# Chapter 9
# Social Resilience and Critical Infrastructure Systems

**Benjamin D. Trump, Kelsey Poinsatte-Jones, Meir Elran, Craig Allen, Bojan Srdjevic, Myriam Merad, Dejan M. Vasovic, and José Manuel Palma-Oliveira**

**Abstract** Resilience analysis and thinking serve as emerging conceptual frameworks relevant for applications assessing risk. Connections between the domains of resilience and risk assessment include vulnerability. Infrastructure, social, economic, and ecological systems (and combined social-ecological systems) are vulnerable to exogenous global change, and other disturbances, both natural and anthropologically derived. Resilience analysis fundamentally seeks to provide the groundwork for a 'soft landing', or an efficient and robust restoration following disturbance as well as the ability to reduce harms while helping the targeted system rebound to full functionality as quickly and efficiently where possible. Such applications are consistent

B.D. Trump (✉)
US Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS, USA

University of Lisbon, Lisbon, Portugal
e-mail: Benjamin.D.Trump@usace.army.mil

K. Poinsatte-Jones
US Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS, USA

M. Elran
Tel Aviv University, Tel Aviv-Yafo, Israel

C. Allen
University of Nebraska, Lincoln, NE, USA

B. Srdjevic
University of Novi Sad, Novi Sad, Serbia

M. Merad
National Center for Scientific Research, Paris, France

D.M. Vasovic
University of Niš, Niš, Serbia

J.M. Palma-Oliveira
University of Lisbon, Lisbon, Portugal



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with The National Academy of Sciences (NAS) definition of resilience, which more broadly denotes the field as “the ability to plan and prepare for, absorb, recover from, and adapt to adverse events” (Larkin S, Fox-Lent C, Eisenberg DA, Trump BD, Wallace S, Chadderton C, Linkov I (2015) Benchmarking agency and organizational practices in resilience decision making. Environ Sys Decisions 35(2):185–195). Given this definition, we seek to describe how resilience analysis and resilience thinking might be applied to social considerations for critical infrastructure systems. Specifically, we indicate how resilience might better coordinate societal elements of such infrastructure to identify, mitigate, and efficiently recover from systemic shocks and stresses that threaten system performance and service capacity.

## 9.1 Introduction

Resilience analysis and thinking serve as emerging conceptual frameworks relevant for applications assessing risk. Connections between the domains of resilience and risk assessment include vulnerability. Infrastructure, social, economic and ecological systems (and combined social-ecological systems) are vulnerable to exogenous global change, and other disturbances, both natural and anthropologically derived. Here, resilience analysis fundamentally seeks to provide the groundwork for a ‘soft landing’, or an efficient and robust restoration following disturbance as well as the ability to reduce harms while helping the targeted system rebound to full functionality as quickly and efficiently where possible. Such applications are consistent with The National Academy of Sciences (NAS) definition of resilience, which more broadly denotes the field as “the ability to plan and prepare for, absorb, recover from, and adapt to adverse events” (Larkin et al. 2015).

However, resilience is also being applied to the context of individual and collective social behaviors – i.e. social resilience (Berkes et al. 2008; Pelling 2012; Cacioppo et al. 2011). Specifically, Cacioppo et al. (2011) note that “social resilience […] is inherently a multilevel construct, revealed by capacities of individuals and groups to respectively foster, engage in, and sustain positive social relationships and to endure and recover from stressors and social isolation.” In other words, social resilience serves as a metaphor for the ability of individuals and communities to adapt, reorganize, and improve in the midst of external shocks and stresses (Norris et al. 2008; Pelling 2012). However, regardless of an individual or collective focus relative to social resilience, phenomena systems focus is essential where even individual resilience is strongly influence by social and physical factors “outside” of the particular individual (Sippel et al. 2015).

Further, in almost all levels of systems resilience, resilience is directly affected by the involvement and participation of key stakeholders before, during, and after a disruption to a system. Specifically, the actions of such stakeholders may mitigate or exacerbate such disruptions based upon the public’s awareness of the challenge and to its relevant response strategies, which find expression in (i) the resources and readiness committed to promoting resilience for a given system and community, (ii) the priorities defined and the risks evaluated and (iii) the efforts at crafting effective involvement and risk communication to align community actions, reactive or preventive. Based upon the system and community in question, such stakeholders may range from the communities at large to local, regional, and national as well as policymakers and decision makers, where specific focus must be levied upon engaging the correct and relevant stakeholders to prepare for and recover from adverse events. In this way, stakeholder engagement is an essential element of promoting social resilience in response to various adverse events and system stresses, and serves as a key task in aligning incentives and unifying members of government, industry, and the lay public to address potential or ongoing challenges that may otherwise generate lasting harms to given communities.

This chapter reviews discussion on social resilience held at a NATO Conference in the Azores, Portugal, from June 26–29, 2016. Specifically, this chapter includes the perspectives of various participants of the Social Resilience Working Group, which was tasked with the goal of addressing (i) the purpose and definition of social resilience, (ii) how social resilience is fostered, and (iii) challenges that complicate social resilience or otherwise must be considered for future work in the field. In this respect, the Working Group discussed social resilience as comprising both 'resilient societies' as well as 'the actions and involvement of key social groups to improve resilience of systems from engineering applications'. As such, this chapter begins with a general review of social resilience and resilient societies, and then reviews how social mechanisms such as stakeholder engagement are critical to promote system resilience for ecological or infrastructural applications.

## 9.2 Resilience in the Social Domain

Societal resilience has come to include several different activities and areas of study, such as with community resilience amid gradual stresses (Adger et al. 2002; House 2007; Simich and Andermann 2014) and more acute events such as climatological and/or ecological shocks (Pendall et al. 2009; Leichenko 2011; Smith and Stirling 2010). Unpacking such discussion, 'shocks' include those events that generate unexpected and fast-acting effects upon individuals or communities within a particular area (Mitchell and Harris 2012). Typically referred to as 'one-off events', or in situations of high uncertainty and surprise 'black swans', shocks are characterized by the relatively rapid manner in which they appear and subside (although their resulting impact can cause long-lasting damage). From a climatological perspective, examples of such shocks include Hurricanes Katrina and Sandy in the United States, which made landfall on certain coastal communities and dramatically damaged local economies and public health over an extended period.

On the other hand, 'stresses' include those influences or factors that, over a more extended period of time, challenge and potentially compromise individual or group resilience. Rather than overwhelm existing infrastructural and systemic resources within a brief period, such stresses act slowly to reduce such system's efficiencies and abilities to perform at a high level. Examples here include challenges from climate change, which can hinder agricultural output and community wellbeing over time without proper protections and countermeasures. Other examples may include the effect of mass migration upon society, where gradual effects can stress infrastructural systems in the absence of a plan to accommodate a large influx of people. While stresses generally may not possess dramatic adverse effects within a short period, the consequences of such gradual effects may be equally challenging to societal resilience and the ability of respective communities to absorb and recover from potential threats and problems over time.

Social resilience within this context may apply to societies and communities of various size, ranging from local neighborhoods and towns to more regional or national governments. For smaller communities, organizations, and businesses, discussions of resilience may center on the ability of local governments and set communities to address long-term concerns such as with the impact of climate change (Berkes and Jolly 2002), ecological disasters (Adger et al. 2005; Cross 2001), earthquakes (Bruneau et al. 2003), and cybersecurity concerns (Williams and Manheke 2010), as well as other manmade hazards such as transnational wars, civil wars, terrorism, migration, and industrial hazards. For larger communities and governments, such concerns are similar yet often more complex and varied in nature, where they involve hundreds to potentially thousands of stakeholders and include the interaction of various infrastructural systems.

Regardless of the size and characteristics of the community observed, an important consideration for any social resilience exercise includes the notion of panarchy, or the ability of differing systems and sub-systems to affect and potentially harm other systems and sub-systems during various shocks and stresses (Walker et al. 2004; Garmestani et al. 2008). Within the concept of panarchy, a systemic shock or stress may generate cascading effects and feedback loops that overwhelm system capacities to absorb and recover from adverse events. Panarchy serves as a framework for a complex series of interaction effects that, without a contextually rich and thorough understanding of how a given system interacts and operates with other infrastructural and societal elements, can greatly exacerbate the damages wrought by shocks and stresses over time. Palma-Oliveira and Trump (2016) argue that "understanding the consequences and magnitude of such cascade effects is crucial to identify areas where systems may be brittle or resilient."

Panarchic effects are particularly troublesome for large governments due to the many stakeholders and interconnected infrastructural systems that must be accounted for on a grand scale (Angeler et al. 2016; Cross 2001). For social considerations, such cascading effects from various shocks and stresses may overtax the ability of societies to absorb adversity and maintain normatively beneficial growth and development. DeWitte et al. (2016) note epidemic disease as one example of such complications throughout history, where the arrival bubonic plague of the fourteenth century-onward often shattered commerce and daily life in Europe. Linkov et al. (2014) applied similar lessons to modern epidemics as with the ebolavirus, which Ali et al. (2016) describe as overtaxing local public health authorities and drastically limiting economic activity within ebola-endemic areas.

Further, Walker et al. (2004), Magis (2010), and Briske et al. (2010) argue that systems generally have two outcomes in the face of an external shock event – either (i) they absorb the shock and any temporary losses in system optimality in order to return to full function at a later time, or (ii) collapse and reorganize under the strain of the shock. For the former, the system seeks to preserve itself by adapting to adverse events and recovering to near or total efficiency over a period of time (Walker et al. 2004; Briske et al. 2010). Further, such systems are considered resilient to a varying degree to those particular shocks or stresses (predictable or unpredictable), where they possess the ability to weather such challenges without completely collapsing and inducing permanent damage to social function. While often discussed as being an inherently positive trait within published literature, this is not necessarily always true, where a resilient system may be harmful or a reinforcing social trap in nature (Palma-Oliveira and Trump 2016).

For the latter, shocks that overwhelm system capacity to absorb challenges and operate normally can cause the system to fail outright (Briske et al. 2010). Upon such failure, the system might be reorganized in a manner that differs from its original state, either in the form of more beneficial and robust action in response to similar shocks in the future, or as a more brittle and/or negatively reinforcing set of actions and behaviors. History is crowded with countless examples of societal collapse on the micro and macro scales – some of which were able to rebuild and prosper, while others struggled under social traps like with recurring environmental damage, economic weakness, poor public health, and many others (Redman and Kinzig 2003; Dai et al. 2012; Schwartz and Nichols 2010).

With respect to improving social resilience, Linkov et al. (2014), Larsen et al. (2011), Bosher et al. (2009), and Djalante (2012) state that a dedicated response by key stakeholders and government decision makers is required to mitigate and manage shocks to societal resilience, where such actors foster 'safe-to-fail' and recovery options when an adverse shock arises. In this vein, stakeholders and decision makers that are actively involved with promoting social resilience in anticipation of various shocks and stresses (and take appropriate steps to fund and create relevant systems to shore up social resilience) may improve the resilience capacity of such systems before, during, and after the imposition of a shock or stress (Djalante 2012; Bosher et al. 2009).

Looking at an example of multi-purpose water resource systems, surface reservoirs are often located near important urban or industrial infrastructures. Breakage in water containment capacities as with dams, levees, and other infrastructure can contribute to sudden flood events without proper controls put into place beforehand. A critical component of such controls (and thereby bolstering water system resilience) centers on the willingness of decision makers and key stakeholders to invest resources into promoting such helpful countermeasures – where a failure to do so may result in widespread and potentially lasting damages to infrastructure, the local economy and public health.

Over extended time horizons, the critical infrastructural resilience for applications like water resource management (dams, pumping facilities, evacuation structures, spills etc.) should be modeled as an attempt to reduce recovery time post-shock as much as feasible (Hashimoto 1980; Hashimoto et al. 1982). In turn, this requires, based on the magnitude of damage caused by the disruption: (i) the existence of precise plan of recovery, (ii) pre-defined responsibilities, and (iii) sets of relevant operational actions to ensure control and reduction of damages. In each of these considerations, there exists a clear need for systems analysis techniques in various planning and construction phases to tackle aforementioned problems (Moy et al. 1986). For instance, systems analysis may help to simulate possible hydrologic conditions and various operational scenarios to control water flows into and from reservoirs (McMahon et al. 2006). With such analysis, social impacts may be weighted to be of high importance, including consideration of time intervals to determine shifting social priorities and/or infrastructural functions to meet the demands of local economic, health, and social needs (Srdjevic and Srdjevic 2016).

## 9.3 The Various Levels of Social Groups Relevant to Infrastructural Resilience

An essential consideration of promoting resilience in infrastructural systems includes an understanding of the differing levels of stakeholder involvement within the process of developing resilience. In essence, risk analysis and governance for uncertain technologies and infrastructures such as with critical infrastructural systems do not exist in a vacuum (Berkes and Jolly 2002; Pelling 2012; Larkin et al. 2015; Trump et al. 2017; Trump 2016), and often depend heavily on the actions, inaction, and interactions of various individuals and groups that operate and use such services. In this way, policymakers and stakeholders concerned with critical infrastructure resilience must be mindful of the social factors and drivers that may facilitate or hinder response and recovery from adverse shocks and stresses (Chapin et al. 2004; Palma-Oliveira et al. 2017).

A key requirement of reviewing critical infrastructure resilience is to consider what it is that must be protected. For many cases in ecological, cyber, medical, and energy security, a primary concern is the continued safety and delivery of services to the local population – not simply the protection of a singular infrastructure project or service (Pelling 2003). As such, to promote social wellbeing, safety, and economic action, key stakeholders and decision makers within various communities and governments must account for social interaction and response to adverse shocks to various systems.

For example, amid pandemic disease, steps must be taken to reassure the public and promote continued economic activity while working to reduce disease incidence. Simply focusing on combating disease may help stave off a larger epidemic and reduce the rate of incidence, but ignoring social factors and not communicating clearly with the public may still generate disastrous economic, social, and medical harms (Davtyan et al. 2014). One example of this includes the 2014 outbreak of the ebolavirus, where poor communication and networking by governments with the public not only caused significant damage to the local economy, but also instilled mistrust by locals and health workers of the government's effort to combat the virus (Torabi-Parizi et al. 2015). Another example includes HIV/AIDS, where limited public engagement, risk communication, or consideration of social factors directly contributed to the increased stigma of HIV positive individuals and discouraged many from seeking treatment at the end of the twentieth century (Vega 2016). Internationally, similar observations were noted with the SARS epidemic in China, where a mistrust of local government caused many to refuse to seek medical care and contributed to a more lasting outbreak of the disease (Chan et al. 2016).

In this way, policymakers and key stakeholders must be mindful of the need to strengthen and protect infrastructural systems to fend off, as much as possible, ecological, medical, and anthropologically-derived shocks, and recover as fast as possible and return to normal functionality. An equally important consideration includes how individuals and groups will behave and interpret information during and after such a shock. Such considerations may include public awareness and risk communication drives, the allocation of financial and physical resources to be activated before and in the event of an emergency, and well-established and distributed safety guidelines and best practices, among others. With such preparation, local and national governments may be able to limit the negative social impacts that inevitably arise from consequential shocks to energy, medical, environmental, or economic infrastructure, and may help reduce recovery time in the aftermath of the event in question.

We review stakeholder involvement in the promotion of resilience as a function of three critical stakeholder groups, which are noted below:

1. Stakeholder groups that deal with infrastructural resilience
2. Stakeholder groups and key parties that deal with infrastructural resilience in disasters
3. Stakeholder groups that evaluate the importance of infrastructural systems and assess risk

For the first group, these stakeholders typically comprise those individuals tasked with the daily management and preservation of the critical infrastructural system at hand. These stakeholders work to build critical infrastructure resilience agnostic of any particular threat, and instead work to promote overall system health and its ability to prevent, protect, mitigate, absorb, and recover from a diverse array of threats. Such stakeholders will often have permanent positions managing such systems, and serve a role of 'maintenance and preparation' as opposed to higher-level resource allocation and system evaluation.

The second group focuses more upon promoting resilience and rebounding system function and efficiency in the midst of disasters and shocks. While such stakeholders are not typically involved in the daily management of a given infrastructural system, their services are engaged in events categorized as disasters or shocks that require abnormal or extraordinary involvement from higher level decision makers and policymakers. More scenario driven, these stakeholders respond to specific threats to a system and its nested sub-systems, and generally maintain a level of expertise on their specific subject (i.e. expertise in cybersecurity, in ecosystem health, in disease control, etc.). Such individuals will interface with the first group of stakeholders, yet may have additional authority to make decisions and report findings should a threat within their area of expertise surface.

Lastly, the third group serves as those stakeholders that assess system risk and evaluate the importance of a given infrastructural system (or group of systems). Given their ability to strategize and distribute resources based upon their decisions, such stakeholders may be more senior level policymakers and decision makers. As such, the crucial role with stakeholder engagement for resilience projects at this stage is to demonstrate the value and necessity of a given system to maintain function and quickly rebound from adverse shocks. Without such a valuation, these stakeholders may not provide the necessary level of resources and manpower needed to plan for, respond to, and recover from such adverse events.

Interfacing with each level of stakeholder is of crucial importance to acquire resources, manpower, and political willpower needed to shore up system resilience to various threats. The first two stakeholder groups are required to engage in 'on-the-ground' tasks to assess risk and work to promote resilience, while the last group must be engaged to ensure that such a system's resiliency remains a priority both now and in the future.

## 9.4 Future Developments

The growing sophistication and interconnectedness of critical infrastructure ranging from energy to cybersecurity to transportation allow for an improved coordination and delivery of services over time. However, such system interconnectedness and complexity also generates the potential for more consequential and lasting damage to accrue should those systems fail. As noted above, these failures may arise suddenly as shocks or gradually as stresses, and could yield lasting harmful effects upon local societies if not adequately prepared for and recovered from before, during, and after the shock or stress occurs.

Though more substantial and consequential events are relatively rare, recent history has demonstrated how social issues may improve or detract from an infrastructural system's resilience in the face of adversity. One such example includes the impacts of Hurricanes Katrina and Rita, which devastated New Orleans and surrounding areas in Louisiana and resulted in lasting damage to the local economy and public health (Goodman and West-Olatunji 2008; Colten et al. 2008).

Emerging challenges such as with climate change, mass migration, economic instability, pandemic disease, technology innovation, cybersecurity risk, terrorism, and many others all yield potential threats to social resilience and stability (DeWitte et al. 2016; Maguire and Hagan 2007; Seager et al. 2017; Keck and Sakdapolrak 2013). As critical systems such as with energy, medical care, communication, defense, and others continue to centralize and grow in interdependency, external shocks and stresses may cause substantial and cascading system failure that may cause lasting damage to social strength and wellbeing. As such, methods and strategies are required that adequately assess system and nested sub-system resilience across society and inform decision makers of the actions under high uncertainty that must be taken before, during, and in the aftermath of an adverse event.

A further concern includes the future development of quantitative and qualitative methods to correctly assess and measure resilience both for social systems and from a general perspective. As resilience continues to mature and enter the lexicon of micro and macro-scale risk management stakeholders, a necessary development in the field includes the use of practical and user-friendly risk and decision models that illustrate and compute system and nested sub-system resilience. Currently, such methods and regulatory approaches are limited in scope (Linkov et al. 2015). Similarly, Larkin et al. (2015) noted that as of 2015, few methodological approaches of resilience analysis were formally used to facilitate risk assessment within United States government agencies. However, Larkin et al. (2015) did state that many agencies have begun experimenting with prototypical resilience models for local and regional governments and communities, where such methods may become more standardized and mandatory as their use is proven beneficial for bolstering various elements of social and infrastructural resilience.

Given the complexity of the systems and the different levels at present, one further question includes how to integrate and distinguish between the various levels of a system and, within such systems, the different actions that could generate cascading action. The panarchy framework (Cutter et al. 2008) jointly with Linkov et al.'s systematic measurement of indices could help advance our understanding of such complex systems and their resilience. Within such a focus, the involvement and training of stakeholders is a central element of improving social resilience.

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