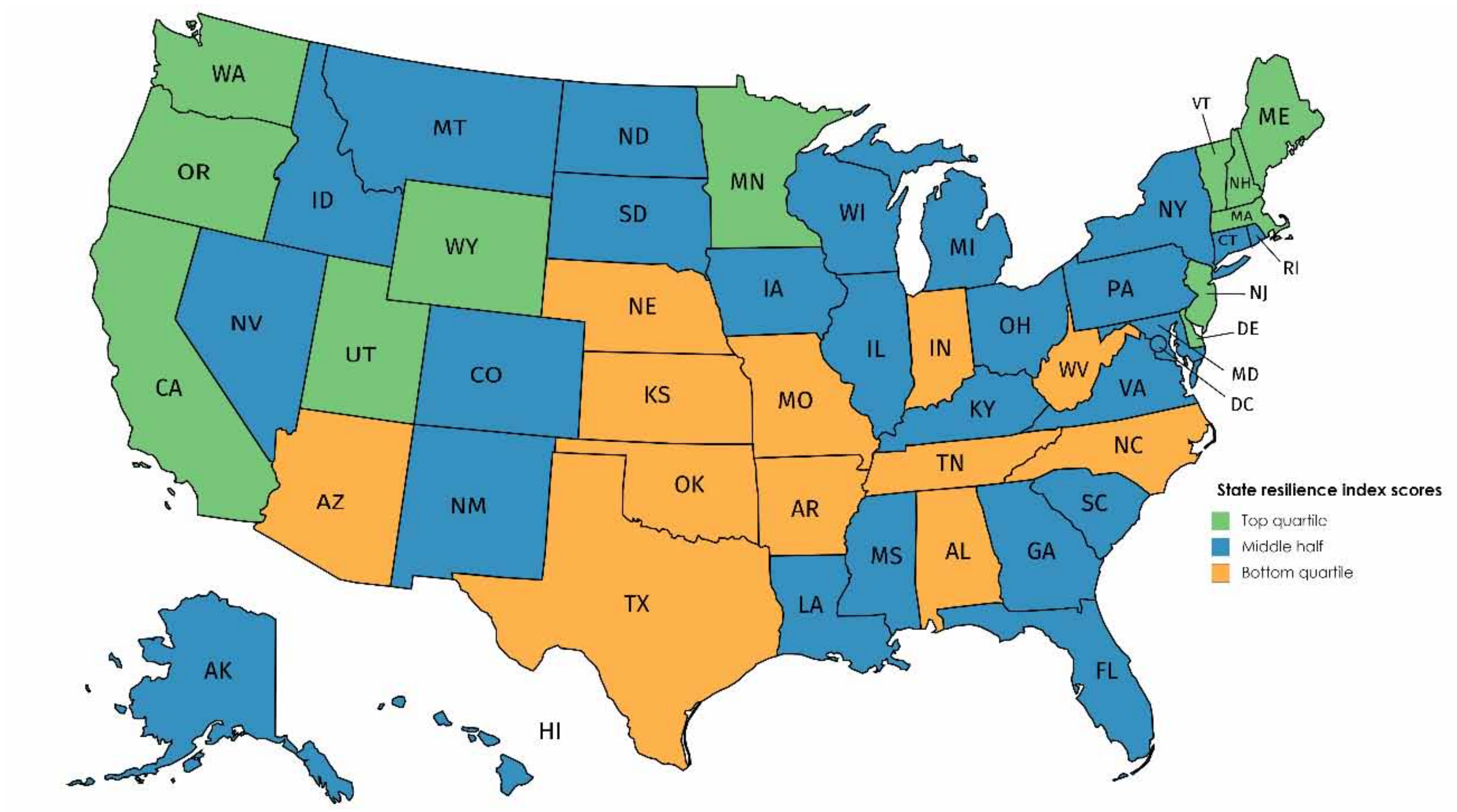

Figure 14. State Resilience Index Scores [173]

173 See Appendix A for data sources. Created using mapchart.net.

In addition to gathering weights through surveys or simply using even weights, the OECD handbook outlines how to establish weights based on factor analytic methods such as PCA. Discussed in greater detail in Chapter III.E.1.a, these methods involve creating a correlation matrix and estimating from that matrix which indicators account for the greatest amount of variance in the overall dataset.[174] This technique can help remove irrelevant indicators and can also help determine weights—modelers weight more heavily those indicators that account for more variance.[175]

Also discussed in greater detail in Section III.E.1.a, we did conduct an exploratory factor analysis to identify the key drivers and the variance that each accounted for. However, the model was not a very good fit so we did not use it to adjust indicator weights. The next chapter discusses this more, including how we checked if the model was accurate.

E. VALIDITY: INTERNAL AND EXTERNAL

We have discussed two points that bear repeating here. First, the goal of this index is to provide a useful tool for decision–makers. Second, knowing that "all models are false but some are useful," we still wanted this index to be as accurate as possible, termed here "valid."[176] As Tate puts it succinctly, "The big question facing proponents of vulnerability indices is, how do you know that the model is correct?"[177] This section outlines techniques that can help answer that question.

To clarify first, internal validity deals with whether all the ideas in a model seem to be measuring the same idea, while external validity deals with whether the model actually corresponds with reality, or external events. An accurate index will be both internally and externally valid.[178]

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174 OECD and European Commission, *Handbook on Constructing Composite Indicators*, 63–71.

175 OECD and European Commission, 63, 89–90.

176 Box, "Robustness."

177 Tate, "Social Vulnerability Indices," 340.

178 Tate, 340.

1. Internal Validity

A framework is internally valid if it agrees with itself. Put another way, if the different indicators in the index and domains are internally consistent and are all pointing in the same direction, based on a range of mathematical techniques, the index is internally valid.[179] These techniques can also drive revision of previous decisions, such as weighting.

a. Factor Analysis

In modeling complex ideas such as resilience, one key goal is to better understand what is most important. Which are the key areas that drive most of the output of the index? Factor analysis (FA) can help to answer this question by finding the key factors in the dataset. The term *factor* here should not be confused with indicator (i.e., a specific data point in the framework such as the GDP per capita). In this context, factors are "unobservable latent variables, the presence of which is manifest by a larger set of directly observable variables."[180] Put another way, they are areas in the data that drive much of the output but that cannot be seen directly. These factors can then be named based on the specific indicators (e.g., an actual point such as GDP per capita) they are associated with, and they can also provide insight into the importance of the actual indicators in the index, which modelers can use to adjust the weights of the indicators when the index is aggregated, as mentioned in Section III.D.[181] Again, it is important to clarify that these factors are not individual indicators but, as mentioned, are aspects of the full dataset that cannot otherwise be seen.[182] This section provides more detail on the factor analysis process and our results specifically.

Cutter et al.'s Social Vulnerability Index (SoVI) provides a real example. They started with more than 250 variables, narrowed those to 85, and then used factor analysis

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179 Tate, 340.

180 Louis W. Glorfeld, "An Improvement on Horn's Parallel Analysis Methodology for Selecting the Correct Number of Factors to Retain.," *Educational and Psychological Measurement* 55, no. 3 (1995): 377.

181 Erik Pettersson and Eric Turkheimer, "Item Selection, Evaluation, and Simple Structure in Personality Data," *Journal of Research in Personality* 44, no. 4 (2010): 412; OECD and European Commission, *Handbook on Constructing Composite Indicators*, 89.

182 Glorfeld, "Horn's Parallel Analysis," 377.

to extract 11 factors "which explained 76.4 percent of the variance."[183] The key point is that there is variability in all datasets and that Cutter et al. determined that these eleven specific factors accounted for the majority of it for their data. This is important because it allows practitioners to focus their efforts more pointedly on the factors that make the most difference—those that contribute to most of the variance. How would one actually do that?

To start, researchers can name the factors and can use them to structure (or restructure) the composite indicator.[184] Table 1 shows the variation for each factor in Cutter et al.'s SoVI and their name for each factor, which they chose based on which of the real variables in the dataset were most strongly correlated with that factor.

Table 1. Social Vulnerability Factors[185]

Factor	Name	Percent Variation Explained	Dominant Variable	Correlation
1	Personal wealth	12.4	Per capita income	+0.87
2	Age	11.9	Median age	–0.90
3	Density of the built environment	11.2	No. commercial establishments/mi^2	+0.98
4	Single-sector economic dependence	8.6	% employed in extractive industries	+0.80
5	Housing stock and tenancy	7.0	% housing units that are mobile homes	–0.75
6	Race—African American	6.9	% African American	+0.80
7	Ethnicity—Hispanic	4.2	% Hispanic	+0.89
8	Ethnicity—Native American	4.1	% Native American	+0.75
9	Race—Asian	3.9	% Asian	+0.71
10	Occupation	3.2	% employed in service occupations	+0.76
11	Infrastructure dependence	2.9	% employed in transportation, communication, and public utilities	+0.77

183 Cutter, Boruff, and Shirley, "Social Vulnerability," 249–51.

184 Pettersson and Turkheimer, "Item Selection," 412; OECD and European Commission, *Handbook on Constructing Composite Indicators*, 89.

185 Source: Cutter, Boruff, and Shirley, "Social Vulnerability," 252.

The table also shows the "dominant variable" in each factor, but the researchers based the factor names on the other variables that are also strongly correlated to the factor. Table 3 shows an example from personality research that can be more clear. So if one factor contributes to a large portion of the total index variability, and then a handful of specific indictors are strongly correlated with that factor, practitioners could focus efforts on improving those specific indicators. The analogy falls down a little for this vulnerability index because no emergency manager can change the wealth or age of an area, but for a broader resilience index with more actionable indicators, this exercise could show specific variables that are within a practitioner's control.

To rephrase a little, "[t]he objective is to explain the variance of the observed data through a few linear combinations of the original data."[186] FA ultimately helps explain which indicators contribute how much variance to the overall index, and then helps us retain or weight more heavily those factors that contribute to more variance. In addition to the focus we described in the previous paragraph, researchers can also use the FA process to weight indicators that contribute most to the variance of the index more heavily in the aggregation process.[187] The following paragraphs outline the process in more detail.

Erik Petterson and Eric Turkheimer outline the steps in the process. The first few focus on creating the index, which we have covered already. The final three are the actual FA itself, the rotation, and the interpretation of this analysis. The third step is a choice between techniques such as FA or PCA.[188] Though FA and PCA are similar, they do use different statistical methods.[189] Rather than discussing the math here, however, we will provide an example to illustrate PCA.

Just as road atlases used to include a mileage chart listing one set of cities along the top, the same set of cities along the left, and all the cells filled with the distances from each city to the others, factor analysis creates a similar chart comparing each indicator in the

[186] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 63.

[187] ECD and European Commission, 63.

[188] Pettersson and Turkheimer, "Item Selection," 407.

[189] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 63–69.

index with each of the other indicators, and each cell is populated with their correlation. This is a correlation matrix. Modelers then calculate eigenvalues (a measure of variance) from the correlation matrix. “The eigenvalues of the matrix … are the variances of the principal components.”[190] Table 2 shows an example.

Table 2. Example Correlation Matrix[191]

	PATENTS	ROYALTIES	INTERNET	EXPORTS	TELEPHONE	ELECTRICITY	SCHOOLING	UNIVERSITY
PATENTS	1.00	0.13	-0.09	**0.45**	0.28	0.03	0.22	0.08
ROYALTIES		1.00	**0.46**	0.25	**0.56**	0.32	0.30	0.06
INTERNET			1.00	**-0.45**	**0.56**	**0.84**	**0.63**	0.27
EXPORTS				1.00	0.00	-0.36	-0.35	-0.03
TELEPHONE					1.00	**0.64**	0.30	0.33
ELECTRICITY						1.00	**0.65**	0.26
SCHOOLING							1.00	0.08
UNIVERSITY								1.00

The FA creates a number of factors equal to the number of indicators, not all of which are equally important. The next decision is how many factors to retain. Though PCA was once broadly used for this, both seemingly endorsed by the OECD handbook and used by Cutter et al. to create the SoVI, it has fallen out of favor.[192] PCA leads to over extraction of factors, meaning that it says more factors are relevant than actually are, and it also does not capture error appropriately.[193] Specifically, PCA “does not distinguish between

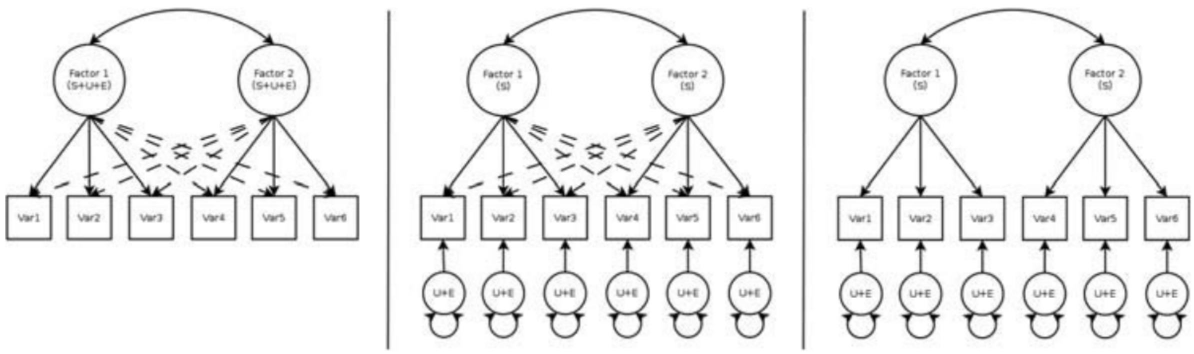
[190] OECD and European Commission, 64.

[191] Source: OECD and European Commission, 64.

[192] Beccari, “Comparative Analysis,” 10; Cutter, Boruff, and Shirley, “Social Vulnerability,” 251; OECD and European Commission, *Handbook on Constructing Composite Indicators*, 63.

[193] Tate, “Social Vulnerability Indices,” 330; Thomas A. Schmitt, “Current Methodological Considerations in Exploratory and Confirmatory Factor Analysis,” *Journal of Psychoeducational Assessment* 29, no. 4 (2011): 307, https://doi.org/10.1177/0734282911406653.

shared, unique, and error variance, and a value is estimated for the loading of each item onto each component."[194] Figure 15 illustrates this.



S = shared variance, U = unique variance, E = error variance

Figure 15. Differences between a Principal Components Model, Exploratory (Common) Factor Analysis Model, and Confirmatory Factor Analysis Model[195]

Parallel analysis seems to extract factors more accurately than PCA.[196] It achieves this by conducting two analyses in parallel. The first uses the scree plot method of graphing the real eigenvalues. The second also uses the scree plot but in addition to graphing the real eigenvalues, it uses the Monte Carlo method to calculate random variables for each indicator based on the range and variability for that indicator. It does this many times (we used 1,000), calculates eigenvalues based on this random dataset, and then graphs those.[197]

On the line graphed from the real data, points that fall beneath the random-data line are called scree, so called because they resemble the field of small rocks (or random data) at the base of a mountain, called a scree slope. Modelers should retain the number of factors

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[194] John K. Sakaluk and Stephen D. Short, "A Methodological Review of Exploratory Factor Analysis in Sexuality Research: Used Practices, Best Practices, and Data Analysis Resources," *The Journal of Sex Research* 54, no. 1 (2017): 3, https://doi.org/10.1080/00224499.2015.1137538.

[195] Sakaluk and Short, 3.

[196] Tate, "Social Vulnerability Indices," 330.

[197] Tate, 330; Sakaluk and Short, "Methodological Review," 4; Schmitt, "Current Methodological Considerations," 309.

above the random-data line and discard the scree factors.[198] Figure 16 shows that, based on the parallel analysis scree plot for our data, we should retain five factors. We used R to conduct the parallel analysis and graph the results.[199] Specifically, we used the psych package developed by William Revelle and the factor.parallel function.[200]

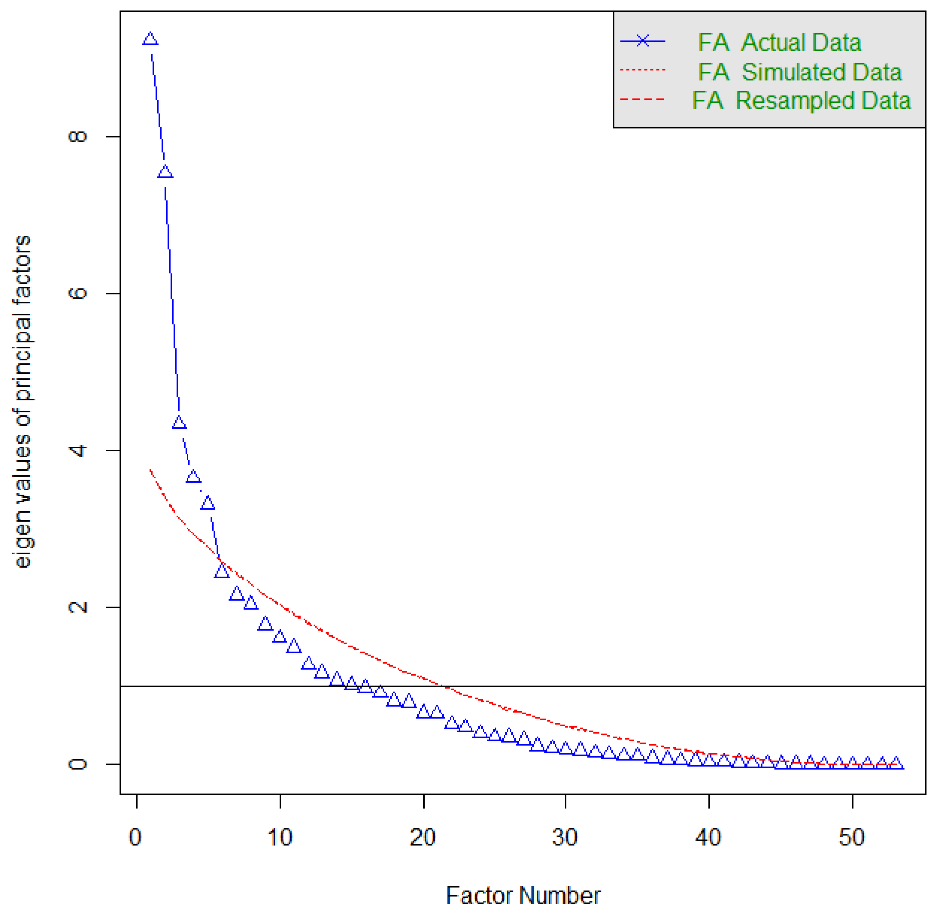

Figure 16. Parallel Analysis Scree Plot for This State Resilience Framework

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[198] Sakaluk and Short, "Methodological Review," 5; Marley W. Watkins, "Determining Parallel Analysis Criteria," *Journal of Modern Applied Statistical Methods* 5, no. 2 (2005): 344.

[199] R Core Team, *R: A Language and Environment for Statistical Computing* (Vienna, Austria: R Foundation for Statistical Computing, 2018), https://www.R-project.org/.

[200] William Revelle, "Procedures for Psychological, Psychometric, and Personality Research," version 1.8.4, Personality Project 2018, April 29, 2018, 129, https://personality-project.org/r/psych-manual.pdf; Sakaluk and Short, "Methodological Review," 8; "Using R and Psych for Personality and Psychological Research," Personality Project, June 1, 2015, https://personality-project.org/r/psych/.

Parallel analysis simply determines *how many* factors to retain, so the next step is to actually extract the factors and see *which* ones should be kept. John Sakaluk and Stephen Short recommend maximum likelihood extraction because it allows for the computation of the chi-squared (χ^2) statistic and the "standard errors for factor loadings and correlations."[201] However, we were unable to extract the factors with the maximum likelihood model so instead used the minimum residuals method. As Revelle discusses, "[t]he minimum residual (minres) solution is an unweighted least squares solution that … uses the `optim` function and adjusts the diagonal elements of the correlation matrix to minimize the squared residual when the factor model is the eigen value decomposition of the reduced matrix."[202] Harry H. Harman and Wayne H. Jones also show that minres produces almost identical extraction to maximum likelihood.[203]

After determining the extraction method, the next step is to rotate the factors "to enhance the interpretability of the results. The sum of eigenvalues is not affected by rotation, but changing the axes will alter the eigenvalues of particular factors and will change the factor loadings."[204] Rotating factors can also help modelers find additional clusters of variables that are initially obscure.[205] Rotations can generally be either right-angle (orthogonal) or non-right angle (oblique). The difference is in assumed correlation—orthogonal assumes uncorrelation and oblique does not.[206] The consensus in the literature seems to be on oblique rotation for two reasons. First, most real data is at least somewhat correlated; and second, "oblique rotation methods generally produce accurate and comparable factor structures to orthogonal methods even when inter-factor correlations are negligible."[207] In short, oblique methods are more accurate.

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201 Sakaluk and Short, "Methodological Review," 3.

202 Revelle, "Personality Research," 133.

203 Harry H. Harman and Wayne H. Jones, "Factor Analysis by Minimizing Residuals (Minres)," *Psychometrika* 31, no. 3 (1966): 367.

204 Pettersson and Turkheimer, "Item Selection," 412; OECD and European Commission, *Handbook on Constructing Composite Indicators*, 70.

205 Schmitt, "Current Methodological Considerations," 311.

206 Sakaluk and Short, "Methodological Review," 3.

207 Sakaluk and Short, 4; Schmitt, "Current Methodological Considerations," 312.

We again used Revelle's psych package in R to do the factor analysis, including extraction and rotation. Specifically, we used the `fa` function with minimum residual extraction and oblimin rotation (oblique).[208] We also repeated the extraction with Varimax rotation (orthogonal) to see how the factor loadings would differ.

The results of the analysis were fairly clear: the dataset we had did not create an accurate index. Better data and more iterations of the framework are necessary to understand the primary drivers of resilience (the factors of the analysis) and which indicators in turn drive these factors. Two indicators of index quality include the Tucker-Lewis Index (TLI) of factoring reliability and the root mean square error of approximation (RMSEA). RMSEA should be below .005 and the TLI should be over 0.9.[209] Some have pointed out, however, that RMSEA is not always a helpful measure of model accuracy. The RMSEA for our model was only 0.195 and our TLI was 0.381, both well outside the accepted ranges.[210] David Kenny also briefly outlines some choices that could drive better or worse model fit, and these deserve greater exploration in future research.[211]

In addition to these quantitative metrics, the index simply did not lend itself to ready interpretability. For example, a use of factor analysis comes from personality psychology, where researchers attempt to draw the underlying factors of personality from lengthy questions about moods and traits such as upset, happy, or relaxed. Individuals answer a host of these questions, then personality researchers use factor analysis to draw out the key elements. Table 3 shows an example. The loadings indicate the strength and direction of the relationship between that indicator and the specific factor. Based on these, researchers can determine what the factors represent and then name them. For example, the first factor in Table 3 (the far left column, named "agreeableness") correlates most positively with the

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[208] R Core Team, *R*; `fa (r = All.data.v7_slim, nfactors = 5, n.obs = NA, n.iter = 1, rotate = "oblimin," scores = "regression," residuals = FALSE, SMC = TRUE, covar = FALSE, min.err = 0.001, max.iter = 50, symmetric = TRUE, warnings = TRUE, fm = "minres," alpha = 0.1, p = 0.05, oblique.scores = FALSE, cor = "cor," correct = 0.5).`

[209] Puneet Rajput, "Exploratory Factor Analysis," RPubs, April 2, 2018, https://rpubs.com/Pun_/Exploratory_factor_Analysis.

[210] Schmitt, "Current Methodological Considerations," 307.

[211] David A. Kenny, "Measuring Model Fit," David A. Kenny's Homepage, November 24, 2015, http://davidakenny.net/cm/fit.htm.

“kind-hearted” indicator and most negatively with “unfriendly.”[212] Based on this, as well as the other indicators, it does seem reasonable to name the factor “agreeableness.”

However, for the resilience index outlined here, the indicators that were loaded on specific factors did not present easily discernable commonalities. Table 4 shows the loadings from the oblimin factor analysis. Looking at the first factor (F1) in Table 4, for example, the most positively correlated indicator is GDP per capita while the most negatively correlated indicator is percent owner-occupied housing. These do not seem to be opposites as the should be, generally speaking.

[212] Pettersson and Turkheimer, “Item Selection,” 412.

Table 3. Factor Analysis Personality Example[213]

Agreeableness		Conscientiousness		Surgency		Neuroticisism	
Item	Loading	Item	Loading	Item	Loading	Item	Loading
Unfriendly	−0.51	Irresponsible	−0.46	Shy	−0.38	Self-assured	−0.40
Inconsiderate	−0.42	Unreliable	−0.42	Bashful	−0.37	Relaxed	−0.38
Insensitive	−0.41	Undependable	−0.40	Soft-spoken	−0.30	Happy	−0.38
Stuck up	−0.37	Wishy-washy	−0.39	Unhappy	−0.29	Calm	−0.37
Impolite	−0.36	Unstable	−0.32	Sad	−0.29	Peaceful	−0.36
Stingy	−0.36	Phony	−0.32	Indecisive	−0.28	Self-confident	−0.34
Self-centered	−0.35	Indecisive	−0.29	Depressed	−0.25	Confident	−0.33
Arrogant	−0.33	Obnoxious	−0.27	Scared	−0.24	Patient	−0.32
Artificial	−0.32	Uncomfortable	−0.27	Lonely	−0.22	Joyful	−0.29
Unreasonable	−0.32	Awkward	−0.26	Uncomfortable	−0.22	Good-natured	−0.26
Helpful	0.64	Logical	0.51	Expressive	0.53	Complaining	0.60
Loving	0.64	Alert	0.51	Excited	0.53	Tense	0.60
Understanding	0.65	Reliable	0.51	Enthusiastic	0.54	Grouchy	0.63
Considerate	0.66	Efficient	0.51	Persuasive	0.54	Irritable	0.64
Warm	0.67	Sensible	0.52	Forward	0.55	Annoyed	0.64
Compassionate	0.72	Realistic	0.53	Assertive	0.55	Sad	0.65
Caring	0.74	Level-headed	0.54	Confident	0.57	Upset	0.65
Kind	0.74	Thorough	0.56	Outgoing	0.57	Grumpy	0.66
Warm-hearted	0.78	Responsible	0.56	Self-confident	0.60	Angry	0.68
Kind-hearted	0.80	Practical	0.57	Entertaining	0.60	Crabby	0.68

213 Source: Pettersson and Turkheimer, 412.

Table 4. List of Factors with Indicators and the Percent Correlation with Each Factor

Indicator	F1	Indicator	F2	Indicator	F3
28. GDP per capita	0.98	29. Retail stores per 10,000 population	0.69	53.1. Average BCEGS commercial score	0.55
13. NGOs per 10,000 population	0.86	35. Negative GINI coefficient	0.64	44. Percent of communities rated PPC 1-3	0.54
31. Homeless per 100,000 population	0.83	11.2. Percent no religious affiliation	0.56	103. CRS communities	0.53
4. Percent of population with bachelors or higher	0.72	32. Average credit score	0.55	53.2. Average BCEGS residential score	0.52
36. Per capita income	0.7	30. Percent owner occupied housing	0.44	74. State has enhanched hazard mitigation plan	0.45
38. Percent roads in poor condition	0.63	7. Percent with health insurance	0.42	61. Number of sources providing 5% electricity generation or more	0.4
87. Emergency management budget per capita	0.52	24. Percent of businesses with fewer than 20 employees	0.4	11.2. Percent no religious affiliation	0.39
7. Percent with health insurance	0.42	12. Percent voted in 2016 presidential election	0.37	11.1. Percent non-christian religious affiliation	0.34
6. Percent without a disability	0.39	6. Percent without a disability	0.37	6. Percent without a disability	0.32
24. Percent of businesses with fewer than 20 employees	-0.37	11. Percent christian	-0.49	3. Percent of population with high school or equivalent	-0.58
3. Percent of population with high school or equivalent	-0.49	1. Percent one-parent households	-0.78	38.1. Percent structurally deficient bridges	-0.6
30. Percent owner occupied housing	-0.56	37. Percent in poverty	-0.78	5. Percent speaks English very well	-0.63
Indicator	F4	Indicator	F5		
104. Percent of general fund expenditures in a rainy day fund	0.83	69. State debt per capita	0.89		
102. 2012-2016 Total PDM per capita	0.68	11.1. Percent non-christian religious affiliation	0.64		
90. 2014-2016 Total EMPG per capita	0.61	101. Total 2012-2016 HMGP per capita	0.56		
24. Percent of businesses with fewer than 20 employees	0.52	36. Per capita income	0.38		
96. Number of WEA authorities	0.47	38. Percent roads in poor condition	0.3		
48. Broadband providers per capita	0.41	38.2. Percent dams with EAPs	0.24		
2. Percent below age 65	0.3	84. CERT programs per capita	0.24		
88. EMAP accredited	-0.33	44. Percent of communities rated PPC 1-3	0.21		
7. Percent with health insurance	-0.45	6. Percent without a disability	0.19		
26. 5 year average percent GDP change	-0.79	38.1. Percent structurally deficient bridges	0.18		

Though we did find the factors and indicators loadings interesting, the patterns between them in the other factors are similarly inscrutable. Additional data and continual iteration would likely help improve the utility of the factor analysis. In addition to these kinds of factor analytic methods, sensitivity analysis is another way to test whether the index is valid.

b. Sensitivity Analysis

Sensitivity analysis complements FA because it "is the study of how the variation in the output can be apportioned, qualitatively or quantitatively, to different sources of variation in the assumptions."[214] We did not perform sensitivity analysis because of time constraints. However, a couple brief points may help guide future researchers.

We have tried to clarify our assumptions in creating this index throughout this paper. Sensitivity analysis builds on this by providing modelers an opportunity to test those assumptions mathematically.[215] An analogy can help clarify the basic idea. A business wants to improve its Web sales, so it conducts a number of A/B tests on its homepage, where half of the visitors see one thing (e.g., color, font, etc.) and half of the visitors see a different variation of the same thing. Over time, the business can see which variations drive more sales. By testing all of the factors, the business can eventually push its site closer to maximizing sales. Sensitivity analysis is a similar idea for the index, making small changes in input assumptions, running the model many times, and comparing outputs.

Generally speaking, sensitivity analysis can be global or local. Local analysis addresses each step to build the model individually while global analysis evaluates more than one step at a time.[216] By way of comparison, FA provides a tool to understand what the key drivers for a concept are and sensitivity analysis analyzes the entire index to see which steps and assumptions change the output, and by how much.[217] To sum, "[t]he key

[214] OECD and European Commission, *Handbook on Constructing Composite Indicators*, 117.

[215] Tate, "Social Vulnerability Indices," 330–31.

[216] Tate, 331.

[217] Tate, 331.

to improving the model lies in increasing its precision by identifying which construction stages contribute most to the uncertainty."[218] Once researchers have evaluated a framework for internal validity, the next step is to see whether it is valid externally.

2. External Validity

While internal validity is concerned with whether a model agrees with itself, external validity focuses on whether the model agrees with reality "using independent proxy data, such as mortality, economic loss, and household survey."[219] As Dmitry Leykin et al. note, comparing their index to "valid indicators of personal resilience, various psychological indicators, sociological measures and more, can provide a broader multidisciplinary understanding of the interrelations between people and their community as well as the individual's effect on their personal and community resilience."[220] The point is to understand if and how the model predicts various aspects of reality. Regression analysis provides one tool with which to do this.

a. An Appropriate Dependent Variable

In their 2016 review of five vulnerability and resilience indices, Bakkensen et al. note that "Choice of outcomes to use for empirical validation must be grounded in theory. One logical choice is to use the stated objective of an index as a guide."[221] They ultimately used multivariate analysis of economic damage, deaths, and federal disaster declarations to determine whether the tools they studied predicted reality.[222] We followed suit, comparing each indicator in the index here to deaths and damage. Specifically, we used data from the National Weather Service, averaging 2016 and 2017 to control somewhat for random variation between years.[223] Because 2016 was our target year for analysis, we did

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218 Tate, 337.

219 Tate, 340.

220 Leykin et al., "Conjoint Community Resiliency Assessment," 321.

221 Bakkensen et al., "Validating Resilience and Vulnerability Indices," 990.

222 Bakkensen et al., 990.

223 "Natural Hazard Statistics: Weather Fatalities 2017," National Weather Service, April 25, 2018, http://www.nws.noaa.gov/om/hazstats.shtml.

not want to use comparison data from previous years, but it could be better, for future analyses, to average more years, potentially controlling for variation more effectively. For economic damage, we used the total economic losses available from the National Weather Service, both property and crop. For deaths, we used the total of both fatalities and injuries, following the idea that a resilient state would have fewer of both.[224] We averaged both deaths and damage on a per capita basis. There is random variability in the distribution of deaths and damage and we felt that averaging by per capita helped control for that somewhat.

Another important point is that the hazards vary greatly in their strength. The most precise way to control for this and accurately compare the impact of a snowstorm in Nebraska with the impact of a hurricane in North Carolina would be to develop a technique to control for the size and strength of the disaster in the same way that economists control for the value of a dollar in 1990 compared to 2010. This would be challenging because it would have to be impact-agnostic, only measuring the strength of the system so that the actual impact on a given jurisdiction could be attributed solely to that area's resilience.

On a final note, we used deaths and damage because of precedent in the literature and because those data were available. However, many people could easily be negatively impacted by a disaster without suffering death, injury, or even severe economic loss simply through disruption to normal routine and increased stress, among other things.[225] For this reason, it might be valuable for future indices, given available data, to use well-being or some other larger measure of human happiness as the dependent variable.

b. Actual Regressions

Out of 105 indicators in the final framework, we found acceptable data for forty. Sixty-five did not have data available. While gathering data for the original group, we also found data for eleven new proxies that, while not in the framework, were similar to existing indicators and were plausibly linked to disaster impacts. The total number of data points

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[224] National Weather Service.

[225] Bakkensen et al., "Validating Resilience and Vulnerability Indices," 990.

used in the analysis therefore was fifty-one per state. We followed the NHSPI's precedent again and included the District of Columbia, making it fifty-one total states, for 2,601 data points. We then created two simple scatter plots for each indicator, using the indicator as the independent variable and fatalities/injuries and damage as the dependent variables for each plot, respectively. Finally, we put a best fit line on each scatter plot and noted the R-squared value, a measure of how well the line fits the data, and noted the line slope.

Only four indicators met a threshold of .2 for the R-squared value, meaning that the majority of indicators did not predict real impacts, either deaths or damage. For damage, indicator 25 (the ratio of a state's exports to its GDP) was the only indicator to meet the threshold. For fatalities and injuries, indicator 4 (the percentage of the population with a bachelor's degree or higher), indicator 7 (the percentage of the population with health insurance), and indicator 90.2 (the share of a state's Emergency Management Performance Grant [EMPG] that it allocates within the state to tribal nations—a new proxy found while gathering data) met the threshold.

We also conducted the same analysis with only flood deaths, rather than with deaths from all hazards, to see if isolating one hazard would display a clearer link. Only one indicator met the .2 threshold in this case—the percent of the population with a disability. While this does make sense, it was only a weak relation, with an R-squared value of .2633.

To continue the analysis, we conducted full regressions, beyond the simple scatter plot, on three of the indicators with the highest R-squared values (state exports compared to weather-related economic damage, health insurance rates compared to weather-related deaths and injuries, and rates of attaining a bachelor's degree or higher compared to weather-related deaths and injuries). For all three measures, the p value (the likelihood the data could have appeared by random chance) was .006 or less with the common threshold simply being below .05, meaning it is unlikely the results were chance alone. The correlation rates for each were between .47 and .57, meaning that they were moderately well correlated. Overall, however, the analysis showed that most of the data were not externally valid.

Some indicators were particularly surprising. Indicator 53 focused on evaluating the building codes in a state. While the Insurance Institute for Business and Home Safety (IBHS) publishes a report called “Rating the States” that evaluates state building codes, it is only for coastal states between Texas and Maine.[226] We therefore used the Insurance Services Office (ISO) Building Code Effectiveness Grading Schedule (BCEGS), which was available not only for all fifty states but for both commercial and residential structures. The initiative “assesses a community’s building code enforcement in three areas: code administration, plan review, and field inspection,” so we felt it was a valid measure for building codes.[227] Moreover, a study by the Wharton Risk Management and Decision Process Center at the University of Pennsylvania showed that higher BCEGS scores were associated with less damage from hail.[228]

However, in our analysis against fatalities and injuries, the R-squared values for commercial and residential codes were .0004 and .0002, respectively. Looking at the scatter plots themselves, Texas and Louisiana immediately appeared as outliers, shown in Figure 17. Removing Texas and Louisiana from the calculations increased the R-squared value for other indicators a small amount (e.g., the number of communities in the state that participate in the Community Rating System), but did not markedly affect the R-squared value for either commercial or residential BCEGS.

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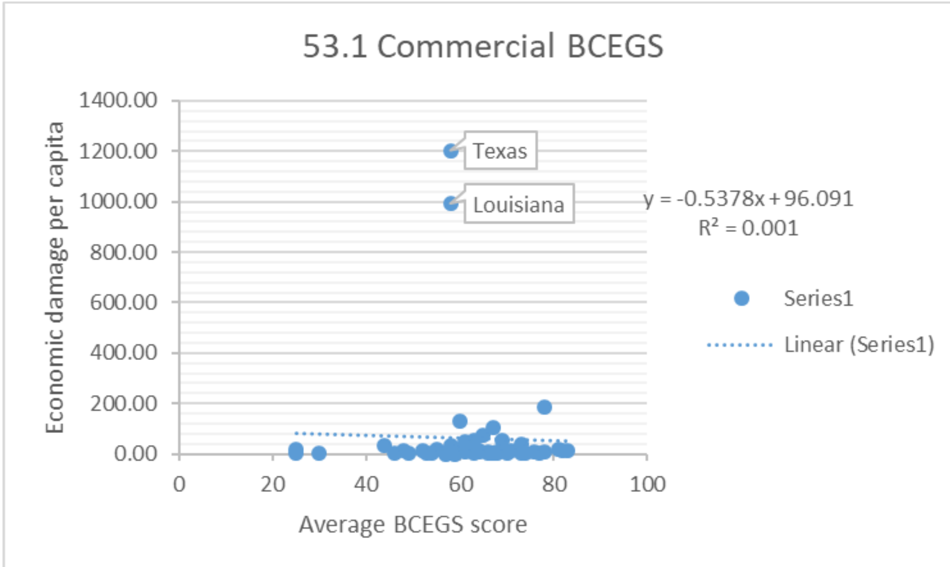
[226] Insurance Institute for Business & Home Safety (IIBHS), *Rating the States: 2018: An Assessment of Residential Building Code and Enforcement Systems for Life Safety and Property Protection in Hurricane-Prone Regions* (Tampa, FL: IIBHS, 2018), 2, http://disastersafety.org/wp-content/uploads/2018/03/ibhs-rating-the-states-2018.pdf.

[227] Insurance Services Office (ISO), *National Building Code Assessment Report: ISO’s Building Code Effectiveness Grading Schedule 2015* (Jersey City, NJ: ISO, 2015), 6, 15.

[228] ISO, 10.



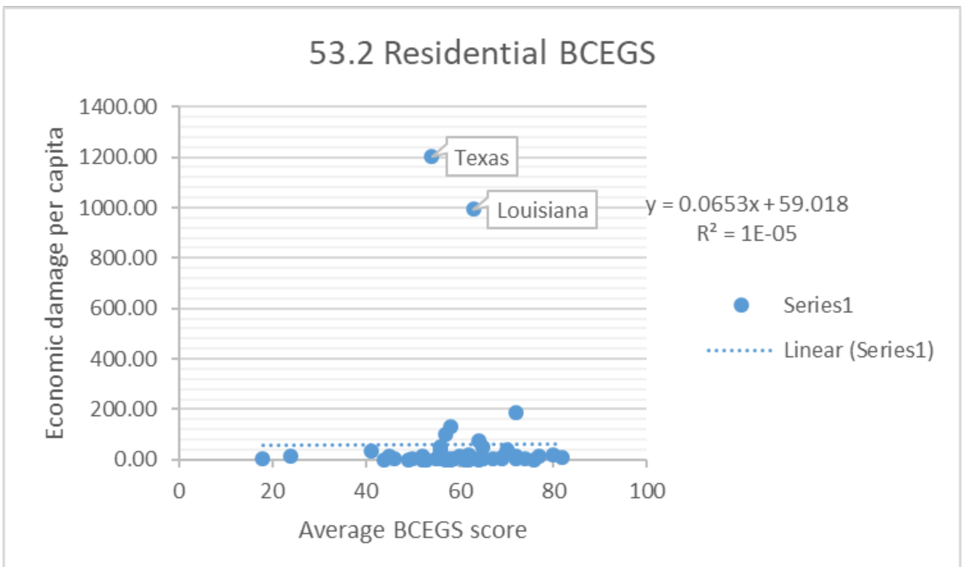


Figure 17. BCEGS Scores Compared to Economic Damage[229]

229 Adapted from ISO, 16–56; National Weather Service, "Natural Hazard Statistics."

The BCEGS data was not the only data that surprisingly showed no relationship to impact. DHS/FEMA provides Emergency Management Performance Grants (EMPGs) to "assist state, local, territorial, and tribal governments in preparing for all hazards."[230] Very few would deny that these grants have helped to improve capability. However, EMPG showed only a weak relationship to impacts in our analysis. We ultimately tested not only EMPG but also the pre-disaster mitigation and hazard mitigation grant programs. None showed a strong relationship with impacts.

In the same vein, we used FY17 state emergency management budgets pulled from the National Emergency Management Association (NEMA) *Biennial Report*.[231] Again, the data did not show any strong relationship with deaths and damage, meaning states that spend a lot on emergency management have just as many deaths and just as much damage as states that spend very little. Perhaps one way to add nuance to these data and draw out more reliable causal links would be to look at how the money is spent.

While more data would certainly be helpful, the NEMA report did include the percentage of EMPG dollars that each state allocates to local jurisdictions, to tribal nations, to other state agencies, to other miscellaneous groups, and to the state agency itself. The percent allocated to tribes had an R-squared value of .2816 when compared to deaths and fatalities, meaning that states that allocate more funding to tribal nations have fewer deaths and injuries. However, only seventeen states reported providing any funding to tribes at all and the average portion provided to tribes among all states was less than 1 percent; with these results in mind, this seems more like random noise than a true causal link. Further, unless the great majority of deaths and injuries were happening on tribal lands, it is unclear exactly how providing more funding to tribal nations would decrease deaths and injuries outside tribal lands.

To test whether there would be a stronger link if year-to-year variability were reduced, we also used the 2007–2016 ten-year average for both fatalities and injuries and

[230] FEMA, "NOFO," 3.

[231] National Emergency Management Association (NEMA), *2018 Biennial Report: The Most Comprehensive and in-Depth Review of State Emergency Management and Homeland Security Available* (Washington, DC: NEMA, 2018), 24–25.

also for economic damage. Recognizing that actions taken in 2016 did not affect deaths in 2007, for example, we used the ten-year average as a simple attempt to control for the year-to-year variability in weather impacts. Assuming that a more long-term average would be at least somewhat predictive of future impacts, we hoped to better understand the true link between these indicators and real-world events. Of course, a better approach would have been to use 2007 data for the indicators, then use the 2007–2016 average impacts to determine if the actions in 2007 had any long-term impacts. However, given both data availability and time constraints, we were only able to compare 2016 data to the 2007–2016 average.

Using the longer-term average resulted in *fewer* indicators rising above the R-squared threshold of .2. Specifically, comparing fatalities and injuries to indicator 6 (the percentage of the population with no disability) and to indicator 11 (the percentage of the population identifying as Christian) resulted in R-squared values of .201 and .22, respectively. No indicators met the threshold for comparisons with economic damage.

c. Next Steps

Many of these findings fly so strongly in the face of conventional wisdom that they demand further explanation. While it is possible that these indicators, from building codes to federal grant investments, do not drive any reduction at all in deaths and damage, it seems unlikely. This raises the question: Where is the error in the analysis?

One possibility is that the National Weather Service data is inaccurate. Indeed, many have recently noted the challenges of effectively determining the cause of death for large numbers of people at the state level. Following Hurricane Maria's impacts in Puerto Rico, the official death toll on the island was sixty-four. However, multiple other studies have estimated the toll as high as 1,000. One study, which involved surveying individual households to determine whether deaths were hurricane related, reported the likely death toll at over 4,000.[232] The official death toll was ultimately raised to 2,975.[233]

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[232] Sheri Fink, "New Data Sheds Light on Death Toll of Hurricane Maria in Puerto Rico," *New York Times*, June 9, 2018, https://www.nytimes.com/2018/06/02/us/puerto-rico-death-tolls.html.

[233] Fink.

The point is that finding the true number of people who were injured or killed by even a high-profile storm like Hurricane Maria is difficult. The Weather Service data on much smaller and more commonplace incidents like tornadoes or severe thunderstorms could also contain inaccuracies, which would in turn skew the analysis here. This warrants more investigation.

Another possibility is that measuring resilience at the state level is simply not practical. Perhaps the best way is, as a Delphi participant noted, to measure resilience locally and aggregate that to the state level. To use the building code example again, several counties in a state could have strong building codes that do save lives and reduce economic losses. If, however, their effects are overwhelmed by other counties in the state without effective building codes, their benefit will be washed out. While many of the indicators we used, especially those from the U.S. Census Bureau, would be available at the county level as well, this does highlight other issues with data availability. The National Weather Service deaths, injuries, and economic loss data we used, for example, are not available at the county level.[234]

Also, most emergency management programs in the country, certainly those at the federal level, are focused on dealing with the effects of a catastrophic event. Perhaps state emergency management budgets, along with other indicators, do not correlate with reduced loss of life in the Weather Service data because true catastrophes are rare and so are not captured there. A final possibility is that more data may help. The dataset we used included only about half of the indicators that we included in the final framework. Perhaps the full dataset of indicators would tell a different story. Similarly, other measures also highlight the need for more nuanced data. We included, for example, whether a state had an enhanced hazard mitigation plan. Though this also showed no relationship with impacts, a better measure such as an estimate of plan quality could show a clearer relationship. This would also help because all states are required to have a hazard mitigation plan so each state would be represented in the index.

[234] National Weather Service, "Natural Hazard Statistics."

This chapter has described the general process for creating a composite indicator and the specific steps that we followed, along with their explanations. We also briefly discussed recommendations, which we outline more thoroughly in the next chapter.

IV. FINDINGS AND RECOMMENDATIONS

This paper set out to answer the question, What drives state resilience? To do so, we created a composite indicator, or index, which involved first creating a theoretical understanding of resilience. We then built a framework of indicators off this understanding and, finally, gathered available high-quality data, and analyzed and aggregated it. To test the index quality, we conducted a factor analysis and multiple regression analysis to understand how the framework indicators correlated with each other and how they correlated with real-world impacts—specifically, weather-related deaths, injuries, and economic damages.

For better or worse, this research raised more questions than it answered. The data highlighted some indicators that do not predict resilience. Indicators that *do* predict resilience, on the other hand, were more elusive. This chapter discusses our findings in more detail and recommends next steps for a range of stakeholders.

A. FINDINGS

1. Framework and Delphi

There is a general consensus that resilience measurement is a valuable tool for changing policy.[235] There is also general consensus around the range of variables that are likely related to resilience.[236] There are even previous examples of composite indicators at the county level such as the BRIC.[237] In the Delphi, the overall comments focused on the need to start from disaster resilience first principles and to consider existing themes such as planning, preparedness, response, and recovery. Multiple other comments encouraged weighting specific indicators.

[235] Knight et al., *Building Blocks*, 37–38.

[236] Beccari, "Comparative Analysis," 3–4.

[237] Cutter et al., "Disaster Resilience Indicators."

2. Factor Analysis

Our findings from the factor analysis simply showed that the data we used did not create a well-fitting index. The goal of factor analysis was to distill a small number of factors from a large number of indicators in the dataset, which we were able to do. However, the next step is to review the factors and, based on how strongly each factor correlates with specific indicators, name the factors to help understand how they drive the output of the index. There were no clear themes for our index, however, and when we checked some measures of index quality, such as the root mean square error of approximation, our index did not meet the common threshold for accuracy.

3. Regression

No indicators from the framework correlated strongly with deaths or economic damage based on National Weather Service data at the state level. Some surprising examples include state emergency management budgets, statewide average building code quality, percentage of roads that are structurally deficient, and federal grant dollars (e.g., the EMPG, Pre-disaster Mitigation, and Hazard Mitigation Grant Programs). Either these factors truly do not impact deaths and damage, or there is a flaw in the analysis.

One good possibility is that the dependent variable—here, the National Weather Service injuries, deaths, and economic damage data—is flawed in some way. In Chapter III we discussed the possibility that the data do not actually provide a helpful baseline, so we want to reiterate here that agreeing upon a clear measure is key. Whether it is a broader public health–style measure, simply more granular deaths and damage data, or a measure of happiness or well-being, establishing a baseline against which to measure the success of resilience programs is key.

For example, previous studies have shown that BCEGS scores are correlated with reduced insurance losses from hail.[238] Our analysis showed that they do not correlate strongly with National Weather Service economic damage data. Which is correct?

[238] ISO, *National Building Code Assessment Report*, 10.

As we discussed a little in Section III.E.2.c, one possible conclusion is that resilience is not measurable at the state level. As one Delphi participant noted, “State performance is the sum of counties’ and communities’ performance.” Following this line, the best way to measure state resilience would be to not measure state resilience at all and instead measure county resilience, then find an accurate way to aggregate the results to the state level. This is an important line of inquiry. However, it will be impossible to know which method is better (measuring at the state level or measuring at the community level and rolling up to the state) without the ability to compare quality frameworks at both levels.

Another possible reason is that the EMPG and other programs are designed not for occasional deaths from thunderstorms, which is more what the National Weather Service data represent, but for catastrophic events.[239] Lightning or deaths, for example, are infrequent and seem more subject to randomness, so they are less under the control of emergency managers.

Measuring at the state level also likely masks nuances that measuring at the county level provides. Because of the complexity of the subject, there is inherent randomness in any effort to measure resilience. Measuring at the county level breaks that resilience down into tiny pieces, rather than lumping it together (which state-level measurements likely do). For example, measuring at the county level can allow researchers, especially those at the state level who may have more time to understand each death in their state, to more easily understand the causes for that specific death.

B. RECOMMENDATIONS

We used a composite indicator to measure resilience and learned some valuable lessons from it. Despite the challenges discussed in Sections III.E.1 and III.E.2, we still believe it is the most rigorous method, and ultimately has the most potential to accurately measure resilience. Modelers, however, have much work to do.

Given this, the recommendations here focus on improving existing tools and taking gradual steps to iterate over time, all with the ultimate goal of understanding how to build

[239] National Weather Service, “Natural Hazard Statistics.”

resilience and prevent loss of lives and property. Many recommendations deal with the THIRA because it is currently the most commonly used tool for assessing preparedness and, insofar as they are related, resilience. Other recommendations, however, are broader.

1. Use Resilience to Unify

a. Stakeholders at All Levels of Government Should Use Resilience as a Way to Unify Diverse Stakeholders toward a Common Goal

To quote the cliché, we are stronger together. Resilience is a broad term; federal, state, local, tribal, territorial, and other stakeholders can all take advantage of that by using a broad measurement tool and assigning different departments and agencies each one piece of the overall goal. This allows a range of stakeholders to stay focused on their primary mission while still working together to achieve a broader goal—increased resilience.

b. Pick One Measurement Tool and Stick with It

Researchers across disciplines have already put forward ideas and potential options, each with its own benefits and challenges. Multiple federal agencies also publish their own resilience assessments, and we outline two in Sections II.6 and II.7. Practitioners, however, need one standard process they can use if we want resilience measurement to become a useful and commonplace tool of policy. The THIRA is likely the best tool for this because it is already so widely used.

Additionally, many tools currently iterate in isolation; they come closer to understanding resilience, but only through one lens (e.g., critical infrastructure or emergency management). By combining efforts around one tool, it could be possible to iterate more quickly and come to a better understanding of all the different pieces of resilience and how they interact. Adding complexity could certainly slow down iteration as well. Without a unified effort, however, it will always be hard to fully understand resilience.

2. Add Nuance and Quantitative Measures Where Possible

a. FEMA Should Build on and, Where Necessary, Reformat the THIRA to Publish a Clear List of Indicators for Each Core Capability

FEMA is heading this direction with the publication of the third edition of the *Comprehensive Preparedness Guide 201*, but we were unable to find a complete framework like the ANDRI or DROP/BRIC provide.[240] The goal is to allow states and other jurisdictions to begin adding quantitative measures, as well as to ensure that all stakeholders are working with the same set of indicators. As mentioned, resilience is a broad term that can allow a range of stakeholders to all work toward a shared goal. However, this means that each section of the measurement tool used must also provide appropriate detail.

For example, one core capability in the THIRA is *community resilience*. In the Core Capability Development Sheet, however, the only example indicator put forward for this capability is the number of education programs for residents around emergency preparedness.[241] The *health and social services* capability similarly outlines only a handful of goals for the capability, such as restoring and improving the resilience of the health care system.[242] Though more details may be provided during in-person trainings, without a publicly available framework with realistic and nuanced indicators, understanding and measuring resilience will be challenging.

Another example that highlights the need for a broader framework is community preparedness. The Preparedness in America Survey currently measures individual and household preparedness actions across the country.[243] However, as part of the THIRA,

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[240] DHS, *THIRA*.

[241] "Core Capability Development Sheets: Mitigation," FEMA, last updated February 10, 2018, 8, https://www.fema.gov/core-capability-development-sheets#.

[242] "Core Capability Development Sheets: Recovery," FEMA, last updated February 10, 2018, 12, https://www.fema.gov/core-capability-development-sheets#.

[243] "Preparedness in America: Research Insights to Increase Individual, Organizational, and Community Action," FEMA, last updated August 2014, 1, https://www.fema.gov/media-library-data/1409000888026-1e8abc820153a6c8cde24ce42c16e857/20140825_Preparedness_in_America_August_2014_Update_508.pdf.

this valuable preparedness information is ignored. Publishing a broader framework could allow states to include this type of existing data to inform how resilient their jurisdiction is.

b. FEMA Should Continue to Include More Quantitative Measures in the THIRA, and Other Jurisdictions Should Add Their Own Quantitative Measures

It could be valuable to gradually start including quantitative measures in the THIRA process. Again, with the new CPG 201, FEMA places new emphasis on quantitative indicators and there is more still to be done. Jurisdictions and federal stakeholders could then, over time, determine the right blend of objective and subjective data.

Another argument in favor of including quantitative indicators in the THIRA is that it adds balance. Because it is based on survey data, the THIRA can be thought of as a bottom-up tool. As discussed in Section III.A.3, bottom-up contrasts with top-down and refers to how the data is collected. Top-down tools use existing census or other high-level data, while bottom-up tools survey residents at the community level.[244] As Knight et al. mention, an ideal framework could combine top-down and bottom-up data, so one way to improve the THIRA could be to begin using quantitative data such as census or economic indicators.[245]

c. Measure at the County Level

Measuring at the state level almost certainly masks some drivers of resilience. In reality, there are very few weather-related deaths and injuries in each state each year. Moreover, random chance certainly plays a role in when and where these deaths take place. Though it is impossible to eliminate this randomness, measuring at the county level may provide an opportunity to reduce it and add granularity that would allow researchers to remove some of this randomness.

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[244] Knight et al., *Building Blocks*, 5, 20.

[245] Knight et al., 14.

This is further support for modifying the current THIRA approach, rather than starting fresh with a new tool. In addition to all states using the THIRA, many local jurisdictions do as well, so the tool is already well-positioned to help county-level practitioners.

d. FEMA Should Provide Additional Resources for the Local THIRA and Delineate between Local and State-Specific Responsibilities

Building on the previous recommendations, if the THIRA is the best tool currently and measuring at the county level is likely most accurate, FEMA should provide additional resources to ensure (to the degree possible) that county practitioners accurately measure resilience.

Carrying this one step further, there are likely some things that a county will do best and some that a state will do best. FEMA can play the lead role in clarifying what those different responsibilities are and including measurement resources in the relevant THIRA. Urban search and rescue teams provide a good example. Most counties do not maintain this capability on their own, and it is usually met by state resources. These are resources the jurisdiction can bring to bear, however, so they should be included in the resilience measurement for the appropriate jurisdiction. Clarifying which level should count these types of resources can also help to prevent double counting. This can set the stage to address another important question: What is the best way to build local capability?

Finally, using this approach allows for comparison of resilience measurements at different levels. How would a strictly national resilience measurement compare to a measurement at each county that was aggregated together? Focusing on the local THIRA can help set the stage for this type of comparison.

e. Validate Any and All Tools (e.g., the THIRA or Specific Measures of Quality) to Ensure They Improve Real-World Outcomes

We used National Weather Service deaths, injuries, and economic damage as external markers of resilience. Researchers and practitioners should also use them (or other metrics) to test whether tools like the THIRA actually correlate with real-world impacts. For example, we recommend in Section IV.C.4.a to focus on indicator quality, such as that of a state hazard mitigation plan. Once practitioners find and implement appropriate quality measures, it is important to validate those as well and ensure that areas with better plans really have fewer impacts from disasters.

f. If Possible, Future Use of the Delphi Method Should Be Done with More Than Ten People

We used the Delphi method to evaluate the quality of the framework presented here, including specific indicators, and also to evaluate the weights for specific indicators. The results of this, however, were limited, especially for the weights. This is largely due to the Paperwork Reduction Act, which limited our sample size to ten people. As a comparison, the NHSPI used approximately 150 stakeholders for a Delphi review of weights in its framework.[246] The Delphi could be done by a non-federal entity; alternatively, it is possible, though time consuming, to get approval for federal surveys of more than ten people.

3. Control for the Impact

a. Future Resilience Research Should Investigate Better Methods of Controlling for the Strength of Shocks to the System, Especially Natural Hazards

Just how economists control for the value of money in a specific year (e.g., to compare income in 1990 with income in 2000), a true understanding of the key drivers for resilience requires controlling for all variables in the equation. As we discussed in Section I.D.1.d, formulaic descriptions of resilience generally include four key components: the shock, the current state or vulnerability, the coping capacity, and the adaptive capacity. Most resilience measurement efforts focus on understanding the latter three factors, but it is equally important to understand the strength of the “attack” on the jurisdiction to isolate and better understand the coping and adaptive capacities.

For example, a jurisdiction mounts a slow response to an incident. One explanation could simply be lack of capability to respond. Another equally plausible explanation would

[246] NHSPI, “Methodology for the 2018 Release,” 8.

be that this particular incident is the third Category 5 hurricane to make landfall in that jurisdiction in three weeks. In this case, the slow response does not indicate low capability but simply the overwhelming strength of the repeated incidents.

4. Focus on Data Quality

One note on limitations for quality measures: they are generally more time consuming so may be better for states to do individually. For example, there may not be a centralized national public dataset on the number of local emergency planning committees (LEPCs), their structure, and their meeting frequency. However, this data may be easily accessible for a single state. On the other hand, FEMA could add these types of data points to existing data solicitations such as the THIRA or different grant-reporting mechanisms.

a. FEMA Should Continue Publishing Data Standards, Especially around Resilience Indicators

As described in Section IV.C.2.a, FEMA should publish a resilience measurement framework based on the THIRA. This also creates the opportunity for FEMA to provide data standards for how jurisdictions report information. Different parts of FEMA are doing this already, and a broader resilience framework would simply provide another venue. In addition to creating more broadly accessible data, this also takes a large step toward ensuring that available data meet the appropriate standards of quality, such as timeliness.

b. FEMA Should Add Measures of Quality to Current Requirements, Such as Those for Exercises and Hazard Mitigation Plans

FEMA currently requires states to publish a hazard mitigation plan in order to be eligible for grants.[247] Whether a state has an enhanced plan may be less important than the quality of the plan. A good regular plan may be better, for example, than a bad enhanced plan. The same goes for exercises: whether they happen is probably less important than

[247] "Hazard Mitigation Plan Requirement," FEMA, October 31, 2017, https://www.fema.gov/hazard-mitigation-plan-requirement.

how good or effective they are. Ward Lyles, Philip Berke, and Gavin Smith outline some examples of plan quality.[248]

Wireless emergency alert programs provide another example of applying quality measures. We simply used the number of alert authorities in a state as our measure, but higher-quality measures could include specific measures on training or technology adoption.

c. Resilience Frameworks Should Iterate Regularly, at Least Every Year

Part of focusing on data quality is iterating to see which factors truly make a difference. This may be one of the more difficult recommendations to implement but, as Eric Ries notes, it is better to fail early and often.[249] We will not always correctly chose accurate resilience measures at first. The best solution is to iterate more rapidly, at least every year, as the NHSPI does.

While rapid iteration may disturb some stakeholders who prefer more stability in policy, it is important to acknowledge that, as a field, we still cannot say with assurance what drives resilience. As Section III.E.2 showed, many traditional standbys of emergency management, such as better building codes and mitigation investments, do not correlate with fewer deaths or reduced property damage at the state level. Continued iteration in measurement efforts is vital if we are to understand what does and does not drive resilience.

d. Invest in Better Data

Simply put, we were unable to find data for many indicators because of our limited (nonexistent) budget. We will not belabor the point, but it is worth noting that with a larger budget, better data would be available. As Gregory Myers notes in his Naval Postgraduate School thesis, the Department of Homeland Security has spent tens of billions to improve

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[248] Ward Lyles, Philip Berke, and Gavin Smith, “Evaluation of Local Hazard Mitigation Plan Quality” (report, UNC Institute for the Environment, 2012).

[249] Eric Ries, *The Lean Startup: How Today’s Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses* (Lark Arbor, MD: Crown Books, 2011), 56, 162.

our security. Investing even a tenth of a percentage of that annually could lead to a much better understanding of the outcome.[250]

e. Future Iterations Should Incorporate GIS More Effectively

A final point on data quality is to make better use of geospatial data. Mapping can help not only to understand the data and impacts but also to communicate the results and create buy-in among diverse stakeholders on the value of the measurement and the need to improve it.

5. Use Common Sense

This is ultimately just a thought exercise. In order for it to be useful, it is important to keep a basic perspective of what makes sense. For example, as we have discussed, our test of the external validity of this framework showed that the percentage of structurally deficient roads in a state, among many other things, was weakly associated with deaths and economic damage. While this is certainly possible, it does not make sense. If roads are already very damaged, would a bad storm not damage them even more, resulting in economic loss? Given this, it is important (as our Delphi reviewers pointed out) to stay focused on the basics. This research did not show any silver-bullet solutions for emergency management, and we have discussed reasons for that above. Another reason may simply be that they do not exist. Focusing on the fundamentals is a sound strategy in either case.

Another example of keeping common sense in mind comes from Cutter et al.'s SoVI, one of the first composite indicators in the field of vulnerability and resilience.[251] This index showed that "The most socially vulnerable county in the nation is Manhattan Borough (part of New York City), largely based on the density of the built environment."[252] Again, while it is plausible that Manhattan is the most vulnerable county

[250] Gregory A. Myers, "Assessing the Performance Management of National Preparedness: A Conceptual Model" (master's thesis, Naval Postgraduate School, 2015), 119–20, https://www.hsdl.org/?abstract&did=790359.

[251] Beccari, "Comparative Analysis," 2.

[252] Cutter, Boruff, and Shirley, "Social Vulnerability," 255.

in the country, it seems at least a little surprising and really shows that the model needs more iteration.

We have argued throughout that more quantitative measurements of resilience are not only valuable but vital. In that light, we will conclude with one final piece of common sense—if you can't measure progress, how will you ever know if you've gotten there?

APPENDIX A. FINAL FRAMEWORK AND NOTES

This appendix outlines each domain, sub-domain, and indicator for the state resilience index we proposed. For the measures below, the justification for each indicator is almost always simply a theory. We have used this convention to omit including "in theory" in each sentence. Instead, we are including it once here—all justifications and linkages are theories which the data may or may not prove.

For U.S. Census Bureau data, if not otherwise specified, we used the American Fact Finder Advanced Search with the geographic type filter "All States within the United States and Puerto Rico."

Each domain includes a subdomain on adaptive capacity. Adaptive capacity is challenging to measure because, to some level, it is a reflection of community leader intent. To that end, and following the idea that the best predictor of future performance is past performance, we included measures of how actively the community is addressing known vulnerabilities. The assumption is that if a community is actively addressing vulnerabilities outside of a disaster, then when a disaster highlights additional vulnerabilities in the community, they will also actively address those and thus help the community adapt and grow.

Additionally, we standardized a number of indicators so they would fit with the index scoring structure of "higher is better," including indicators 2 (the percentage of people below age sixty-five), 6 (the percentage of people without a disability), 27 (unemployment versus employment rate), and 32 (Gini rate). Finally, the indicators are numbered up to 106. However, there are actually only 105 official indicators because we removed indicator 56 after the final round. This also does not include the ad-hoc indicators that we included simply because we found available data for them. We left the original numbering for consistency.

Table 5. Full List of Measures, Sources, Justifications, and Limitations

State Resilience Framework Indicators, Data Source, Notes, and Limitations		
Domain 1: Social capital	**Data Title**	**Data ID**
Subdomain 1.1: Characteristics		
1: Ratio of single parent families to two parent families[253]		
Dataset: 2012–2016 American Community Survey 5-Year Estimates	HOUSEHOLDS AND FAMILIES	S1101
Justification and theoretical linkage: Having a greater portion of families with two parents could create more stability in the community and thus reduce injuries, deaths, and economic damage.		
Notes and limitations: We summed the male householder-no wife present and the female householder-no husband present categories, then divided that by the total number of households.		
2: Percent of the population below 65 years of age[254]		
2012–2016 American Community Survey 5-Year Estimates	AGE AND SEX	S0101
Justification and theoretical linkage: Elderly residents affect communities in a variety of ways and also add challenges to response operations with additional medical and evacuation needs. We were therefore interested in the effect the percentage of the population below age 65 would have on resilience.		
Notes and limitations: We used percent below 65 so that, generally speaking, it corresponded with a 'higher is better' scoring system.		
3: Percentage primary education completion rates[255]		
2012–2016 American Community Survey 5-Year Estimates	SELECTED ECONOMIC CHARACTERISTICS FOR THE CIVILIAN NONINSTITUTIONALIZED POPULATION BY DISABILITY STATUS	S1811
Justification and theoretical linkage: A more well educated population might be more resilient through a variety of mechanisms such as being more financially secure or being more willing to take preparedness and mitigation actions.		
Notes and limitations: We used the percent of the population age 25 and over that has graduated high school or the equivalent.		
4: Percentage advanced education rates (bachelors or higher)[256]		
2012-2016 American Community Survey 5-Year Estimates	SELECTED ECONOMIC CHARACTERISTICS FOR THE CIVILIAN NONINSTITUTIONALIZED POPULATION BY DISABILITY STATUS	S1811

[253] Parsons et al., *The Australian Natural Disaster Resilience Inde*, 8.

[254] Cutter, Burton, and Emrich, "Disaster Resilience Indicators," 69.

[255] Cutter, Burton, and Emrich, 69.

[256] Rockefeller Foundation and Arup, *Inside the CRI: Reference Guide* (New York: Rockefeller Foundation, 2016), 114.

Justification and theoretical linkage: A more well educated population might be more resilient through a variety of mechanisms such as being more financially secure or being more willing to take preparedness and mitigation actions.		
Notes and limitations: We used the percent of the population age 25 and over that has a bachelor's or higher.		
5: Percent Population proficient English speakers[257]		
2012–2016 American Community Survey 5-Year Estimates	SELECTED SOCIAL CHARACTERISTICS IN THE UNITED STATES	DP02
Justification and theoretical linkage: People who don't speak English well may have challenges in understanding the risks they face or in heeding local emergency manager instructions in an active response.		
Notes and limitations: We used the percent of the population five or older that speaks English less than "very well." This is not a perfect measure though and contains some inherent ambiguity. Something more precise could be more accurate.		
6: Percent Population without sensory, physical, or mental disability[258]		
2012–2016 American Community Survey 5-Year Estimates	SELECTED ECONOMIC CHARACTERISTICS FOR THE CIVILIAN NON-INSTITUTIONALIZED POP. BY DISABILITY STATUS	S1811
Justification and theoretical linkage: People with disabilities are not well incorporated in traditional emergency management plans and procedures, so may face greater risk in active response situations.		
Notes and limitations: As with other measures, we used 'without' disabilities so that, generally speaking, a higher number would correspond with higher resilience.		
7: Health insurance rate[259]		
2012–2016 American Community Survey 5-Year Estimates	SELECTED ECONOMIC CHARACTERISTICS	DP03
Justification and theoretical linkage: Having health insurance could serve as a proxy for willingness to take protective actions and to mitigate personal risks.		
Notes and limitations: None.		

[257] Parsons et al., "Top-Down Assessment," 8; Cutter, Ash, and Emrich, "Geographies," 69.

[258] Cutter, Ash, and Emrich, "Geographies," 69; Parsons et al., "Top-Down Assessment," 7.

[259] Cutter, Ash, and Emrich, "Geographies," 69.

Subdomain 1.2: Resident cohesiveness		
8: Hate crimes reported per 100,000 population[260]		
FBI 2016 Hate Crime Statistics	Table 11: Offense Type by Participating State	
Justification and theoretical linkage: A high number of hate crimes could show that there is little cohesive community feeling, which has been shown to improve resilience.		
Notes and limitations: Other studies have shown that hate crime reporting is not accurate, so this measure should be taken as only a general number.[261]		
9: Percentage of people who responded that they know the names of their immediate neighbors (by survey)[262]		
No data was used.		
Justification and theoretical linkage: Similar measures of social capital can improve community resilience.		
Notes and limitations: The RAND Culture of Health survey seems to capture this but responses are not tagged by state so we could not use it. The data is also not collected regularly.		
10: Percentage of respondents who felt a sense of pride in their neighborhood[263]		
No data was used.		
Justification and theoretical linkage: Similar measures of social capital can improve community resilience.		
Notes and limitations: None.		
11: Percentage Christian, non-Christian, and non-religious[264]		
2015 Pew Religious Landscapes Study		
Justification and theoretical linkage: Perhaps the networks religions provide can help cushion disaster impacts.		
Notes and limitations: We simply looked by state at the percent Christian, percent other, and percent non-religious in the Pew data. In the actual analysis, we termed number 11 as percent Christian, 11.1 as percent non-Christian, and 11.1 as percent no religion. We used the Pew data from 2015, and one limitation is that it is not updated more frequently.		
Subdomain 1.3: Resident engagement		
12: Percent voting age population participating in presidential election[265]		
U.S. Census Bureau: Voting and Registration in the Election of November 2016	Table 4a: Reported Voting and Registration, for States	
Justification and theoretical linkage: This is another proxy for community involvement and social capital, which likely help increase community resilience.		

[260] Rockefeller Foundation and Arup, *Inside the CRI*, 72.

[261] Ken Schwencke, "Why American Fails at Gathering Hate Crime Statistics," December 4, 2017, https://www.propublica.org/article/why-america-fails-at-gathering-hate-crime-statistics.

[262] Rockefeller Foundation and Arup, 70.

[263] Rockefeller Foundation and Arup, 76.

[264] Cutter, Ash, and Emrich, "Geographies," 69.

[265] Cutter, Ash, and Emrich, 69.

Notes and limitations: None.		
13: Number of social advocacy organizations per 10,000 population[266]		
National Center for Charitable Statistics	Number of Registered Nonprofit Organizations by State	2012
Justification and theoretical linkage: Having a relatively large number of non-profits could help to increase the response and recovery resources available to a community.		
Notes and limitations: The NCCS data does not appear to be updated regularly, and it is not clear where they get their own data from. We did look at using IRS data on 501(c)3 organizations per state but were unable to format it correctly.		
14: Average minutes per day spent on volunteer activities[267]		
No data was used.		
Justification and theoretical linkage: Having a larger portion of people who already volunteer regularly could serve as a proxy for the number of people willing to help in the immediate response and recovery phases of a disaster.		
Notes and limitations: Though the Bureau of Labor Statistics does publish the American Time Use Survey, we were unable to process the data by state, though it is theoretically possible.		
15: Proportion of corporate charitable giving within community as a percentage of total charitable giving in state[268]		
No data was used.		
Justification and theoretical linkage: This could show that large local corporations are engaged in the community before a disaster, which could be a good indicator for whether they would also be engaged after in response and recovery.		
Notes and limitations: The corporate tax report is available from the IRS but only from 2013, so we did not use it. More regularly updated data is needed here.		
16: Percentage of community groups which attend events / meet with other community groups[269]		
No data was used.		
Justification and theoretical linkage: A greater percentage of engaged (as measured by regular attendance at meetings) community groups could help to quicken the pace of immediate response and recovery efforts.		
Notes and limitations: As with indicator 14 on volunteer time per day, this could potentially be found from the American Time Use Survey, but we were unable to process the data.		
Subdomain 1.4: Community response capacity		
17: Number of VOADs in the state (new indicator)		
No data was used.		
Justification and theoretical linkage: Because of their close role with response and recovery efforts, a greater number of Voluntary Organizations Active in Disaster (VOADs) should increase resilience.		

[266] Cutter, Ash, and Emrich, 69.

[267] Parsons et al., "Top-Down Assessment," 8.

[268] Rockefeller Foundation and Arup, *Inside the CRI*, 80.

[269] Rockefeller Foundation and Arup, 81; Cutter, Ash, and Emrich, "Geographies," 69.

Notes and limitations: With more time, it could be possible to gather this data, at least on a semi-annual basis, if it is not already gathered.		
18: Statewide total VOAD budget (new indicator)		
No data was used.		
Justification and theoretical linkage: Just like with state emergency management budgets, it is plausible that states with more well-funded whole community response organizations, including VOADs, are more resilient.		
Notes and limitations: With more time, it could be possible to gather this data, at least on a semi-annual basis, if it is not already gathered.		
19: Are emergency management plans ADA compliant? (new indicator)		
No data was used.		
Justification and theoretical linkage: Adequately planning for people with disabilities and access and functional needs could help prevent people with disabilities from dying. In some cases, people with medical needs, for example, may make up a large part of a potential death undercount.		
Notes and limitations: As with the other evaluations of plan quality, this would require states to have best practices against which to evaluate their own plans or would require a third party to evaluate the plan.		
20: Number of exercises in the past year that include members of a vulnerable population (e.g., babies, the elderly, people with access and functional needs, non-native English speakers, etc.) (new indicator)		
No data was used.		
Justification and theoretical linkage: Adequately planning for people with disabilities and access and functional needs could help prevent people with disabilities from dying.		
Notes and limitations: As with the other evaluations of quality, this would require states to have best practices against which to evaluate their own exercise or would require a third party to evaluate the exercise. While it is important to measure exercise quality, specific indicators like this should be avoided in future iterations in favor of a general exercise quality metric.		
Subdomain 1.5: Community recovery capacity		
21: Number of community organizations with community recovery plans for relevant hazards (new indicator)		
No data was used.		
Justification and theoretical linkage: More thorough planning and better plan integration across stakeholders should lead to more effective response.		
Notes and limitations: None.		
Subdomain 1.6: Adaptive capacity		
22: Number of new projects undertaken to address key weaknesses in social capital in the state (new indicator)		
No data was used.		
Justification and theoretical linkage: See general note in Appendix A introduction on adaptive capacity measures.		
Notes and limitations: None.		

Domain 2: Economic capacity	Data Title	Data ID
Subdomain 2.1: Diverse economy		
23: Percentage employment per sector by broad industry group[270]		
2016 ACS 5-year estimates	Selected economic characteristics	DP03
Justification and theoretical linkage: By having a relatively even spread (low variance) among different employment sectors, a jurisdiction would prove resilient if one sector were to fail because of a disaster (or for any other reason). Dependence on only one industry, on the other hand, would represent a vulnerability.		
Notes and limitations: The Census does have employment data by sector. We calculated the variance from this and had planned to use the variance as the actual metric but did not include it in the final count because the theoretical link was not completely clear.		
24: Percentage share of small businesses (20 employees or fewer)[271]		
2016 Business Patterns	Geography Area Series: County Business Patterns by Employment Size Class	CB1600A13
Justification and theoretical linkage: We included this metric because, in theory, having a large and diverse base of small businesses would, just like diversity of employment by sector immediately above, allow a jurisdiction to absorb a disturbance easily. However, it also seems plausible that a large share of small businesses could increase vulnerability because they have less time and resources to devote to preparedness and mitigation activities than a large organization would. If a jurisdiction has only small businesses, for example, and they all fail due to poor planning, the area is not resilient.		
Notes and limitations: Though ‘small business’ has a range of definitions, we used 20 employees or fewer because it was a moderate choice in the available categories in the census, neither the largest nor the smallest.		
25: Value of state exports as a percentage of state GDP[272]		
U.S. Census, Foreign Trade, State and Metropolitan Area Trade Data	Origin of Movement Exports, Origin-state based	
Justification and theoretical linkage: If a sizeable share of total GDP comes from shipments to other states, it could indicate a short-term vulnerability in that if transportation networks go down in an incident, this part of the economy could be limited. Alternatively, it could represent a long-term source of strength if those sources of demand continue unabated after the disaster.		
Notes and limitations: We used total exports for the December 2017 excel file and divided that by the state’s GDP. However, this only includes foreign exports. In some ways, state-to-state exports would also be valuable to measure as a potential indicator of a diverse and therefore resilient economy.		

[270] Rockefeller Foundation and Arup, *Inside the CRI*, 107.

[271] Parsons et al., “Top-Down Assessment,” 8; Cutter, Ash, and Emrich, “Geographies,” 69; Rockefeller Foundation and Arup, *Inside the CRI*, 107.

[272] Rockefeller Foundation and Arup, *Inside the CRI*, 116.

<table>
<tr><th colspan="3">Subdomain 2.2: Stable economy</th></tr>
<tr><td colspan="3">26: Average GDP per capita percentage change over last 5 years [273]</td></tr>
<tr><td>2012 Economic Census of the United States</td><td>Retail Trade: Geographic Area Series: Summary Statistics for the U.S., States, Metro Areas, Counties, and Places: 2012</td><td>EC1244A1</td></tr>
<tr><td colspan="3">Justification and theoretical linkage: In theory, continued GDP growth would indicate a resilient economy while GDP decline would indicate a vulnerability.</td></tr>
<tr><td colspan="3">Notes and limitations: Newer data would likely be more accurate.</td></tr>
<tr><td colspan="3">27: Percentage employment change from the previous year [274]</td></tr>
<tr><td>Bureau of Labor Statistics, Local Area Unemployment Statistics</td><td>Over-the-Year Change in Unemployment Rates for States, Seasonally Adjusted</td><td></td></tr>
<tr><td colspan="3">Justification and theoretical linkage: Like with GDP change, increasing employment rates likely indicates a strong economy, and a theoretically resilient state, while decreasing employment could indicate the opposite.</td></tr>
<tr><td colspan="3">Notes and limitations: We calculated the employment rate, rather than the unemployment rate, so that when aggregating the index, a higher number would generally indicate resilience. Then we divided the employment rate from 2018 by the employment rate from 2017 to get the year-to-year change.</td></tr>
<tr><td colspan="3">28: GDP (PPP,$) per capita [275]</td></tr>
<tr><td>Bureau of Economic Analysis, GDP & Personal Income</td><td>Gross Domestic Product (GDP) by state (millions of current dollars)</td><td></td></tr>
<tr><td colspan="3">Justification and theoretical linkage: A higher GDP likely indicates greater available resources to support response and recovery.</td></tr>
<tr><td colspan="3">Notes and limitations: None.</td></tr>
<tr><td colspan="3">29: Large retail stores per 10,000 persons [276]</td></tr>
<tr><td>2012 Economic Census of the United States</td><td>Retail Trade: Geographic Area Series: Summary Statistics for the U.S., States, Metro Areas, Counties, and Places: 2012</td><td>EC1244A1</td></tr>
<tr><td colspan="3">Justification and theoretical linkage: Having access to retail stores could indicate robust supply chains that would help ensure the economic resilience of an area.</td></tr>
<tr><td colspan="3">Notes and limitations: We used the NAICS Code 4521 for Department Stores as the proxy for ‘large retail stores’. It could be valuable to look at other codes as well or group a few together.</td></tr>
</table>

[273] Rockefeller Foundation and Arup, 108.

[274] Rockefeller Foundation and Arup, 33.

[275] Rockefeller Foundation and Arup, 109.

[276] Cutter, Ash, and Emrich, “Geographies,” 69; Parsons et al., “Top-Down Assessment,” 8.

Subdomain 2.3: Economic opportunity and inequality		
30: Percent Owner-occupied housing units[277]		
2012-2016 American Community Survey 5-Year Estimates	TOTAL POPULATION IN OCCUPIED HOUSING UNITS BY TENURE BY YEAR HOUSEHOLDER MOVED INTO UNIT: Total population in occupied housing units	B25026
Justification and theoretical linkage: A larger portion of the population living in homes they own could indicate a greater willingness to take protective or mitigation actions for the home and a less transient population that may be more invested in the community.		
Notes and limitations: None.		
31: Number of homeless people per 100,000 population[278]		
Department of Housing and Urban Development, Annual Homeless Assessment Report	2007-2017 Point in Time Estimates by State	2017
Justification and theoretical linkage: A relatively large population of homeless people could indicate that other social services, including those for disaster recovery, are not available. It could also indicate a housing shortage that would be exacerbated during a disaster.		
Notes and limitations: None.		
32: Average credit score for the state (new indicator)		
Experian Vantage Score	2017 State of Credit article by Bob Sullivan	
Justification and theoretical linkage: Assuming that the credit score is an accurate measure of a person's financial risk and health, states with higher average credit scores have less debt and more resources than states with low credit scores.		
Notes and limitations: We used the Experian Vantage average score for a state as a proxy for liquid asset poverty.		
33: Percentage of population with access to programs for improving credit scores, credit counselling centers[279]		
No data was used.		
Justification and theoretical linkage: This assumes that access to financial resources is a key to preparedness, mitigation, and recovery. It also further assumes (perhaps more plausibly) that improving access to credit scores increases access to these financial resources.		
Notes and limitations: The Hope Foundation does provide financial literacy trainings, but we were unable to find any data on the location or density of these centers and trainings.		

[277] Parsons et al., "Top-Down Assessment," 8; Cutter, Ash, and Emrich, "Geographies," 69.

[278] Rockefeller Foundation and Arup, *Inside the CRI*, 8.

[279] Rockefeller Foundation and Arup, 38.

34: Percent by state of population with less than 3 months savings available in liquid assets (new indicator)		
No data was used.		
Justification and theoretical linkage: Having liquid assets (cash) on hand can help meet emergency needs during a disaster and can help individuals recover.		
Notes and limitations: The Bureau of Economic Analysis has savings rate data, but it isn't the same as asset poverty so was not used. The Census has some Wealth, Asset, and other data but it is old (from 2013) and not categorized by state so we did not include anything.		
35: Gini coefficient for income[280]		
2012-2016 American Community Survey 5-Year Estimates	GINI INDEX OF INCOME INEQUALITY: Households	B19083
Justification and theoretical linkage: This is a different perspective on simple measures of poverty. A state with very unequal income distribution could be less resilient because a large section of the population would not have the financial resources to recover.		
Notes and limitations: We also reversed this to the 'negative Gini' so it fit with the index direction, 'higher is better'.		
36: Median income[281]		
2012-2016 American Community Survey 5-Year Estimates	SELECTED ECONOMIC CHARACTERISTICS	DP03
Justification and theoretical linkage: This is another different perspective on simple measures of poverty. A state with very low per capita income could be less resilient because a large section of the population would not have the financial resources to recover.		
Notes and limitations: None.		
37: Percent low income residents[282]		
2012-2016 American Community Survey 5-Year Estimates	SELECTED ECONOMIC CHARACTERISTICS	DP03
Justification and theoretical linkage: A state with a high percent of the population in poverty could be less resilient because that section of the population would not have the financial resources to recover.		
Notes and limitations: None.		

[280] Cutter, Ash, and Emrich, "Geographies," 69.

[281] Parsons et al., "Top-Down Assessment," 8.

[282] Parsons et al., 8; Rockefeller Foundation and Arup, *Inside the CRI*, 28.

Domain 3: Infrastructure and ecosystems	Data Title	Data ID
Subdomain 3.1: Infrastructure characteristics		
38: Percent of public roads in poor condition (new indicator)		
American Society of Civil Engineers, Infrastructure Report Card, Infrastructure Super Map	Percent of roads in poor condition	
Justification and theoretical linkage: Weak infrastructure could be easily damaged by even small incidents, making response and recovery more challenging.		
Notes and limitations: For 38, 38.1, and 38.2, the American Society of Civil Engineers seemed to be have the most robust available data. Though it would be ideal to choose specific datasets based on the strength of their theoretical link to resilience, this is an area where we simply took what was available.		
38.1: Percent of bridges rated structurally deficient (new indicator)		
American Society of Civil Engineers, Infrastructure Report Card, Infrastructure Super Map	Percent of bridges rated structurally deficient	
Justification and theoretical linkage: Weak infrastructure could be easily damaged by even small incidents, making response and recovery more challenging.		
Notes and limitations: For 38, 38.1, and 38.2, the American Society of Civil Engineers seemed to be have the most robust available data. Though it would be ideal to choose specific datasets based on the strength of their theoretical link to resilience, this is an area where we simply took what was available and used that.		
38.2: Percent of dams in the state with Emergency Action Plans (EAPs) (new indicator)		
American Society of Civil Engineers, Infrastructure Report Card, Infrastructure Super Map	Percent of dams in the state with Emergency Action Plans	
Justification and theoretical linkage: Weak infrastructure could be easily damaged by even small incidents, making response and recovery more challenging.		
Notes and limitations: For 38, 38.1, and 38.2, the American Society of Civil Engineers seemed to be have the most robust available data. Though it would be ideal to choose specific datasets based on the strength of their theoretical link to resilience, this is an area where we simply took what was available and used that.		
39: Average annual hours of water service interruptions per household[283]		
No data was used.		
Justification and theoretical linkage: Continual breaks in access to water could indicate aging infrastructure and vulnerability to hazard impacts.		
Notes and limitations: None.		

[283] Rockefeller Foundation and Arup, *Inside the CRI*, 159.

40: Average number of flood events by cause[284]		
No data was used.		
Justification and theoretical linkage: Understanding the causes of flooding can help communities take action to mitigate the flood risk. In future iterations it might be valuable to look more broadly at other factors such as percent impermeable surfaces.		
Notes and limitations: This is one of the indicators where using GIS would likely add significant value.		
41: Annual percentage of wastewater system losses (due to storms or malfunction) prior to treatment and/or discharge to the environment[285]		
No data was used.		
Justification and theoretical linkage: This is another measure of system conditions (vulnerability) prior to an incident. If a system doesn't work before the disaster strikes, it will likely go offline quickly when a disaster does happen.		
Notes and limitations: None.		
42: Average length of electrical interruptions (hours per year per customer)[286]		
U.S. Energy Information Administration Electricity Data	Electric power sales, revenue, and energy efficiency Form EIA-861 detailed data files	
Justification and theoretical linkage: This is another measure of system conditions (vulnerability) prior to an incident. If a system doesn't work before the disaster strikes, it will likely go offline quickly when a disaster does happen.		
Notes and limitations: We used the total SAIDI (System Average Interruption Duration Index) with MED for all utilities in the state divided by the number of customers to come up with the average outage time per customer in minutes.		
43: Average number of open hospital beds[287]		
No data was used.		
Justification and theoretical linkage: If few hospital beds are available during routine operations outside an incident, the system will likely struggle to adapt to any influx of patients caused by the incident.		
Notes and limitations: The American Hospital Directory seems to have data on this, but we did not use it because of cost.		
44: Percent of communities receiving a PPC rating of 3 or better[288]		
ISO Public Protection Classification	Distribution of Communities by PPC Class by State	
Justification and theoretical linkage: The PPC rating evaluates communities on their ability to reduce losses related to fire. Insofar as this ability can directly reduce fire related hazard losses, and also insofar as it extends to other hazards, communities that rate more highly should have fewer deaths and less damage.		

[284] Cutter, Ash, and Emrich, "Geographies," 70.

[285] Rockefeller Foundation and Arup, *Inside the CRI*, 160.

[286] Rockefeller Foundation and Arup, 158.

[287] Rockefeller Foundation and Arup, 55; Cutter, Ash, and Emrich, "Geographies," 70.

[288] Rockefeller Foundation and Arup, *Inside the CRI*, 9.

Notes and limitations: We simply summed the number of communities with a PPC rating of 1, 2, or 3 (the highest three categories), then divided that by the total PPC rated communities in the state. It could be more accurate to divide by the total number of communities in the state or by population to get a more accurate indicator of relative rank.		
45: Percentage of emergency responders with equipment which enable them to communicate in an emergency (e.g., MTPAS (UK), satellite phones, airwaves etc.)[289]		
No data was used.		
Justification and theoretical linkage: By focusing on communications interoperability, jurisdictions will be able to better coordinate response and reduce loss of lives and property.		
Notes and limitations: None.		
46: Percentage of emergency responders which have undertaken an emergency communication exercise in the last 5 years[290]		
No data was used.		
Justification and theoretical linkage: Regularly testing plans can ensure that jurisdictions respond effectively to actual incidents.		
Notes and limitations: Many states already conduct and report on their exercises. More data standardization could help improve tracking.		
47: Percentage of government systems protected by a dynamic proactive I.T. security system[291]		
No data was used.		
Justification and theoretical linkage: Cyber-attacks or unplanned outages can have real world impacts, so these vulnerabilities can affect a jurisdiction's resilience.		
Notes and limitations: NIST offers a Cybersecurity Framework for a range of stakeholders, including states and other governments. The results of this are not public, but a jurisdiction could incorporate the results into their own resilience measurement. Further, based on this framework, the Center for Internet Security runs a National Cybersecurity Review, which could provide additional data.		
48: Broadband providers per capita[292]		
Federal Communications Commission	Fixed Broadband Deployment Data	Dec. 2016
Justification and theoretical linkage: Having regular access to broadband could serve as an economic driver and, through this, as an aid to recovery.		
Notes and limitations: Using GIS could improve this measure. We simply used the number of broadband providers in a state divided by the state's population, but this obviously masks other important variables such as the percent of the population with access to broadband or the actual speed of the connection.		

289 Rockefeller Foundation and Arup, 179.

290 Rockefeller Foundation and Arup, 179.

291 Rockefeller Foundation and Arup, 182.

292 Cutter, Ash, and Emrich, "Geographies," 70; Rockefeller Foundation and Arup, *Inside the CRI*, 177.

Subdomain 3.2: Protective natural resources		
49: Number of dollars spent on restoring ecosystem services (such as wildland-urban interface to reduce fire risk or dune restoration to mitigate storm surge) per year[293]		
No data was used.		
Justification and theoretical linkage: Aspects of the natural environment, like dunes or marshes, can mitigate aspects of the hazard (e.g., storm surge) so can reduce impacts. Dollars spent is only an input but can provide a baseline to measure against.		
Notes and limitations: This is one of the indicators where using GIS would likely add significant value. The Multi-Resolution Land Characteristics Consortium (MRLS), for example, could have relevant data.		
Subdomain 3.3: Land use		
50: Percentage of high risk areas within the state where development is restricted or prohibited under planning guidelines[294]		
No data was used.		
Justification and theoretical linkage: Plans can help to limit development in vulnerable areas and can help strengthen developments that already exist in these areas.		
Notes and limitations: None.		
51: Percentage of current planning policies and land use/zoning plans that have been developed with reference to a relevant hazard risk assessment[295]		
No data was used.		
Justification and theoretical linkage: Plans can help to limit development in vulnerable areas and can help strengthen developments already in these areas.		
Notes and limitations: None.		
Subdomain 3.4: Codes, standards, and enforcement		
52: Average population serviced per certified building code official in the state[296]		
ISO National Building Code Assessment Report; National Building Code Effectiveness Grading Schedule (BCEGS)	State Pages	2015
Justification and theoretical linkage: This assumes that building inspectors are effective at enforcing code and that, following this, effective code enforcement will reduce damage and deaths during a disaster in a measurable way.		
Notes and limitations: This data may not be updated regularly.		

[293] Rockefeller Foundation and Arup, *Inside the CRI*, 138.

[294] Rockefeller Foundation and Arup, 220; Parsons et al., “Top-Down Assessment,” 8.

[295] Rockefeller Foundation and Arup, *Inside the CRI*, 220.

[296] Rockefeller Foundation and Arup, 125–27; Parsons et al., “Top-Down Assessment,” 8.

<table>
<tr><td colspan="3">53.1: ISO BCEGs Score Commercial</td></tr>
<tr><td>ISO National Building Code Assessment Report; National Building Code Effectiveness Grading Schedule (BCEGS)</td><td>State Pages</td><td>2015</td></tr>
<tr><td colspan="3">Justification and theoretical linkage: Building codes represent, to some degree, the building’s structural resilience. Higher codes mean a building is more resilient, so having higher codes across the state would mean buildings would, on the whole, be less likely to be damaged in a disaster.</td></tr>
<tr><td colspan="3">Notes and limitations: BCEGS breaks down into both commercial and residential, so we included both (even though this was not in the original framework). IBHS also publishes a periodic ‘Rate the States’ Report on state building codes. However, it only rates the coastal states from Texas to Maine so was not used here.</td></tr>
<tr><td colspan="3">53.2: ISO BCEGs Score Residential</td></tr>
<tr><td>ISO National Building Code Assessment Report; National Building Code Effectiveness Grading Schedule (BCEGS)</td><td>State Pages</td><td>2015</td></tr>
<tr><td colspan="3">Justification and theoretical linkage: Building codes represent, to some degree, the building’s structural resilience. Higher codes mean a building is more resilient, so having higher codes across the state would mean buildings would, on the whole, be less likely to be damaged in a disaster.</td></tr>
<tr><td colspan="3">Notes and limitations: BCEGS breaks down into both commercial and residential, so we included both (even though this was not in the original framework). IBHS also publishes a periodic ‘Rate the States’ Report on state building codes. However, it only rates the coastal states from Texas to Maine so was not used here.</td></tr>
<tr><td colspan="3">54: Are programs or legislation in place to encourage code plus construction (e.g., the IBHS Fortified Home standard)? (new indicator)</td></tr>
<tr><td>No data was used.</td><td></td><td></td></tr>
<tr><td colspan="3">Justification and theoretical linkage: Building codes represent, to some degree, the building’s structural resilience. Higher codes mean a building is more resilient, so having higher codes across the state would mean buildings would, on the whole, be less likely to be damaged in a disaster. This indicator focuses on other legal and policy issues in addition to codes and also on hazard specific updates.</td></tr>
<tr><td colspan="3">Notes and limitations: None.</td></tr>
<tr><td colspan="3">55: Percentage of critical facilities evaluated for adequate performance during primary hazards[297]</td></tr>
<tr><td>No data was used.</td><td></td><td></td></tr>
<tr><td colspan="3">Justification and theoretical linkage: This is focused on ensuring that facilities necessary for government mission critical functions are able to withstand the relevant hazard.</td></tr>
<tr><td colspan="3">Notes and limitations: None.</td></tr>
</table>

[297] Rockefeller Foundation and Arup, *Inside the CRI*, 202.

Subdomain 3.5: Comprehensive continuity		
57: Proportion of business sectors that have been identified as critical to continuity of state functions as state adapts to predicted long-term stresses (expressed as percentage contribution to state-wide GDP)[298]		
No data was used.		
Justification and theoretical linkage: Ensuring that key businesses and, to some degree, sectors are able to continue functioning after a disaster can speed recovery and thus improve resilience.		
Notes and limitations: None.		
58: Percentage of large businesses (500+ employees) within the state that have developed business continuity plans[299]		
No data was used.		
Justification and theoretical linkage: Ensuring that key businesses and, to some degree, sectors are able to continue functioning after a disaster can speed recovery and thus improve resilience.		
Notes and limitations: None.		
59: Percentage of large businesses which have comprehensive insurance for the high risk hazards within the state's risk profile[300]		
No data was used.		
Justification and theoretical linkage: Ensuring that key businesses and, to some degree, sectors are able to continue functioning after a disaster can speed recovery and thus improve resilience.		
Notes and limitations: None.		
60: Percentage of population which can be supplied water by alternative methods for 72 hours during disruption[301]		
No data was used.		
Justification and theoretical linkage: Ensuring that residents have access to water; whether through on hand supplies, transport capability, or another means; is key to immediate response.		
Notes and limitations: None.		
61: Number of different supply sources providing at least 5 percent of electricity generation capacity[302]		
Energy Information Administration Electricity Data	Net Generation by State by Type of Producer by Energy	1990 - 2016
Justification and theoretical linkage: A state where only one or two sources provide most of the power is, in theory, more vulnerable than an otherwise similar state that has access to a greater diversity of power sources.		
Notes and limitations: None.		

[298] Rockefeller Foundation and Arup, 103.

[299] Rockefeller Foundation and Arup, 104.

[300] Rockefeller Foundation and Arup, 105.

[301] Rockefeller Foundation and Arup, 17.

[302] Rockefeller Foundation and Arup, 143.

62: Percentage per capita food reserves within state (including supermarket agreements) for 72 hours (percentage population which could be served)[303]		
No data was used.		
Justification and theoretical linkage: Just like indicator 60 on water access, if residents cannot access food, they will not be as resilient.		
Notes and limitations: None.		
63: Percent of population which has set aside emergency packaged food[304]		
No data was used.		
Justification and theoretical linkage: Having their own food could reduce residents' dependence on first responders, which could allow them to better focus their efforts elsewhere.		
Notes and limitations: The USDA Economic Research Service does publish some data on food security, but we did not include it because it is not similar enough.		
64: Percent of businesses with more than 50 employees that exercise their business continuity plans[305]		
No data was used.		
Justification and theoretical linkage: Ensuring that key businesses and, to some degree, sectors are able to continue functioning after a disaster can speed recovery and thus improve resilience.		
Notes and limitations: None.		
65: Percentage of identified critical assets which have emergency standby power generation arrangements in place[306]		
No data was used.		
Justification and theoretical linkage: Planning for which assets need power can help focus response efforts and can increase resilience.		
Notes and limitations: None.		
66: Average length of electrical interruptions for critical assets in last 2 years[307]		
No data was used.		
Justification and theoretical linkage: If critical infrastructure faces common electricity interruptions during non-disaster times, it is plausible that power would more easily be knocked out completely during a disaster.		
Notes and limitations: None.		

[303] Cutter, Ash, and Emrich, "Geographies," 70; Rockefeller Foundation and Arup, *Inside the CRI*, 24.

[304] Rockefeller Foundation and Arup, 24; Cutter, Ash, and Emrich, "Geographies," 70.

[305] Rockefeller Foundation and Arup, *Inside the CRI*, 103–5.

[306] Rockefeller Foundation and Arup, 164.

[307] Rockefeller Foundation and Arup, 164.

Subdomain 3.6: Infrastructure response capacity		
67: Ability of state utilities to restore power quickly and call in additional resources if necessary[308]		
No data was used.		
Justification and theoretical linkage: Restoring power quickly facilitates a broad array of other response and recovery activities.		
Notes and limitations: Because power is so critical, we used this as a proxy for general infrastructure response capacity. However, utilities seem generally able to call in resources on their own so this may not be an effective measure. It would also be helpful to add measures for other infrastructure sectors.		
Subdomain 3.7: Adaptive capacity		
68: Number of new projects undertaken to address known vulnerabilities in the state infrastructure capabilities (new indicator)		
No data was used.		
Justification and theoretical linkage: See general note on adaptive capacity measures.		
Notes and limitations: None.		
Domain 4: Governance	**Data Title**	**Data ID**
Subdomain 4.1: Financial capacity		
69: State debt per capita[309]		
US Census, 2015 State Government Finances	State Government Finances: 2015	SG1500A1
Justification and theoretical linkage: We used this as a proxy for overall financial health of the state. If a state has a high level of debt and low amount of savings, it may be slower to fund the necessary response and recovery actions.		
Notes and limitations: Newer data would likely be more accurate.		
70: Debt service ratio: total long-term debt servicing costs including lease payments, temporary financing and other debt charges divided by total own source revenue and expressed as a percentage[310]		
No data was used.		
Justification and theoretical linkage: We used this as a proxy for overall financial health of the state. If a state has a high level of debt and low amount of savings, it may be slower to fund the necessary response and recovery actions.		
Notes and limitations: None.		

[308] Rockefeller Foundation and Arup, 164.

[309] Rockefeller Foundation and Arup, 99; Parsons et al., "Top-Down Assessment," 8.

[310] Rockefeller Foundation and Arup, *Inside the CRI*, 99.

Subdomain 4.2: Effective planning		
71: Number of state-federal or state-state projects in last 5 years[311]		
No data was used.		
Justification and theoretical linkage: Plans can help to bring stakeholders together before a disaster so that when a disaster happens, they are able to respond and recover more effectively. This is a proxy for the strength of the state-to-federal relationships.		
Notes and limitations: One example of this could be the number ongoing recovery projects in the state. New York City, for example, has a fairly close working relationship with FEMA (and other federal partners) now because they are still spending Hurricane Sandy recovery funding.		
72: Number of times state emergency responders meet and undertake joint activities (e.g., exercises, risk assessment, plan reviews) per year[312]		
No data was used.		
Justification and theoretical linkage: Regular planning and exercises can strengthen relationships between responders. Stronger relationships can (in theory) speed response and recovery operations.		
Notes and limitations: None.		
73: The number of times the 5 most significant hazards identified in the state's local risk profile have been exercised in the last 5 years[313]		
No data was used.		
Justification and theoretical linkage: This is another measure of whether a state is prepared for the hazards they face, with the assumption that exercises increase preparedness.		
Notes and limitations: None.		
74: The state have an Enhanced Hazard Mitigation Plan (new indicator)		
FEMA Hazard Mitigation Plan Status		2018
Justification and theoretical linkage: All states are required to have a hazard mitigation plan for certain grant programs, and they can be eligible for additional funding after a disaster if they have an enhanced plan. By meeting the additional requirements for an enhanced plan, states should have become more resilient.		
Notes and limitations: We simply marked 1 for yes and 0 for no. Measures of plan quality would likely be more accurate but would certainly be more time consuming so were not used.		
75: Existence of clear consultation guidelines on the planning process, including different ways of public engagement and involvement of technical experts[314]		
No data was used.		
Justification and theoretical linkage: By using a collaborative planning process, jurisdictions are better able to motivate people around a common goal (determined through the collaboration) and develop a more realistic plan. By increasing plan quality, these jurisdictions are able to respond and recover more quickly.		
Notes and limitations: None.		

311 Rockefeller Foundation and Arup, 191; Parsons et al., "Top-Down Assessment," 9.

312 Rockefeller Foundation and Arup, *Inside the CRI*, 204.

313 Rockefeller Foundation and Arup, 199.

314 Rockefeller Foundation and Development, 222–24.

Subdomain 4.3: Risk assessment		
76: Percentage of state area for which a comprehensive exposure and vulnerability assessment has been undertaken within the past 5 years[315]		
No data was used.		
Justification and theoretical linkage: Communities that understand their vulnerability can better mitigate it.		
Notes and limitations: None.		
77: 3rd party verification for HIRA, THIRA, or other common risk and capabilities assessment (new indicator)		
No data was used.		
Justification and theoretical linkage: Having a third party validate a community's risk assessment could strengthen the understanding of risks and vulnerabilities.		
Notes and limitations: None.		
78: Number of community risk assessments in last 2 years[316]		
No data was used.		
Justification and theoretical linkage: If a large number of communities understand their risks, the state as a whole will be more resilient.		
Notes and limitations: None.		
Subdomain 4.4: Continuity of government		
79: Percentage of government departments that have tested their own continuity arrangements in the last 2 years[317]		
No data was used.		
Justification and theoretical linkage: Exercising continuity of government helps agencies better prepare to use these capabilities during a real disaster.		
Notes and limitations: None.		
Subdomain 4.5: Community preparedness		
80: Percentage of school children educated in community preparedness[318]		
No data was used.		
Justification and theoretical linkage: A common theory is that when a community educates children in emergency preparedness they then educate their parents and so teaching children can drive family and community preparedness.		
Notes and limitations: None.		

[315] Rockefeller Foundation and Arup, 122.

[316] Rockefeller Foundation and Arup, 199.

[317] Rockefeller Foundation and Arup, 201.

[318] Rockefeller Foundation and Arup, 211; Parsons et al., "Top-Down Assessment," 8.

81: Percentage of population that have made a household resilience plan[319]		
No data was used.		
Justification and theoretical linkage: Just as governments that plan for crises are likely more resilient, so too households that plan for the hazards they face are more likely to be resilient and to contribute to community and state resilience.		
Notes and limitations: None.		
82: Red cross volunteers per 10,000 persons[320]		
No data was used.		
Justification and theoretical linkage: This is a proxy for community readiness. In theory, an area with a high number of volunteers would be able to rapidly activate them to create a large force to support response and recovery.		
Notes and limitations: None.		
83: Percentage of population with first aid or similar certification (last 5 years)[321]		
No data was used.		
Justification and theoretical linkage: People who understand first aid are more able to help in incidents where there are a large number of injured people, such as mass casualty events. However, their training may also increase their confidence and/or make them more willing to help in different but related incidents such as basic search and rescue or simply checking on their neighbors.		
Notes and limitations: None.		
84: CERT programs per capita[322]		
OpenFEMA	Community Emergency Response Team (CERT) Dataset	2015
Justification and theoretical linkage: CERT programs provide training on a broad range of emergency management related material including first aid and search and rescue. Areas with a high number of CERT programs should have a large number of people trained in these areas and therefore be more ready to respond and recover.		
Notes and limitations: We had originally used 'Percent Communities with a Citizen Corps program' and changed to CERT programs per capita based on Delphi reviewer feedback. This is likely still not the best measure since simply the number of programs may not tell much about the quality of their training or how active they are.		

[319] Rockefeller Foundation and Arup, *Inside the CRI*, 211.

[320] Cutter, Ash, and Emrich, "Geographies," 69; Parsons et al., "Top-Down Assessment," 8; Rockefeller Foundation and Arup, *Inside the CRI*, 212.

[321] Cutter, Ash, and Emrich, "Geographies," 69; Rockefeller Foundation and Arup, *Inside the CRI*, 212.

[322] Cutter, Ash, and Emrich, "Geographies," 69; Rockefeller Foundation and Arup, *Inside the CR*, 212.

85: Percent Housing units covered by National Flood Insurance Program[323]		
No data was used.		
Justification and theoretical linkage: Insurance coverage can provide access to funding after a disaster, which can allow individuals to recover more quickly. Simply having a normal homeowners policy may not be enough, however, so hazard-specific insurance can be a helpful supplement.		
Notes and limitations: GIS data would be helpful here. Also, much of this data exists and simply is not public. Negotiating that could be helpful.		
86: Extent of hazard specific insurance (e.g., wildfire) for residential properties[324]		
No data was used.		
Justification and theoretical linkage: Insurance coverage can provide access to funding after a disaster, which can allow individuals to recover more quickly. Simply having a normal homeowners policy may not be enough, however, so hazard-specific insurance can be a helpful supplement.		
Notes and limitations: GIS data would be helpful here. Also, much of this data exists and simply is not public. Negotiating that could be helpful.		
Subdomain 4.6: General emergency management		
87: Emergency management budget per capita[325]		
NEMA Biennial Report	Operating budget FY17 (excluding federal funds)	
Justification and theoretical linkage: Insofar as more money spent means more capability, states with a higher emergency management budget per capita have more capacity to respond when a disaster strikes.		
Notes and limitations: We had started with 'Percentage budget allocated for emergency relief ' but used EM budget per capita for consistency with other measurements that used per capita. Using percent of total budget allocated for EM could provide an interesting comparison.		
88: EMAP accreditation (new indicator)		
Emergency Management Accreditation Program	Accredited State Programs	
Justification and theoretical linkage: EMAP covers 64 standards for emergency management programs from training to hazard mitigation. Accredited programs should be more ready to respond and recover on a range of fronts.		
Notes and limitations: We used a simple 1 for accredited and 0 for not accredited though, again, more nuance could help.		
89: Number of EMAC deployments in the past five years (new indicator)		
No data was used.		
Justification and theoretical linkage: Insofar as regular experience with disasters can help prepare an area for future disasters, a state that regularly deploys their teams to support other states would be better able to respond to disasters in their own state.		

[323] Cutter, Ash, and Emrich, "Geographies," 69; Rockefeller Foundation and Arup, *Inside the CRI*, 41.

[324] Rockefeller Foundation and Arup, 41.

[325] Parsons et al., "Top-Down Assessment," 8; Rockefeller Foundation and Arup, *Inside the CRI*, 101.

Notes and limitations: There are likely other ways to measure this idea of regular experience with disasters leading to better capability. EMAC deployments are a common method but others could be better.		
90: Total EMPG grants 2014–2016 per capita[326] **(new indicator)**		
OpenFEMA Data Feeds	Emergency Management Performance Grants v1	
Justification and theoretical linkage: The Emergency Management Performance Grant (EMPG) Program aims to help states improve their EM capability.		
Notes and limitations: We had started with 'Average EMPG dollars over the last five years' to mirror other indicators that used the last five years as a reference but instead put this as a per capita indicator for the past two years because that was the available data.		
90.1-.5: EMPG allocations within the state (new indicator)		
NEMA Biennial Report	How EMPG is allocated by percentage	
Justification and theoretical linkage: The Emergency Management Performance Grant (EMPG) Program aims to help states improve their EM capability. Further, there is likely some ideal balance for funding allocations that allows capability states and counties to develop capability most effectively. To try to find this balance out, we included this metric in the framework after the Delphi process.		
Notes and limitations: The NEMA report includes five groups within the state to which they can allocate funds: local, tribal, other state agencies, the receiving agency itself, and other. We included each group as its own category.		
91: Average UASI dollars over the last five years (new indicator)		
No data was used.		
Justification and theoretical linkage: This is another grant program designed to increase capability, though for cities instead of states. If more capable cities can reduce the overall loss of lives and damage in the state, it would then be more resilient, so we included this indicator.		
Notes and limitations: None.		
92: National Guard search and rescue units available per 10,000 population[327]		
No data was used.		
Justification and theoretical linkage: Having a greater ability to rescue people can reduce loss of life.		
Notes and limitations: This is, in some ways, a limiting metric because there are so many other partners that can conduct search and rescue operations. We included it as a way to start measuring this type of response capacity. This section should be expanded in future iterations.		
93: Number of full-time emergency managers per county [or per capita] (new indicator)		
No data was used.		
Justification and theoretical linkage: The emergency manager is usually the only one responsible with bringing together diverse stakeholders from across the jurisdiction to plan for disasters or with other functions that, in theory, will lead to reduced loss of lives and property.		
Notes and limitations: Some states, like Florida, require a certain number of emergency managers per county, while in other areas the emergency manager at the county is a part-time position.		

[326] Cutter, Ash, and Emrich, "Geographies," 69.

[327] Rockefeller Foundation and Arup, *Inside the CRI*, 61.

94: Number of LEPCs and frequency of meetings (new indicator)		
No data was used.		
Justification and theoretical linkage: Under the Emergency Planning and Community Right-to-Know Act (EPCRA), Local Emergency Planning Committees (LEPCs) must develop an emergency response plan, review the plan at least annually, and provide information about chemicals in the community to citizens. Insofar as chemicals are a relevant local hazard, LEPCs can help mitigate that. Because of the required planning and collaboration, they (in theory) can also have broader impacts in helping communities prepare for hazards generally.		
Notes and limitations: This data is usually public at the state level, but we did not have time to go state by state to find it all. As far as we know, it is not centrally located anywhere.		
Subdomain 4.7: Response capacity		
95: Capacity of evacuation routes out of state (cars per hour)[328]		
No data was used.		
Justification and theoretical linkage: If a community is able to evacuate the population rapidly, they are less vulnerable to hazards like hurricanes that usually have some fore-warning.		
Notes and limitations: One Delphi reviewer noted that this is relevant more to hurricane prone states. It may also be relevant to states with wildfires, but the general point is that a better indicator in future disasters might focus on a more broadly relevant measure of community response capacity.		
96: Number of Wireless Emergency Alert (WEA) alerting authorities in the state[329] **(new indicator)**		
FEMA Integrated Public Alert and Warning System	Organizations with Alerting Authority Completed	2018
Justification and theoretical linkage: The assumption is that communities that can rapidly reach all residents with important emergency messages will use that capability during disasters to share information, such as evacuation orders, that will reduce subsequent loss of life.		
Notes and limitations: We only used organizations with alerting authority completed, rather than also include in-progress organizations because they cannot send alerts. A better future indicator could be how many alerts an authority has sent, the degree of training, or some other measure of quality more nuanced than simply whether an organization can send an alert.		
97: Hotels/motels per 10,000 persons[330]		
No data was used.		
Justification and theoretical linkage: A larger number of hotels per capita could, theoretically, indicate more space available for an evacuating population in the event of a disaster.		
Notes and limitations: There are likely better indicators of spare housing capacity because, for example, New York City likely has a high number of hotels but a small amount of space for any evacuating population because hotels are usually booke. We did look at using the NAICS code for traveler accommodations, but ultimately decided not to because quality data was still hard to find.		

[328] Rockefeller Foundation and Arup, 175.

[329] Rockefeller Foundation and Arup, 198.

[330] Cutter, Ash, and Emrich, "Geographies," 70.

98: Percentage of population that could be served by state's access to stock of emergency shelters for 72 hours[331]		
No data was used.		
Justification and theoretical linkage: For disasters that require evacuation, this is a measure of the state's ability to shelter the population, while working with partners.		
Notes and limitations: This data is likely available but simply not public.		
99: Percentage of population within a 2 mile radius of an appropriately sized, designated rest center/emergency shelter[332]		
No data was used.		
Justification and theoretical linkage: For disasters that require evacuation, this is a measure of the state's ability to shelter, while working with partners, the population.		
Notes and limitations: GIS data would be helpful here. Also, much of this data exists and is simply not public. Negotiating that could be helpful.		
Subdomain 4.8: Recovery capacity		
100: Number of mechanisms in place to support local, small- and medium-sized businesses following a disaster[333]		
No data was used.		
Justification and theoretical linkage: This is a measure of the state's ability to support economic recovery locally.		
Notes and limitations: None.		
101: Total Hazard Mitigation Program Grants 2012–2016 per capita[334]		
OpenFEMA Data Feeds	Hazard Mitigation Grants	
Justification and theoretical linkage: States can improve their resilience by doing mitigation projects, and this is a measure of investment in those mitigation projects.		
Notes and limitations: We started with 'Ten-year average per capita spending for mitigation projects ' but went to 2012–2016 because that data was available.		
102: Total Pre-Disaster Mitigation Program Grants 2012–2016 per capita (new indicator)[335]		
OpenFEMA Data Feeds	Hazard Mitigation Grants	
Justification and theoretical linkage: States can improve their resilience by doing mitigation projects, and this is a measure of investment in those mitigation projects.		
Notes and limitations: None.		
103: Number of communities participating in the Community Rating System (new indicator)		
FEMA National Flood Insurance Program Community Rating System	Number of CRS Communities by State	
Justification and theoretical linkage: The Community Rating System incentivizes communities to take specific actions to reduce their flood risk, so a larger number of communities in the program could indicate appreciable state-wide risk reduction.		

331 Rockefeller Foundation and Arup, *Inside the CRI*, 10.

332 Rockefeller Foundation and Arup, 10, 202.

333 Rockefeller Foundation and Arup, 43.

334 Cutter, Ash, and Emrich, "Geographies of Community," 69.

335 Cutter, Ash, and Emrich, 69.

Notes and limitations: We simply used the total number of CRS communities. However, a more nuanced measure would likely be helpful such as the number of CRS communities by class.		
104: Days' worth of general fund expenditures in rainy day funds[336]		
National Association of State Budget Officers Fiscal Survey of the States	Days' worth of general fund expenditures in rainy day funds	
Justification and theoretical linkage: States with ready funding on hand for any unforeseen circumstances may be able to bring response and recovery tools to bear more quickly after an incident.		
Notes and limitations: There seem to be two kinds of 'rainy day fund,' a general account for any unforeseen expenses and an emergency management specific account, like the federal Disaster Relief Fund. Here we used the general measure because the data was available more easily. The NEMA Biennial Report does discuss state Disaster Relief Funds somewhat, but there does not appear to be standardized data for each state. Another way to look at this could also be 'Percentage of annual state revenue contained in a rainy day fund.'		
105: State has a recovery plan		
No data was used.		
Justification and theoretical linkage: Planning for recovery, not only economic but housing and other, is likely just as important as response planning, land-use planning, and hazard mitigation planning.		
Notes and limitations: Another indicator could be 'Percent of counties with a recovery plan.'		
Subdomain 4.9: Adaptive capacity		
106: Number of new projects undertaken to address known vulnerabilities in the state emergency management and governance capabilities (new indicator)		
No data was used.		
Justification and theoretical linkage: See general note on adaptive capacity measures.		
Notes and limitations: None.		

[336] Rockefeller Foundation and Arup, *Inside the CRI*, 100–104.

APPENDIX B. DELPHI FRAMEWORK 1

The following introduction was sent to Delphi participants for the first round.

A State Resilience Framework: Background and Introduction

This research seeks to answer the question of how we as a community of emergency managers can better understand which programs increase resilience and which do not. The end product will be a framework which can be used as a practical tool to guide investments to increase resilience. As an example, please visit the National Health Security Preparedness Index at https://nhspi.org/. This framework uses 140 indicators to create a comprehensive measure of health security. The NHSPI also demonstrates the goal of this research—a practical tool that can guide investments to increase resilience.

The tool I am working on for emergency management looks at the existing research to determine not only what resilience is and how to measure it, but also which statistical techniques are most valid for creating a composite index. This document will outline the key assumptions and decisions made in developing the framework, and the survey will then ask for your feedback on these decisions and on the framework as a whole.

Goal, Definition, and Conceptual Framework

To begin, the goal of this framework is to serve as a useful tool for decision–makers at the state and federal level to support resource allocation as we strive to build a resilient nation. Subsequent iterations may work more toward modeling resilience with perfect accuracy, but this aims only to set the stage for future iterations.

For the purposes of this framework, resilience is defined as when a state gets stronger after something bad happens. There are three key parts of this definition: it is focused on states, not simply the government but all people within the area; it focuses beyond simple recovery to the baseline conditions, and instead on growth and adaptation; and it is all-hazards.

It is important to highlight that this definition is broader than the traditional scope of emergency management. It is sufficiently broad that it encompasses almost the entire normal function of a government—the whole society gets stronger. I had planned to limit the scope of the definition when I started my research but, because during disasters the emergency manager frequently has to solve problems outside their normal scope, I decided that resilience measurements should be equally broad. For example, long-term housing is a common challenge in recovery operations. This is the case because people who were already vulnerably housed or homeless went into shelters and then became the emergency manager's responsibility.

In measuring resilience, it is important to capture all the aspects that create vulnerability and that could create challenges in the response or recovery for an emergency manager. The next section discusses some of the main options in developing a framework and outlines the decisions here.

Index Structure

Ultimately, a framework to measure resilience will include weighting and interdependencies of the different sub-indices and potentially even probability estimates for possible future states of resilience. This round of review simply focuses on determining the structure of the framework and the key indicators.

To measure actual resilience, one would have to look at a state before and after it experienced a disaster. Instead, this framework measures capacities for resilience. For example, what is the capacity of the electrical grid to withstand a disruption, and what is the capacity of the company to quickly restore the grid? The underlying assumption is that by building capacities in a range of key areas, the state will become more resilient.

Additionally, this tool will be top-down and hierarchical. Top-down frameworks use existing strategic level data, such as national census or economic information. Bottom-up frameworks, on the other hand, use individual or household surveys to gain an understanding of resilience at the community level. For the purposes of measuring resilience at the state-level, it is more feasible to use a top-down framework, not only because it provides a more central view of capacities, but also because it uses existing data.

Because the framework is hierarchical, multiple indices will aggregate into one overall index with the indicators in each index given specific weight based on their relative importance.

Finally, the framework will also measure resilience at a single point in time. Multiple estimates can then be compared to gather an understanding of trends.

Factors Affecting Resilience

The next question is, to measure resilience broadly at the state level, what are the most important aspects of resilience to measure? The full list of factors that potentially affect resilience are below. For the most part, I have included these indicators because they were used in previous efforts, such as the Rockefeller 100 Resilient Cities Initiative, the Australian Natural Disaster Resilience Index, the Baseline Resilience Indicators for Communities, or another framework. I intentionally left out health indicators because, as mentioned above, the National Health Security and Preparedness Index captures the resilience of that sector already, though it could be added to future versions to provide a more holistic picture of resilience. Where possible, I have included the specific justification or the previous efforts that have used this framework.

The survey questions are provided here for your reference:

Theme	Questions
Utility and simplicity	1. What could make this framework more useful? 2. Could this framework actually be used to support decisions? If not, why? 3. What could make this framework simpler?
Scope and themes	4. Are these four themes the most useful ways to initially categorize resilience goals and indicators? 5. Should other aspects of resilience be included or given more prominence? Larger frameworks/definitions for resilience provide a broader umbrella for more people to work toward the same goal. Is this valuable or is it more valuable to focus

Theme	Questions
	on specific goals/sectors, such as emergency management or critical infrastructure?
Indicators and final thoughts	6. If you had to remove 5–10 indicators because they were irrelevant, which would they be? Please simply list the indicator number from the provided framework or, if it's easier for you, type out each indicator. 7. Which are the 5–10 most important indicators? Please simply list the indicator number from the provided framework or, if it's easier for you, type out each indicator. 8. Are any indicators missing that would significantly increase resilience? 9. Are there other general ways to make this framework better or more useful?

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Theme	Goal		Summary		Indicator (Source)
Social Capital	1	Local community support	1	Support for vulnerable populations	Percentage children living outside of the care of a responsible adult (Arup, 2015)
			2	Community to community support	Percentage of people who responded that they know the names of their immediate neighbours (by survey) (Adapted from AP-NORC (at the University of Chicago))
	2	Cohesive communities	3	Cohesiveness across ethnic and racial divides	Hate crimes reported per 100,000 population (FBI, 2015)
			4	Support to disadvantaged groups	Women as a percentage of total elected to state-level office (ISO 37120)
			5	Support to youth	Youth unemployment rate (percentage of youth labour force) (UNSDN, 2015)
			6	Cohesive identity	Percentage of respondents who felt a sense of pride in their neighbourhood (Arup, 2015)
			7		Persons affiliated with a religious organization per 10,000 persons (Cutter BRIC 2010)
			8		Response rate to survey about identity and culture (new indicator)
	3	Actively engaged citizens	9	Citizen engagement	% Voting age population participating in presidential election (Cutter BRIC 2010)
			10		Number of social advocacy organizations per 10,000 population (new indicator)
			11		Average minutes per day spent on volunteer activities (OECD BLI adapted)
			12	Private sector involvement	Proportion of corporate charitable giving within community as a percentage of total charitable giving in state.
			13	Networks of community organizations	Percentage of community groups which attend events / meet with other community groups (Arup, 2015)
	4	Social character and demographics	14	Family composition	One parent families (ANDRI)
			15		Households with children (ANDRI)
			16	Household composition	Lone person households (ANDRI)
			17		Group households (ANDRI)
			18	Age	Population aged over 75 (ANDRI); % Population below 65 years of age (Cutter BRIC 2010)
			19		Population aged under 15 (ANDRI)
			20		Median age of persons (ANDRI)
			21	Education accessibility	Percentage primary education completion rates (Adapted from World Bank)
			22	Education attainment	Higher Education Degrees per 100,000 (ISO 37120)
			23	Educational attainment equality	Negative absolute difference between % population with college education and % population with less than high school education (???)
			24	English language competency	% Population proficient English speakers (ANDRI; and (Cutter BRIC 2010)
			25	Non-special needs	% Population without sensory, physical, or mental disability (Cutter BRIC 2010)

Economic capacity	5	Diverse protection of livelihoods following a shock	26	Supportive financing mechanisms	Percentage of population with access to programs for improving credit scores, credit counselling centres (Arup, 2015)
			27	Household and business insurance	Percentage of businesses with insurance cover for high risk hazards relevant to the state (Arup, 2015)
			28		Extent of natural hazard insurance coverage for homes, business, agriculture and public infrastructure (UNISDR, 2008)
			29	Post-disaster business support	Number of mechanisms in place to support local, small- and medium sized businesses following a disaster (Arup, 2015)
	7	Diverse economic base	30	Diverse economy	Percentage employment per sector by broad industry group (Arup, 2015)
			31		Percentage share of small businesses (20 employees or fewer) (Arup, 2015)
			32		% Employees not in farming, fishing, forestry, extractive industry, or tourism (Cutter BRIC 2010)
			33	Stable economic base	Average GDP per capita percentage change over last 5 years (Brookings, 2015)
			34		Percentage employment change from the previous year (Brookings, 2015)
			35	Productive economy	GDP (PPP,$) per capita (Brookings, 2015)
			36	Regionally integrated economy	Value of state exports as a percentage of state GDP (Arup, 2015)
			37	Business size	Ratio of large to small businesses (Cutter BRIC 2010)
			38	Large retail-regional/national geographic distribution	Large retail stores per 10,000 persons (Cutter BRIC 2010)
	8	Economic foundation and poverty	39	Homeownership	% Owner-occupied housing units (Cutter BRIC 2010); Population owning home outright (ANDRI)
			40		Population owning home with a mortgage (ANDRI)
			41		Population renting (ANDRI)
			42		Income to mortgage differential (ANDRI)
			43	Liquid asset poverty	% by state of population with less than 3 months savings available in liquid assets (new indicator)
			44	Income equality	Negative Gini coefficient (Cutter BRIC 2010)
			45		Median total family income (ANDRI)
			46		Low income residents (ANDRI)

Infrastructure and ecosystems	9	Effectively managed protective ecosystems	47	Ecosystem services have been identified and valued	Percentage of natural areas within the state that have undergone ecological evaluation for their protective services (Arup, 2015); % Land in wetlands (Cutter BRIC 2010)
			48	Ecosystems services have been integrated	Percentage green, open space increase or decrease over the past 5 years (Arup, 2015)
			49	Ecosystems services have been protected	Percentage of state area that has been officially recognised for environmental protection (including shorelines down to low-tide mark). Adapted from World Bank
			50	Legal protections for ecosystem services	Are there state laws in addition to the federal laws? (new indicator)
			51	Protection and restoration of ecosystem services	State Department of Natural Resources budget as proportion of whole (new indicator)
	10	Codes, standards and enforcement	52	Building codes are enforced	Estimated % of new infrastructure completed each year within the state that conforms to building codes and standards (new indicator)
			53	Previous building code enforcement	Estimated percentage of buildings within the state that meet the safety requirements of current building codes and standards (UNISDR Scorecard)
			54	Building codes are updated as necessary	Number of years since oldest current building code was reviewed (Arup, 2015); Buildings constructed after 1980 (ANDRI)
	11	Comprehensive business continuity planning	55	Government has identified mission essential businesses	Proportion of business sectors that have been identified as critical to continuity of state functions as state adapts to predicted long-term stresses (expressed as percentage contribution to state-wide GDP) (Arup, 2015)
			56	Government support to businesses for their continuity	Percentage of large businesses (500+ employees) within the state that have developed business continuity plans in accordance with ISO 22301 (Arup, 2015)
			57		Percentage of large businesses which have comprehensive insurance for the high risk hazards within the state's risk profile (Arup, 2015)
	12	Utility continuity	58	Alternative water supplies	Percentage of population which can be supplied water by alternative methods for 72 hours during disruption (Arup, 2015)
			59		Percent of population which has set aside emergency bottled water (FEMA)
			60	Diverse electricity supply and distribution	Number of different supply sources providing at least 5 percent of electricity generation capacity (World Bank)
			61	Redundant food supply networks	Percentage per capita food reserves within state (including supermarket agreements) for 72 hours (percentage population which could be served) (Adapted from UNISDR, 2014)
			62		Percent of population which has set aside emergency packaged food (FEMA)
			63	Business continuity plans exercised	% of businesses employing more than 500 people that exercise their business continuity plans (new indicator)
			64	Critical infrastructure loss modeling	Number of years since the last DHS RRAP (new indicator)
			65	Redundant power for critical infrastructure	Percentage of identified critical assets which have emergency standby power generation arrangements in place (Arup, 2015)
			66		Average length of electrical interruptions for critical assets in last 2 years (Arup, 2015)
	13	Utility	67	Roads	American Society of Civil Engineers Rating (new indicator); Major road egress points per 10,000 persons (Cutter BRIC 2010)
			68	Drinking water	American Society of Civil Engineers Rating (new indicator); Average annual hours of water service interruptions per household ISO 37120
			69	Storm water	American Society of Civil Engineers Rating (new indicator)

	1	vulnerability	70	Waste	American Society of Civil Engineers Rating (new indicator)
			71	Waste water	American Society of Civil Engineers Rating (new indicator); Annual percentage of wastewater system losses (due to storms or malfunction) prior to treatment and/or discharge to the environment (Arup, 2015)
			72	Energy	American Society of Civil Engineers Rating (new indicator); Average length of electrical interruptions (hours per year per customer) (ISO 37120)
	14	Communications and IT	73	Communications infrastructure for emergency responders	Percentage of emergency responders with arrangements which enable them to communicate in an emergency (e.g., MTPAS (UK), satellite phones, airwaves etc.) (Arup, 2015)
			74		Percentage of emergency responders which have undertaken an emergency communication exercise in the last 5 years (Arup, 2015)
			75	IT security and continuity	Percentage of government databases protected by a dynamic proactive I.T. security system (Arup, 2015)
			76	High speed internet infrastructure	% Population with access to broadband internet service (Cutter BRIC 2010)
	15	Housing	77	Sturdier housing types	% Housing units not manufactured homes (Cutter BRIC 2010)
			78	Temporary housing availability	% Vacant units that are for rent (Cutter BRIC 2010)
			79	Housing stock construction quality	% Housing units built prior to 1970 or after 2000 (Cutter BRIC 2010)
			80	Temporary shelter availability	Hotels/motels per 10,000 persons (Cutter BRIC 2010)
			81	Safe and affordable housing	Number of homeless people per 100,000 population (ISO 37120)
			82		Percentage of household income spent on housing (mortgage or rent?) by the poorest 20 percent of the population (Adapted from the University of Buffalo Regional Institute)
			83	Emergency shelter capacity	Percentage of population that could be served by state's access to stock of emergency shelters for 72 hours (Arup, 2015)
			84		Percentage of population within a 2 mile radius of an appropriately sized, designated rest centre/emergency shelter (Arup, 2015)
			85		Safe hazard shelter vs perceived public demand (Arup, 2015)

Leadership and Management	16	Government to government coordination	86	Effective communication between the state and federal governments	Number of multi-stakeholder projects in last 5 years (Arup, 2015)
			87	Effective communication within the state government	Percentage of major policy / regulatory decisions made within the last year that were that are the product of cross-departmental government consultation (Arup, 2015)
			88	Effective communication between emergency managers	Number of times multi-stakeholder emergency responders meet and undertake joint activities (e.g. exercises, risk assessment, plan reviews) per year (Arup, 2015)
	17	Government to outside government collaboration	89	Private sector involvement in decision-making	Percentage of major projects within the last year which included private sector consultation (Arup, 2015)
			90	Civil society involvement in decision-making	Percentage of state government major policy and plan changes within the past year sent out to public consultation (Arup, 2015)
	18	Continuity of government	91	Continuity of government	Percentage of government departments that have tested their own continuity arrangements in the last 2 years (Arup, 2015
	19	Emergency management	92	State emergency management capability	Percentage budget allocated for emergency relief (Arup, 2015)
			93		EMAP accreditation (new indicator)
			94		Number of EMAC requests in the past five years (new indicator)
			95		Average EMPG dollars over the last five years (new indicator)
			96		Average UASI dollars over the last five years (new indicator)
			97		Average PA dollars over the last five years (new indicator)
			98		National Guard search and rescue units available per 10,000 population (new indicator)
			99		Number of swiftwater, high-angle, and other rescue teams in the state (new indicator)
			100		Presidential disaster declarations divided by number of loss-causing hazard events from 2000 to 2009 (Cutter BRIC 2010)
			101	Local emergency management capability	Number of full-time emergency managers per county (new indicator)
			102		Number of LEPCs and frequency of meetings (new indicator)
			103	Mitigation spending	Ten year average per capita spending for mitigation projects (Cutter BRIC 2010)
			104		Average PDM dollars over the last five years.(new indicator)
			105		Number of communities participating in the Community Rating System (new indicator)
			106	Evacuation plans	Number of years since the state evacuation plan was updated (Arup, 2015)
			107		capacity of evacuation routes out of state (cars per hour) (Arup, 2015)
			108	Alert and warning	Number of Wireless Emergency Alert (WEA) alerting authorities in the state (new indicator)
	20	Community preparedness	109	Effective risk communication	Percentage of school children educated in DRR (UNISDR, 2008)
			110	Community preparedness	Percentage of population that have made a household or a community resilience plan (Arup, 2015)
			111		Red cross volunteers per 10,000 persons (Cutter BRIC 2010)
			112		Percentage of population with (last 5 years) first aid or similar certification (EJM Harvard)
			113	Local disaster training	% Population in communities with Citizen Corps program (Cutter BRIC 2010)
			114	Insurance coverage	% Housing units covered by National Flood Insurance Program [or other relevant hazard (e.g. wildfire)] (Cutter BRIC 2010)
			115		Percentage of state area for which a comprehensive exposure and vulnerability assessment has been undertaken within the past 5 years. (Arup, 2015)

Leadership and Management	21	Comprehensive hazard and exposure mapping	116	Risk assessment	How good is the THIRA/SPR process? What is a measure for quality there? (new indicator)
			117		Number of (multi-stakeholder) hazard risk assessments in last 2 years (Arup, 2015)
			118	Future trends analysis	Number of qualified staff involved in research & intelligence informing state planning (Arup, 2015)
			119	Focus on high-risk and long-term change areas	Percentage of residential dwellings within the state that are situated within high risk areas (which could be addressed by zonation and relocation?) (Arup, 2015)
			120		Percentage of current planning policies and land use/zoning plans that have been developed with reference to a relevant hazard risk assessment (Arup, 2015)
			121		Percentage urban development within the state that are situated within high risk areas (Arup, 2015)
	22	Planning	122	Inclusive and transparent planning process	Percentage of current land use and zoning plans that have been subject to a formal consultation process (Arup, 2015)
			123	Plans and strategies are aligned across departments and agencies	Percentage of current land use and zoning plans that have been subject to a formal consultation process with utility providers and transport agencies (Arup, 2015)
			124	Inclusive and transparent recovery process	Percentage of current land use and zoning plans that have been subject to a formal consultation process with minority communities affected by the development (Arup, 2015)
			125	Emergency specific plans	The number of times the 5 most significant hazards identified in the state's local risk profile have been exercised in the last 5 years. (Add up total and divide by 5) (Arup, 2015)
			126		Number of times the top 5 state risks have had their plans updated in last 5 years (Arup, 2015)
	23	Appropriate land use and zoning	127	Clear zoning plans focused on community priorities	Green area (hectares) per 100 000 population (ISO 37120)
			128		Percentage of high risk areas within the state where development is restricted or prohibited under planning guidelines. (Arup, 2015)
			129		Percentage of construction or building projects in floodplains and other mapped hazard-prone areas. (UNISDR, 2008)
			130	Regularly updated planning strategies	Does the state have an Enhanced Hazard Mitigation Plan? (new indicator)
			131		Existence of clear consultation guidelines on the plan making process, including different ways of public engagement and involvement of technical experts (Arup, 2015)
	24	Well-managed public finances	132	Diverse revenue streams	Own-source revenue as a percentage of total revenues (ISO 37120)
			133	Funding for routine service delivery	Debt service ratio: total long-term debt servicing costs including lease payments, temporary financing and other debt charges divided by total own source revenue and expressed as a percentage (ISO 37120)

APPENDIX C. DELPHI FRAMEWORK 2

The following introduction was sent to Delphi participants for the second round discussion.

State Resilience Framework Delphi Second Round

I want to first reiterate my gratitude for your participation. Thank you! The first round of feedback was very helpful, and I think the framework is simpler and the measures are more accurate and actionable. This round of feedback will focus on two areas, the sub-categories under each of the four main themes and the weights for these categories.

Based on feedback provided earlier, I have reorganized the framework based on first principles of emergency management including planning, response, and recovery. The four main themes, however, capture the same concepts: social capital, economic capacity, infrastructure and ecosystems, and governance (formerly leadership and management). I also have tried to highlight more explicitly key aspects of resilience, including the current situation and vulnerabilities in a state, the response and recovery capacity, and a state's adaptive capacity. The current situation encompasses relatively static traits like per capita income or percent of population above or below a certain age, while the adaptive capacity aims to capture the extent to which a state will follow the adage, "A disaster is a terrible thing to waste" and shore up the vulnerabilities highlighted by the crisis. These ideas don't fit each theme perfectly. There are no response metrics for the Economic capacity theme, for example, but I have included them where possible.

A number of reviewers also recommended inclusion of weights for each theme, category, and indicator, so this is the second main area where I'm requesting your feedback. I weighted each theme equally because I'm not confident enough in further prioritizing the indicators. Governance is obviously much more in a state's control, but there isn't sufficient data showing that it is actually more important than social capital, for example. I will use your input on weights to set the stage for the final step of my thesis, gathering data from a state and analyzing it to determine what is really more important.

To sum, please let me know what you think about the categories under each theme and the weights provided to them. Comments on specific indicators were very helpful in the first round so are welcome if time allows. For the sake of brevity, I have not detailed other changes to the framework from the first round, but if you have specific questions please ask. The revised categories and weights are on the second page and the full framework (also revised) is on the following pages.

There seemed to be general consensus around the themes during the first round, so feedback will now focus on the 24 categories. I have attempted to keep them simple and focus on the key drivers under each theme. I have also added an adaptive capacity category under each theme to try to capture the "top" end of the resilience spectrum, the differentiating factors that drive some jurisdictions to get stronger after a disaster.

Weights

1. How should each theme and category be weighted? Weights are currently evenly distributed under each theme.

a. Social Capital (25%)

i. Characteristics and vulnerabilities (16%)

ii. Citizen cohesiveness (16%)

iii. Citizen engagement (16%)

iv. Community response capacity (16%)

v. Community recovery capacity (16%)

vi. Adaptive capacity (16%)

b. Economic capacity (25%)

i. Diverse and stable economy (50%)

ii. Economic opportunity and inequality (50%)

c. Infrastructure and ecosystems (25%)

i. Infrastructure characteristics and vulnerabilities (14%)

ii. Protective natural resources (14%)

iii. Land use (14%)

iv. Codes, standards, and enforcement (14%)

v. Infrastructure continuity (14%)

vi. Infrastructure response capacity (14%)

vii. Adaptive capacity (14%)

d. Governance (25%)

i. State characteristics and vulnerabilities (11%)

ii. Effective planning (11%)

iii. Risk assessment (11%)

iv. Continuity of government (11%)

v. Community preparedness (11%)

vi. General emergency management (11%)

vii. Response capacity (11%)

viii. Recovery capacity (11%)

ix. Adaptive capacity (11%)

Theme		Category				Summary	Indicator (Source)
Social capital	Weighted 25%	1	Characteristics and vulnerabilities	16.60%	1	Family composition	One parent families (ANDRI)
					2	Household composition	Lone person households (ANDRI)
					3	Age	Population aged over 75 (ANDRI)
					4	Education attainment	Percentage primary education completion rates (Adapted from World Bank)
					5		Higher Education Degrees per 100,000 (ISO 37120)
					6	English language competency	% Population proficient English speakers (ANDRI; and (Cutter BRIC 2010)
					7	Access and functional needs	% Population with sensory, physical, or mental disability (new indicator)
					8	Health Insurance	Health insurance rate (new indicator)
		2	Citizen cohesiveness	16.60%	9	Cohesiveness across ethnic and racial divides	Hate crimes reported per 100,000 population (FBI, 2015)
					10		Percentage of people who responded that they know the names of their immediate neighbours (by survey) (Adapted from AP-NORC (at the University of Chicago))
					11	Neighborhood pride and engagement	Percentage of respondents who felt a sense of pride in their neighbourhood (Arup, 2015)
					12		Persons affiliated with a religious organization per 10,000 persons (Cutter BRIC 2010)
		3	Citizen engagement	16.60%	13	Citizen engagement	% Voting age population participating in presidential election (Cutter BRIC 2010)
					14		Number of social advocacy organizations per 10,000 population (new indicator)
					15		Average minutes per day spent on volunteer activities (OECD BLI adapted)
					16	Private sector involvement	Proportion of corporate charitable giving within community as a percentage of total charitable giving in state.
					17	Networks of community organizations	Percentage of community groups which attend events / meet with other community groups (Arup, 2015)
		4	Community response capacity	16.60%	18	VOADs	Number of VOADs in the state (new indicator)
					19	VOAD budget	Statewide total VOAD budget (new indicator)
					20	Support for vulnerable populations	Are emergency management plans ADA compliant? (new indicator)
					21	Inclusive exercises	Number of exercises in the past year that include members of a vulnerable population (e.g. babies, the elderly, people with access and functional needs, non-native English speakers, etc.) (new indicator)
		5	Community recovery capacity	16.60%	22	Community recovery planning	Number of community organizations with community recovery plans for relevant hazards (new indicator)
		6	Adaptive capacity	16.60%	23	Intent to address vulnerabilities	Number of new projects undertaken to address key weaknesses in social capital in the state (new indicator)
Economic capacity	Weighted 25%	7	Diverse and stable economy	50.00%	24	Diverse economy	Percentage employment per sector by broad industry group (Arup, 2015)
					25		Percentage share of small businesses (20 employees or fewer) (Arup, 2015)
					26	Stable economic base	Average GDP per capita percentage change over last 5 years (Brookings, 2015)
					27		Percentage employment change from the previous year (Brookings, 2015)
					28	Productive economy	GDP (PPP,$) per capita (Brookings, 2015)
					29	Regionally integrated economy	Value of state exports as a percentage of state GDP (Arup, 2015)
					30	Large retail-regional/national geographic distribution	Large retail stores per 10,000 persons (Cutter BRIC 2010)
		8	Economic opportunity and inequality	50.00%	31	Homeownership	% Owner-occupied housing units (Cutter BRIC 2010)
					32		Population renting (ANDRI)
					33	Safe and affordable housing	Number of homeless people per 100,000 population (ISO 37120)
					34	FICO score	Average FICO score for the state (Hope foundation and new indicator)
					35	Supportive financing mechanisms	Percentage of population with access to programs for improving credit scores, credit counselling centres (Arup, 2015)
					36	Liquid asset poverty	% by state of population with less than 3 months savings available in liquid assets (new indicator)
					37	Income	Gini coefficient for income (Cutter BRIC 2010)
					38		Per capita income (ANDRI)
					39		% low income residents (ANDRI)

Theme		Category				Summary	Indicator (Source)
Infrastructure and ecosystems	Weighted 25%	9	Infrastructure characteristics and vulnerabilities	14.28%	40	Roads	American Society of Civil Engineers Rating (new indicator)
					41	Drinking water	Average annual hours of water service interruptions per household ISO 37120
					42	Storm water	Average number of flood events from inadequate drainage
					43	Waste water	Annual percentage of wastewater system losses (due to storms or malfunction) prior to treatment and/or discharge to the environment (Arup, 2015)
					44	Energy	Average length of electrical interruptions (hours per year per customer) (ISO 37120)
					45	Health and Medical	Average number of open hospital beds (new indicator)
					46	Fire vulnerability	State fire protection rating (ISO)
					47	Communications infrastructure for emergency responders	Percentage of emergency responders with equipment which enable them to communicate in an emergency (e.g., MTPAS (UK), satellite phones, airwaves etc.) (Arup, 2015)
					48		Percentage of emergency responders which have undertaken an emergency communication exercise in the last 5 years (Arup, 2015)
					49	IT security and continuity	Percentage of government systems protected by a dynamic proactive I.T. security system (Arup, 2015)
					50	High speed internet infrastructure	% Population with access to broadband internet service (Cutter BRIC 2010)
		10	Protective natural resources	14.28%	51	Ecosystem services have been identified and valued	Number of dollars spent on restoring ecosystem services (such as wildland-urban interface to reduce fire risk or dune restoration to mitigate storm surge) per year (new indicator)
		11	Land use	14.28%	52	Land use	Percentage of high risk areas within the state where development is restricted or prohibited under planning guidelines. (Arup, 2015)
					53	Plans incorporate relevant hazards	Percentage of current planning policies and land use/zoning plans that have been developed with reference to a relevant hazard risk assessment (Arup, 2015)
					54	Development in high risk areas	Percentage urban development within the state that are situated within high risk areas (Arup, 2015)
		12	Codes, standards, and enforcement	14.28%	55	Building codes are enforced	Number of engineers doing inspections to enforce code in new construction.[Estimated % of new infrastructure completed each year within the state that conforms to building codes and standards (new indicator)]
					56	Life safety code construction	Estimated percentage of buildings within the state that meet the current building codes and standards (estimated by age of and type of construction)
					57	Code plus construction and retrofit programs	Are programs or legislation in place to encourage code plus construction (e.g. the IBHS Fortified Home standard)? (new indicator)
					58	Structurally resilient key facilities	Are requirements in place to ensure that key facilities are structurally resilient, i.e. are built to beyond code standards? (new indicator)
					59	Building codes are updated as necessary	Is a nationally recognized code adopted without amendment (ISO BCEGS data point)
		13	Infrastructure continuity	14.28%	60	Government has identified mission essential businesses	Proportion of business sectors that have been identified as critical to continuity of state functions as state adapts to predicted long-term stresses (expressed as percentage contribution to state-wide GDP) (Arup, 2015)
					61	Business continuity	Percentage of large businesses (500+ employees) within the state that have developed business continuity plans in accordance with ISO 22301 (Arup, 2015)
					62		Percentage of large businesses which have comprehensive insurance for the high risk hazards within the state's risk profile (Arup, 2015)
					63	Alternative water supplies	Percentage of population which can be supplied water by alternative methods for 72 hours during disruption (Arup, 2015)
					64	Diverse electricity supply and distribution	Number of different supply sources providing at least 5 percent of electricity generation capacity (World Bank)
					65	Redundant food supply networks	Percentage per capita food reserves within state (including supermarket agreements) for 72 hours (percentage population which could be served) (Adapted from UNISDR, 2014)
					66		Percent of population which has set aside emergency packaged food (FEMA)
					67	Business continuity plans exercised	% of businesses with more than 50 employees that exercise their business continuity plans (new indicator)
					68	Redundant power for critical infrastructure	Percentage of identified critical assets which have emergency standby power generation arrangements in place (Arup, 2015)
					69		Average length of electrical interruptions for critical assets in last 2 years (Arup, 2015)
		14	Infrastructure response capacity	####	70	Electric grid response capability	US Army Corps of Engineers power response teams available in state (new indicator)
					71		Ability of state utilities to restore power quickly and call in additional resources if necessary (new indicator)
		15	Adaptive capacity	14.28%	72	New projects addressing key vulnerabilities	Number of new projects undertaken to address known vulnerabilities in the state infrastructure capabilities (new indicator)

Theme		Category				Summary	Indicator (Source)
Governance	Weighted 25%	16	State financial capacity	11.11%	73	Diverse revenue streams	Own-source revenue as a percentage of total revenues (ISO 37120)
					74	Funding for routine service delivery	Debt service ratio: total long-term debt servicing costs including lease payments, temporary financing and other debt charges divided by total own source revenue and expressed as a percentage (ISO 37120)
		17	Effective planning	11.11%	75	Intra-government coordination	Number of state-federal or state-state projects in last 5 years (Arup, 2015)
					76	Regular exercises	Number of times state emergency responders meet and undertake joint activities (e.g. exercises, risk assessment, plan reviews) per year (Arup, 2015)
					77	Emergency specific plans	The number of times the 5 most significant hazards identified in the state's local risk profile have been exercised in the last 5 years. (Add up total and divide by 5) (Arup, 2015)
					78	Enhanced plan	Does the state have an Enhanced Hazard Mitigation Plan? (new indicator)
					79	Consultative planning	Existence of clear consultation guidelines on the planning process, including different ways of public engagement and involvement of technical experts (Arup, 2015)
		18	Risk assessment	11.11%	80	Risk assessment	Percentage of state area for which a comprehensive exposure and vulnerability assessment has been undertaken within the past 5 years. (Arup, 2015)
					81	3rd party verified	3rd party verification for HIRA, THIRA, or other common risk and capabilities assessment (new indicator)
					82	Community assessments	Number of community risk assessments in last 2 years (Arup, 2015)
		19	Continuity of government	11.11%	83	Continuity of government	Percentage of government departments that have tested their own continuity arrangements in the last 2 years (Arup, 2015)
		20	Community preparedness	11.11%	84	Effective risk communication	Percentage of school children educated in community preparedness (new indicator)
					85	Community preparedness	Percentage of population that have made a household resilience plan (Arup, 2015)
					86		Red cross volunteers per 10,000 persons (Cutter BRIC 2010)
					87		Percentage of population with (last 5 years) first aid or similar certification (EJM Harvard)
					88	Local disaster training	% Communities with a Citizen Corps program (Cutter BRIC 2010)
					89	Insurance coverage	% Housing units covered by National Flood Insurance Program [or other relevant hazard (e.g. wildfire)] (Cutter BRIC 2010)
					90	Household and business insurance	Extent of hazard specific insurance (e.g. wildfire) for residential properties (new indicator)
		21	General emergency management	11.11%	91	State emergency management capability	Percentage budget allocated for emergency relief (Arup, 2015)
					92		EMAP accreditation (new indicator)
					93		Number of EMAC deployments in the past five years (new indicator)
					94		Average EMPG dollars over the last five years (new indicator)
					95		Average UASI dollars over the last five years (new indicator)
					96		National Guard search and rescue units available per 10,000 population (new indicator)
					97	Local emergency management capability	Number of full-time emergency managers per county (new indicator)
					98		Number of LEPCs and frequency of meetings (new indicator)
		22	Response capacity	11.11%	99	Evacuation plans	Number of years since the state evacuation plan was updated (Arup, 2015)
					100		Capacity of evacuation routes out of state (cars per hour) (Arup, 2015)
					101		Major road egress points per 10,000 persons (Cutter BRIC 2010)
					102	Alert and warning	Number of Wireless Emergency Alert (WEA) alerting authorities in the state (new indicator)
					103	Temporary shelter availability	Hotels/motels per 10,000 persons (Cutter BRIC 2010)
					104	Emergency shelter capacity	Percentage of population that could be served by state's access to stock of emergency shelters for 72 hours (Arup, 2015)
					105		Percentage of population within a 2 mile radius of an appropriately sized, designated rest centre/emergency shelter (Arup, 2015)
		23	Recovery capacity	11.11%	106	Post-disaster business support	Number of mechanisms in place to support local, small- and medium sized businesses following a disaster (Arup, 2015)
					107	Mitigation spending	Ten year average per capita spending for mitigation projects (Cutter BRIC 2010)
					108		Average PDM dollars over the last five years (new indicator)
					109		Number of communities participating in the Community Rating System (new indicator)
					110	State rainy day fund	Percentage of annual state revenue contained in a rainy day fund
		24	Adaptive capacity	11.11%	111	New projects addressing key vulnerabilities	Number of new projects undertaken to address known vulnerabilities in the state emergency management and governance capabilities (new indicator)

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