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Introduction – Risk Analysis and Society

An Interdisciplinary Characterization of the Field

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1. RISK ANALYSIS AND SOCIETY

Being alive means seeking opportunities and taking risks. For people living in modern society at the beginning of the twenty-first century, being alive means grappling with a complex and growing array of risks to the well-being of humans and the natural environment. It also means increasing concern for the how these risks are understood, characterized, and managed. Hence, we have the human dread of and fascination for risk and the increasingly important role of risk analysis within societies.

Since the beginning of human development, risks to health and well-being have led to adaptive responses that open paths for change. When neolithic family groups shared knowledge and resources for combating hunger, thirst, climate, or outside attack, they were trying to manage risks they faced. Jared Diamond's recent book, *Guns, Germs, and Steel*, presents the complex and fundamental decisions faced by hunter-gatherers when considering whether to adopt food production in place of their traditional foraging way of life (Diamond, 1999). Issues of uncertainty, value trade-offs, community knowledge, outside expertise, ethical dilemmas, and the imposition of risks by others were all part of those choices.

Risk management has been a fundamental motivation for development of social and governance structures over the last 10,000 years. The onset of agricultural production brought increasing population and permanent settlements. Concentrated population in turn led to greater risks of drought, famine, and conquest by others. Settlements thus created the need for infrastructures for managing these risks, such as water supply, food storage, and defenses. Large-scale construction in turn required specialization of labor and governance that could harness the collective resources needed for early societal risk management efforts. Without the risks to life and limb faced by individuals, societies would not have developed as they have.

How concepts of risk analysis originated, evolved, and became formalized provides one of the most compelling stories of the history of human thought. A comprehensive paper by Covello and Mumpower (1985) provides an historical perspective on risk analysis and risk management, starting with a group of decision consultants called the Asipu in the Tigris-Euphrates valley of 3200 B.C. That review considers early developments in probability, epidemiology, insurance, and legislation regarding societal risk analysis. It draws several distinctions about shifts in risk analysis and management from early to modern times. Peter Bernstein's remarkable book, *Against the Gods*, presents a chronology of thinking and understanding about risk, beginning with the development of number systems, games of chance and probability, and then tracing the development of economic thought about risk. In lively and accessible terms, he explores the great works on decision theory of the mid- and latter twentieth century, including von Neumann and Morgenstern (1944) and the writing of Tversky, Kahneman, and their colleagues. Bernstein's overall focus is on our understanding and management of financial risk. Yet his theme of risk analysis and decision theory as a means of reframing our conception of uncertainty (no longer simply fate but rather acting "against the Gods") is important for the history of risk analysis in all domains (Bernstein, 1998).

Analyzing and managing societal risks to health, safety, and environmental quality have become dominant themes in the social and natural sciences. Throughout the last century, economists have characterized the entire rationale for government as based in the support for collective efforts that cannot be accomplished through private markets. Most of those collective endeavors involve responses to risks: national defense, natural hazards, public health and safety, environmental protection, social infrastructure, and so forth. Sociologists such as Ulrich Beck (1992) see risk as an organizing principle for understanding the structure and functional relationships of modern societies. Engineers have for years addressed the risk of failure in their designs using safety factors and standards-based approaches. More recently, they have developed and applied probabilistic tools for explicit consideration of risk-cost and risk-risk trade-offs in areas such as dam, transportation, and product safety. Health scientists have seen an explosion in the number and complexity of health issues that require organized societal responses, and with it a demand for informed analysis to guide and tailor these programs. Toxicologists see their models put to use within a growing number of health, welfare, and ecological contexts, with health and environmental risks now considered fundamental elements of infrastructure, product, and regulatory design. All these disciplines have grappled with the role that uncertainty and precaution should play in managing risks.

2. A BRIEF HISTORICAL PERSPECTIVE ON THE DEVELOPMENT OF RISK ANALYSIS

A number of authors have provided accounts tracing the history and modern development of risk analysis as a field of study (Covello and Mumpower, 1985; Graham, 1995; Paustenbach, 1995; Rechard, 1999; Bedford and Cooke, 2001). The history by Rechard (1999), while focusing upon the implications for nuclear power and radioactive waste management, provides a particularly broad overview of the various disciplines that have contributed to the modern state of the field. Building upon the insights of Cumming (1981) and Ruckelshaus (1983), he notes that "risk assessment is not a distinct branch of science; instead it is a . . . 'hybrid discipline,' in which the current state of scientific and technological knowledge is made accessible to society as input to risk management decisions." Rechard traces early developments in probability theory, medicine, environmental health, chemical toxicology, reliability analysis, health and safety regulation, and risk perception and communication. Among the more recent key milestones (including a few that we have added) are:

- In 1924 Lotka, a U.S. physicist, speculates that, based on 1920 coal use, industrial activity will double atmospheric CO_2 in 500 years (http://www.environmentaldefense.org/pubs/FactSheets/d_GWFact.html, accessed January 3, 2002);
- In 1926 Muller discovers that X-rays induce genetic mutations in fruit flies 1,500 times more quickly than normal (http://www.dnacenter.com/geneticshistory.html, accessed January 2, 2002);
- The International Commission of Radiation Protection (ICRP) is established in 1928 in Sweden;
- The United Kingdom specifies a 99.999% reliability for 1-hour flying time of commercial aircraft in 1939;
- von Neumann and Morgenstern publish the *Theory of Games and Economic Behavior* in 1944;
- Monte Carlo methods are first applied in 1947 for diffusion of neutrons through fissile material (Metropolis and Ulam, 1949);
- In 1949 Callendar, a British scientist, speculatively links the estimated 10% increase of atmospheric CO_2 between 1850 and 1940 with the observed warming of northern Europe and North America that began in the 1880s (http://www.environmentaldefense.org/pubs/FactSheets/d_GWFact.html, accessed January 3, 2002);
- The U.S. Food and Drug Administration (FDA) adopts in 1954 a 100× factor of safety for hazardous chemicals to determine an allowable daily intake (Dourson and Stara, 1983; Goldstein, 1990);
- Fault-tree methods developed in 1961 at Bell Labs for U.S. Air Force to evaluate Minuteman missile launch safety (http://www.safeware-eng.com/pubs/SafAnTooReq.shtml, accessed January 3, 2002);

- Starr presents a risk-cost-benefit analysis for nuclear power plants in 1969 (Starr, 1969);
- In 1972 Berg creates the first recombinant DNA molecule and the first successful DNA cloning experiment is performed in California;
- Ames test developed in 1973 to identify chemicals that damage DNA, in order to identify possibly carcinogenic substances (http://www.dnacenter.com/geneticshistory.html, accessed January 2, 2002);
- Kahneman and Tversky publish "Subjective Probability: A Judgment of Representativeness" in 1972 and "On the Psychology of Prediction" in 1973 (subsequently *Judgment under Uncertainty: Heuristics and Biases* with Slovic in 1982);
- Crutzen (1974) and Molina and Rowland (1974) identify key factors affecting depletion of stratospheric ozone;
- The U.S. Nuclear Regulatory Commission publishes the first probabilistic risk assessment for reactor safety in 1975 (Rasmussen et al., 1975; APS, 1975);
- Turner (1975) summarizes mathematical structure of single- and multi-hit dose-response toxicity models;
- The U.S. Environmental Protection Agency (EPA) issues its first formal guidelines for cancer risk assessments in 1976 (U.S. EPA, 1976; see also, Crump et al. 1976; Albert, Train, and Anderson, 1977; IRLG, 1979);
- Page (1978) identifies the character of risks requiring a precautionary approach;
- Crouch and Wilson (1979) examine interspecies comparisons of carcinogenic potency;
- Mackay (1979) proposes fugacity-based method for multimedia environmental modeling;
- Kaplan and Garrick (1981) characterize risk in terms of outcome scenarios, their consequences, and their probability of occurrence;
- The U.S. National Academy of Sciences issues 1983 study on *Risk Assessment in the Federal Government: Managing the Process* (NRC, 1983);
- Additional U.S. National Research Council studies (NRC, 1989; 1996) and a key Presidential/Congressional Commission Report on Risk Assessment and Risk Management (1997) emphasize critical roles for risk communication and social, deliberative processes in guiding risk assessment and risk management activities;
- Montreal Protocol on Stratospheric Ozone ratified in 1987;
- In 1988 the Intergovernmental Panel on Climate Change (IPCC) is founded and issues its first reports in 1990 (IPCC, 1990a, b, c; see http://www.ipcc.ch/pub/reports.htm);
- International Life Sciences Institute Working Group presents conceptual framework for pathogenic microbial risk assessment for human disease in 1996 (ILSI, 1996);

- Haimes (1999) outlines an important role for risk analysis to address emerging threats to critical infrastructure, including cyber sabotage and terrorism;
- The completion of the Human Genome Project is announced in 2000 (the complete map of the human genome is published in 2001 in the journals *Science* and *Nature*) (http://www.dnacenter.com/geneticshistory.html, accessed January 2, 2002);
- The European Union Environment Commission publishes in 2000 a Communication[1] on the use of the precautionary principle in analyzing risk for environmental and health issues;
- In May 2001, the Convention on Persistent Organic Pollutants (POPs) is signed in Stockholm, Sweden; and
- In November 2001, Advanced Cell Technology of Massachusetts clones first human cells (http://detnews.com/2001/health/0111/26/a01-352254.htm, accessed January 2, 2002).

Clearly, the continued growth of research and applications addressing issues in risk analysis, and their extension to include a broad spectrum of scientific, social, and political perspectives, have been motivated by scientific and technological advances as well as societal needs. The chapters in this volume attempt to characterize the current landscape of risk analysis and to explore the frontiers of risk research and application. In so doing, we recognize that the science behind risk analysis draws upon a wide range of fundamental disciplines, with contributions from different applied fields and new applications emerging at a rapid pace. Table 1.1 provides one representation of the intellectual foundations and adaptations of scientific knowledge that support risk analysis. Clearly, as one moves from the basic disciplines of physics, chemistry, biology, mathematics, logic, and philosophy into the more applied disciplines of environmental science and engineering, medicine, public health, reliability engineering, and systems analysis and on to the social, behavioral, and policy sciences, widely divergent knowledge and insights must be tapped and integrated to solve real problems. This is not easy work, but it is exciting.

The question that we now face is this: To what extent has risk analysis evolved into a defined discipline? Such an *inter*disciplinary evolution can surely entail the benefits of providing a common set of tools and knowledge for addressing complex, multifaceted risk problems. However, it could also lead to a narrowing of the *multi*disciplinary vision of risk analysis that now provides much of its vigor and excitement. By demanding contributions from different disciplinary perspectives, how can we ensure a rich exchange of ideas from the most sound and advanced sources for each? By bringing together in this volume various perspectives on the current state of the social, engineering, health, and ecological risk sciences, we hope to motivate further thinking on this question, but not to resolve it.

Cambridge University Press
978-0-521-53263-1 - Risk Analysis and Society: An Interdisciplinary Characterization of the Field
Edited by Timothy McDaniels and Mitchell J. Small
Excerpt
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TABLE 1.1. *The Disciplinary Foundations of Risk Analysis*

			Risk Analysis				
		Public & Private Infrastructure Security & Safety	National & International Law and Governance		Public Participation		
	Pollution Prevention & Remediation	Sustainable Development	Business, Finance & Investment		Risk Perception and Communication		
Environmental Science & Engineering		Medicine & Public Health		Reliability Engineering and System Analysis	Behavioral and Decision Sciences	Political Science	
	Health Physics	Toxicology	Epidemiology				
						History	
Earth Sciences	Pharmacology & Physiology	Ecology	Statistics	Economics	Psychology	Law	Ethics
PHYSICS	CHEMISTRY	BIOLOGY	MATHEMATICS		LOGIC	PHILOSOPHY	

We suspect that pushes to integrate and synthesize will continue to be met by pulls to focus and specialize within both traditional disciplines and new, spin-off fields of study. For example, the areas of exposure assessment, infrastructure security, global change science, information systems, and biotechnology all could be seen as spin-offs of risk analysis. This dual process of integration and spin-off is healthy. These pulls and pushes can lead to new and deeper knowledge, as well as more insightful and pertinent solutions to the many pressing challenges that require effective applications of the risk sciences. We hope that this volume provides fodder and motivation for researchers and practitioners who need both to "delve deeper" and to "reach wider" to solve their problems.

3. RATIONALE AND GENESIS FOR THIS COLLECTION

While much attention gets focused on specific risks at specific times, or an array of risks as seen from one discipline, relatively little attention has been paid to comprehensive interdisciplinary perspectives on the relationship between risk issues and the broader societies in which they exist. Even less attention has been paid to exploring issues of the state of development and practice regarding risk issues from these different perspectives.

This book provides a characterization of the state of knowledge, research, and practice in the key technical and social disciplines that contribute to risk analysis. Our emphasis is largely on risk analysis as applied to health, safety, and environment questions, although the book also has relevance for diverse topics ranging from the protection of critical infrastructures such as computer systems to insurance for natural and man-made hazards. These disciplines address the performance of engineered systems, human health and the environment, probabilistic assessment, risk perception and communication, economic valuation of outcomes, and social and political mechanisms and institutions for risk management.

Over three days in June 2000, the Society for Risk Analysis (SRA) held an international symposium at Airlie House, outside Washington, DC. One purpose of the symposium was to begin the process of assessing the current state of risk analysis from many different disciplinary perspectives. A second purpose was to foster informed discussion that considers the state of risk analysis and its contributions to governance in various parts of the world. A third purpose was to lay the groundwork for a series of world congresses on risk issues.

As part of that effort, the U.S. National Science Foundation provided support for a series of commissioned papers by some of the world's leading experts on risk issues. Topics were nominated and refined by the organizing committee, and selected authors were commissioned to prepare chapters that would be unusual in terms of the breadth of perspectives

they addressed. The vision was to sponsor a series of papers that offered historical, social, technical, and policy-oriented insights about key aspects of how risk analysis contributes to governance. Initial drafts served as the starting point for group discussions at the symposium and afterwards. All the chapters were subsequently peer reviewed and underwent a series of revisions.

The ten papers resulting from this process together comprise an informed viewpoint on the recent history, current state, and future outlook for the field of risk analysis, and its contributions to private and public decision making. The chapters place particular emphasis on risk analysis within the context of national and international governance. Here the term "risk analysis" collectively refers to risk assessment, risk management, and risk communication. The authors of these chapters include prominent risk scholars from North America, Europe, and Asia, including several past presidents of the SRA.

4. CONTENTS OF THIS BOOK

The papers are presented in three major groupings. The first set addresses the fundamental character of risk, including its inherent variability in natural and engineered systems (Chapter 2 by Dale Hattis); the relationship among system components and whole systems in biological dose-response (Chapter 3, Lorenz Rhomberg); the character and characterization of rare and extreme events (Chapter 4 by Vicki Bier and coauthors); and the social elements of equity and justice that are critical components of risk issues (Chapter 5 by Mary English).

The second section of the book explores advances in methods for risk assessment and analysis. These include a paper by Alison Cullen and Mitchell Small on qualitative and quantitative methods for uncertainty analysis (Chapter 6); an examination of methods for valuing risk by Robin Gregory (Chapter 7); and an assessment of methods for cost-benefit and cost-effectiveness analysis by John Graham, Per-Olov Johansson, and Junko Nakanishi (Chapter 8).

This chapter provides a transition to the final section of the book addressing approaches and needs for risk management. Here Ortwin Renn explores new methods for promoting public input and participation in risk management decisions (Chapter 9). Joyce Tait and Ann Bruce examine institutions for addressing multinational and global risks (Chapter 10), and Michinori Kabuto, Saburo Ikeda, and Iwao Uchiyama provide insights on the special challenges of managing both traditional and newly emerging risks in the developing nations of Asia (Chapter 11).

The concluding Chapter 12 is written by Rae Zimmerman and Robin Cantor, two of the key organizers of the Airlie House symposium that provided the impetus for this book. In their chapter, the authors pull together

integrative themes from the papers and the discussion that occurred at the meetings as these chapters were developed.

This collection does not cover all issues in the diverse and growing field of risk analysis.[2] It does however attempt to highlight the key elements at the forefront of risk theory and application that will most influence directions in the field in coming years. The collection shows how risk analysis has evolved from the largely technical disciplines of systems reliability and health sciences to encompass the full range of political, legal, economic, and social considerations that must be addressed when understanding technical systems and their role in society.

It is hoped that the chapters in this book will form the intellectual basis for future world congresses on risk, and for the emergence of an integrated, multidisciplinary interpretation of risk analysis that could be endorsed by the many professional societies devoted to risk issues. With this book, we seek to move beyond a series of single-discipline perspectives regarding risk issues to an interdisciplinary and multidisciplinary integration of perspectives on risk. Real-world problems do not respect disciplinary boundaries. They require integration and the ability to find understanding through the exploration of linkages, multiple structures, and multiple perspectives.

Notes

1. It indicates that measures based on the precautionary principle should be "[p]roportionate to the chosen level of protection; non-discriminatory in their application; consistent with similar measures already taken; based on an examination of the potential benefits and costs of action (or lack of it); subject to review in light of new scientific data; and capable of assigning the burden of proof for producing a more comprehensive risk assessment."
2. The events of September 11, 2001, have made it clear that if risk analysis is to be useful for society, it must be able to address new, unexpected, and even unimagined threats. While the chapters in this book were commissioned and completed before the terrorist attacks of September 11, the concepts and applied perspectives presented here are applicable to understanding and eventually managing risks of terrorism. As a starting point for understanding the role of risk analysis in addressing terrorism, we can turn to the writing of several of the past presidents of the Society for Risk Analysis. The society's journal *Risk Analysis* asked several of the former presidents of the society to prepare short perspective pieces on the potential application of risk analysis to managing terrorist threats. These short papers were published in the June 2002 edition of the journal, in a special issue titled: *Assessing the Risks of Terrorism: A Special Collection of Perspectives Articles by Former Presidents of the Society for Risk Analysis*. The themes and key points raised in those papers provide some perspectives on what risk analysis has to offer, and what key questions must be addressed, in providing analytical insight into decisions about managing terrorist threats.

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