Risk, Governance and Society

Paolo Gardoni
Colleen Murphy
Arden Rowell *Editors*

Risk Analysis of Natural Hazards

Interdisciplinary Challenges and Integrated Solutions

Springer

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Editors
Paolo Gardoni
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
Urbana, IL
USA

Colleen Murphy
College of Law
University of Illinois at Urbana-Champaign
Champaign, IL
USA

Arden Rowell
College of Law
University of Illinois at Urbana-Champaign
Champaign, IL
USA

Risk, Governance and Society
ISBN 978-3-319-22125-0 ISBN 978-3-319-22126-7 (eBook)
DOI 10.1007/978-3-319-22126-7

Library of Congress Control Number: 2015953837

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Risk, Governance and Society

Volume 19

More information about this series at http://www.springer.com/series/6643

Printed by Printforce, the Netherlands

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Chapter 1
Risk Analysis of Natural Hazards: Interdisciplinary Challenges and Integrated Solutions

Paolo Gardoni, Colleen Murphy, and Arden Rowell

Abstract Natural hazards can have a devastating impact on society. They cause billions of dollars of damage each year, kill thousands, and render millions homeless, and their frequency and severity are expected to increase with climate change. Although the source of damage from natural hazards may appear to be "natural," in fact it results from complex interactions between the natural environment, human decisions about the built environment, and social vulnerability. This volume brings together leading minds in engineering, science, philosophy, law, and the social sciences to develop a deeper understanding of the interdisciplinary challenges involved in the mitigation of natural hazards.

Parts I and II of this volume explore risk assessment, first by providing an overview of the interdisciplinary interactions involved in the assessment of natural hazards, and then by exploring the particular impacts of climate change on natural hazard assessment. Part III discusses the theoretical frameworks for the evaluation of natural hazards. Finally, Parts IV and V address the risk management of natural hazards: Part IV provides an overview of the interdisciplinary interactions underlying natural hazard management, and Part V explores decision frameworks that can help decision makers integrate and respond to the complex relationships among natural events, the built environment, and human behavior.

P. Gardoni (✉)
Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, USA
e-mail: gardoni@illinois.edu

C. Murphy
College of Law and Department of Philosophy, University of Illinois at Urbana-Champaign, Champaign, IL, USA

A. Rowell
College of Law, University of Illinois at Urbana-Champaign, Champaign, IL, USA

P. Gardoni et al. (eds.), *Risk Analysis of Natural Hazards*, Risk, Governance and Society 19, DOI 10.1007/978-3-319-22126-7_1

1.1 Introduction

Natural hazards cause billions of dollars of damage each year, kill thousands, and render millions homeless, and their frequency and severity are only expected to increase with climate change. Although the source of damage from natural hazards may appear to be "natural," in fact it results from complex interactions between the natural environment, human decisions about the built environment, and social vulnerability. The risk associated with natural hazards arises when the interaction of natural events, the built and modified natural environments and social vulnerability creates a possibility for disaster. The impact of natural hazards depends importantly upon the choices individuals and communities make in the construction of the built environment, such as whether individuals will be permitted to live in areas vulnerable to flooding or hurricanes, and what level of safety is demanded of buildings and bridges. It also depends upon differences in vulnerability—the predisposition to loss or damage—which is influenced by individual, household, and societal assets and social protections.

To illustrate, consider the impact of earthquakes. In 2010, a magnitude 7.0 earthquake in Haiti occurred. Much of Haiti's capital city of Port-au-Prince was reduced to rubble. Hundreds of thousands of people died, hundreds of thousands more were injured, and a million were left homeless. The same year, an 8.8-magnitude earthquake struck Chile—a natural event that released over 500 times the energy at its epicenter than the Haitian quake and ranks in the top ten most energetic earthquakes ever recorded. Yet, the death toll from the Chilean quake was three orders of magnitude lower than in Haiti—hundreds rather than hundreds of thousands. What was different about Chile? Just to mention a few differences, Chile, unlike Haiti, had a robust (and enforced) set of building codes that was designed to be resilient to seismic events—meaning that individual structures were less likely to collapse, and the key infrastructures like hospitals could continue to operate after the quake. Chileans, unlike Haitians, were accustomed to earthquakes and had a set of social norms, habits, and supports that allowed for an organized response to the natural event itself. And in Chile, unlike in Haiti, the earthquake itself occurred some distance from the primary areas where people had chosen to build their homes. Both the Chilean and Haitian earthquakes were disasters with tragic outcomes, significant social impact, and wide-ranging economic effects. What the comparison illustrates, however, is that physical processes alone cannot predict or prevent destruction from natural hazards. To understand what makes natural events into disasters, it is critical to understand how those events interact with the built environment, and with the social behaviors of people who act within that environment.

Successful understanding, management, and mitigation of risks from natural hazards require the technical expertise of engineers and scientists; the legal and policy expertise of legal scholars; the ethical expertise of philosophers; and the cultural, psychological, political, and economic expertise of social scientists. The interdisciplinary field of risk analysis is a promising home for the discussions

necessary to manage the complex interactions between the physical, the ethical, and the social that combine into natural hazards.

The general study of risk initially concentrated on a relatively narrow question related to the odds of winning games of chance. The book by Girolamo Cardano (1500–1571) "*Liber de Ludo Aleae* (*Book on Games of Chance*)" is possibly the first systematic attempt to formulate mathematical principles for risk analysis. After him and starting with the Renaissance, the theoretical foundations of the modern theory of risk analysis was laid through the contribution of mathematicians like Pascal and Fermat in the 1600s, Leibniz, Bernoulli, de Moivre and Bayes in the 1700s, Galton in the 1800s, and Markowitz in the 1900s. In more recent years, the field of risk analysis has expanded, benefitting from significant contributions in a number of fields beyond mathematics including engineering, philosophy, law, and psychology. However, much work continues to be done by scholars investigating risk from the perspective of a single discipline while communities face interdisciplinary challenges that call for integrated solutions. Building on a highly successful international working conference, this volume brings together leading minds in engineering, science, philosophy, law, and the social sciences to develop a deeper understanding of the interdisciplinary challenges involved in the mitigation of natural hazards.

Risk analysis is often divided into three types of inquiry: risk assessment (the quantification of the levels of risk associated with particular hazards), risk evaluation (the formulation of value judgment about assessed risks), and risk management (the decision process on whether and how to act upon the information from the risk evaluation). The structure of this volume echoes these categorizations. It begins in Parts I and II by exploring risk assessment, first by providing an overview of the interdisciplinary interactions involved in the assessment of natural hazards, and then by exploring the particular impacts of climate change on natural hazard assessment. Part III discusses the theoretical frameworks for the evaluation of natural hazards. Finally, Parts IV and V address the risk management of natural hazards: Part IV provides an overview of the interdisciplinary interactions underlying natural hazard management, and Part V explores decision frameworks that can help decision makers integrate and respond to the complex relationships among natural events, the built environment, and human behavior.

Part I provides an overview of current interdisciplinary issues involved in risk assessment. One obstacle to effective mitigation strategies is the divergence between risk assessments by risk experts and the lay public. In "Risk Assessment and Social Choice," philosopher Tim McCarthy and sociologist Noreen Sugrue argue that there is no reason to categorically reject either type of risk assessment. Instead, competing risk assessments point to different competencies of and diverse normative constraints endorsed by experts and the lay public, respectively. They propose a framework for amalgamating competing assessments of social interventions, actions taken by actors outside a community designed to solve a given social problem. Through a "spiderweb" diagram competing risk preferences can be ranked along various dimensions, which allows elements of both groups to be represented

and respected. After sketching the framework, McCarthy and Sugrue apply it to two different cases.

Risk assessments by both the public and risk experts are shaped by how those experts implicitly conceptualize nature, technology, and vulnerability. In "Vulnerability to Natural Hazards: Philosophical Reflections on the Social and Cultural Dimensions of Natural Disaster Risk," philosopher Mark Coecklebergh problematizes discussion of "natural" disasters, insofar as both the causes of disasters and impact of disasters are, as noted above, shaped by human choices in policy, infrastructure, and the distribution of goods within a community. Coeckelbergh argues that non-modern viewpoints on risks from natural disasters offer fruitful resources for understanding the limits of technical solutions to natural hazards and the limits of our ability to completely manage and control such hazards.

Finally, in "Discount Rates and Infrastructure Safety: Implications of the New Economic Learning," law professor Daniel Farber explores the relationship between recent economic work on discounting—a tool used by economists to make tradeoffs through time—and disaster policy. A recent and emerging consensus among economists would apply declining discount rates over time: a declining discount rate offers a long-term hedge against uncertainty regarding economic growth. Because discounting is the flipside of compound interest, a declining discount rate has the overall impact of *increasing* the resources allocated to policies that reduce distant-future harm. Farber argues that this new approach to discounting has important and distinctive implication for disaster policy, because natural hazards tend to be spread sparsely over time, such that they tend—at any particular time point—to be most likely to occur in the "distant future." Farber then contrasts the impacts of a declining discount rate with current U.S. practice, which is still to use a fixed discount rate when comparing and analyzing possible policy impacts. He concludes that the new generation of economic analysis, which supports the use of declining discount rates, suggests that existing practice leads society to underinvest in infrastructure resiliency and in other projects that might reduce total losses from natural hazards.

Part II of the volume focuses on future challenges in risk assessment and, in particular, those brought by climate change. In his chapter titled: "Setting the Stage for Risk Management: Severe Weather Under a Changing Climate (Chap. 5)," atmospheric science professor Donald J. Wuebbles summarizes and critically evaluates the latest scientific findings on climate change. Particular emphasis of the chapter is on the latest trends and future projections, which are based on different possible scenarios. Wuebbles discusses the issues related to the uncertainties associated with predictions of future climate changes, and some of the implications of climate change on society. This chapter also emphasizes that climate change is likely to continue to increase the frequency and severity of extreme weather events.

In "Climate Change and Natural Hazards," philosophy professor Doug MacLean discusses the moral dimensions of climate change. He highlights the ways that the temporal and spatial aspects of climate change complicate ethical thinking. MacLean argues that together these aspects produce a unique moral dilemma: the

challenge is to identify a way of framing the problem posed by climate change that makes both justice and intergenerational concern for posterity relevant at the same time. Part of the challenge in achieving this is that, MacLean argues, the values of justice and intergenerational concern pull in competing directions.

Civil infrastructure facilities are essential elements for the well-being of a society. Natural events like hurricanes and cyclones, tornadoes, earthquakes, and floods subject civil infrastructure facilities to extreme loads that could cause their failure with very significant societal impacts. Civil engineering professor Bruce Ellingwood and graduate student Ji Yun Lee critically investigate a number of issues that need to be considered in the life-cycle assessment of such infrastructures. Issues considered include the effects of climate change (in particular on the likelihood and magnitude of some extreme natural events), the role of the interdependency among facilities, the implications of population growth (particularly in coastal regions) and infrastructure development, and the consequences of the longer service life of many civil infrastructure facilities with respect to traditional service lives going well beyond typical budget cycles and charge time of decision makers.

Civil engineering professor David Rosowsky and graduate students Lauren Mudd and Christopher Letchford then investigate the impact of climate change on the likelihood and severity of hurricanes in the Northeastern Coastline of the U.S. in their chapter "Assessing climate Change Impact on the US East Coast Hurricane Hazard (Chap. 8)." They considered multiple climate change scenarios and models to construct probabilistic models of different hurricane characteristics (like frequency, genesis location, and track behavior) and of measures of hurricane intensity (e.g., wind speed and rainfall.) The models are then used to predict the joint likelihood of wind speed intensity, spatial extent/storm size, and rainfall rate. The chapter concludes with a discussion of the implication of climate changes on design provisions for civil structures and infrastructure.

Part III focuses on risk evaluation and in particular on possible theoretical frameworks for risk evaluation. Philosophy professor Adam Hosein in his chapter "Deontology and Natural Hazards (Chap. 9)" sketches an alternative to the widely used cost-benefit approach to policy choice and decision-making. Hosein's starting point is important: widely recognized moral distinctions that cost-benefit analysis does not take into account. One such distinction is the difference between allowing a harm to occur and doing an action that leads to harm. Hosein's deontological approach takes into account such distinctions.

Philosophy professor Sven Ove Hansson concentrates on traditional probabilistic risk assessment and identifies important limitations with it in his chapter "Managing Risks of the Unknown (Chap. 10)." First, he argues, the appropriate way to treat risks for which there can be no meaningful probability assigned must be developed. Second, ethically salient matters such as equity, consent, and voluntariness must be incorporated into risk evaluation. Hansson presents three frameworks for dealing with these issues: possibility analysis, three-party model, and hypothetical retrospection.

Finally, risk analysts Louis Anthony (Tony) Cox, Jr. and Emeline D. Cox in their chapter, "Intergenerational Justice in Resilience Investments with Uncertain Future Preferences and Resources (Chap. 11)," build on themes in the chapters by Hosein and Hansson (Chaps. 9 and 10). Their central question is: "How much should each generation invest in building resilient infrastructure to protect against possible future natural disasters given uncertainty about the preferences, resources, and capacities of future generations?" Cox and Cox discuss a number of different frameworks for dealing with this question, including optimal economic growth models, behavioral economics, and the Rawlsian moral framework. Rather than choosing one framework over the others, Cox and Cox argue that each framework has important insights. Jointly the frameworks highlight the fact that standards of success in investing in resilient infrastructure depend on a rich understanding of human nature and cooperation over time, what is needed to maintain such cooperation over time, the goals of building a resilient infrastructure, and the trade-offs any choice entails.

Part IV focuses on risk management from an interdisciplinary perspective. In "War Rhetoric and Disaster Transparency," law professors Lisa Grow Sun and RonNell Anderson Jones deconstruct the use of war and national security rhetoric to discuss disasters and disaster policy. They argue that rhetorical comparisons of war and disasters—and particularly disaster aftermath—can lead policymakers to select policies that are insensitive to a critical distinction between war and disaster: the existence of a thinking enemy. Sun and Jones prescribe a careful analytical disaggregation of dissimilar forms of emergencies and encourage policymakers to systematically interrogate the assumptions underlying how they choose to prepare for and respond to emergencies.

Government decision-making has historically involved the general public to a different degree. Catastrophist Gordon Woo, in his chapter titled "Participatory Decision Making on Hazard Warnings (Chap. 13)" argues that there are a number of advantages of citizen participation in government decision-making. However, citizens' participation also comes with some challenges especially when dealing with technical or scientific matters of which citizens might not have sufficient understanding and when individual perceptions (like the perception of risk) might lead to irrational decisions. Woo discussed the challenges of public participation and offers some strategies on how they could be overcome.

In "The Natech: Right-to-Know as Space-Time," law professor Gregg Macey explores the legal implications of so-called "natech events:" disasters that occur at the interface of natural hazards and technology, as when an earthquake triggers a chemical spill. He argues that natechs present technical and policy challenges that are importantly different from the types of acute, rare, "worst-case scenario" events on which decision makers often focus. In particular, Macey warns that natechs tend to be geographically dispersed and temporally discontinuous and that traditional approaches to managing disaster risk are likely to mismanage the sorts of cumulative impacts that can cause natech disasters. He prescribes response strategies designed to identify, reconstruct, and track cumulative impacts, and urges increased awareness of the mundane infrastructure stressors that tend to increase natech risk.

Finally, Part V of the volume considers decision frameworks for risk management. In "Private Versus Public Insurance for Natural Hazards: Individual Behavior's Role in Loss Mitigation," law professor Peter Molk explores the relationship between the legal and institutional structures of insurance markets, and social exposure to catastrophic risks. He argues that the way that insurance is provided (for example, whether private homeowners' insurance excludes losses from natural hazards) can affect not only the likely cost of public aid in the event of a disaster (a form of what Molk terms "public insurance") but also individuals' incentives to prevent or mitigate disaster losses. Molk goes on to describe and analyze the current state of disaster insurance in the United States, focusing particularly on the relationship between traditional private insurance and the federally-provided "public" flood insurance program. He concludes by identifying institutionally-sensitive mechanisms for regulating insurance markets in the United States to incentivize individuals to take risk-reducing behaviors, and thus to reduce overall losses from natural hazards.

Decision-makers, including governmental agencies, often face difficult decisions on the allocation of limited resources to promote the safety of the built environment. In the chapter titled "Risk-informed Decision Framework for the Built Environment: The Incorporation of Epistemic Uncertainty (Chap. 16)," civil engineering professor Eun Jeong Cha and mechanical engineering professor Yan Wang present a framework for risk-informed decision-making that is developed to assist decision makers. Cha and Wang illustrate the proposed framework considering the allocation of resources for a Florida county facing hurricane risk.

Finally Civil engineering professors Mahesh D. Pandey and Neil Lind in their chapter "Societal Perspective in Risk Management: Application of Life-Quality Index (Chap. 17)" focus on the fundamental question, "How safe is safe enough?" The chapter answers this question by striking a balance between the cost associated to measures of risk mitigation and the societal benefits that come from the increased safety. While generally applicable to any engineering infrastructure system, the chapter illustrates the proposed formulation considering the mitigation of risk due to radiation exposure from nuclear power plants.

Throughout the volume, authors refer back to both other authors' work, and to the interdisciplinary workshop on which this volume was based. We believe that this sort of cross-disciplinary collaboration is critical to the effective mitigation of natural hazards. No single person—and no single discipline—holds the key to reducing the suffering caused by disasters. If we are to find ways to effectively reduce the harm caused by natural events, it must be through cross-disciplinary conversations of the kind that this volume has sought to foster.

Part I
Risk Assessment: An Interdisciplinary Perspective