Integrated Disaster Risk Management

About the Series

Just the first one and one-half decades of this new century have witnessed a series of large-scale, unprecedented disasters in different regions of the globe, both natural and human-triggered, some conventional and others quite new. Unfortunately, this adds to the evidence of the urgent need to address such crises as time passes. It is now commonly accepted that disaster risk reduction (DRR) requires tackling the various factors that influence a society's vulnerability to disasters in an integrated and comprehensive way, and with due attention to the limited resources at our disposal. Thus, integrated disaster risk management (IDRiM) is essential. Success will require integration of disciplines, stakeholders, different levels of government, and of global, regional, national, local, and individual efforts. In any particular disaster-prone area, integration is also crucial in the long-enduring processes of managing risks and critical events before, during, and after disasters.

Although the need for integrated disaster risk management is widely recognized, there are still considerable gaps between theory and practice. Civil protection authorities; government agencies in charge of delineating economic, social, urban, or environmental policies; city planning, water and waste-disposal departments; health departments, and others often work independently and without consideration of the hazards in their own and adjacent territories or the risk to which they may be unintentionally subjecting their citizens. Typically, disaster and development tend to be in mutual conflict but should, and could, be creatively governed to harmonize both, thanks to technological innovation as well as the design of new institutions.

Thus, many questions on how to implement integrated disaster risk management in different contexts, across different hazards, and interrelated issues remain. Furthermore, the need to document and learn from successfully applied risk reduction initiatives, including the methodologies or processes used, the resources, the context, and other aspects are imperative to avoid duplication and the repetition of mistakes.

With a view to addressing the above concerns and issues, the International Society of Integrated Disaster Risk Management (IDRiM) was established in October 2009.

The main aim of the IDRiM Book Series is to promote knowledge transfer and dissemination of information on all aspects of IDRiM. This series will provide comprehensive coverage of topics and themes including dissemination of successful models for implementation of IDRiM and comparative case studies, innovative countermeasures for disaster risk reduction, and interdisciplinary research and education in real-world contexts in various geographic, climatic, political, cultural, and social systems.

More information about this series at http://www.springer.com/series/13465

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ISSN 2509-7091 ISSN 2509-7105 (electronic)
Integrated Disaster Risk Management
ISBN 978-981-10-2566-2 ISBN 978-981-10-2567-9 (eBook)
DOI 10.1007/978-981-10-2567-9

Library of Congress Control Number: 2016961813

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

To our families

Foreword to the IDRiM Book Series

In 2001, the International Institute for Applied Systems Analysis (IIASA) and the Disaster Prevention Research Institute (DPRI) joined hands in fostering a new, interdisciplinary area of integrated disaster risk management. That year, IIASA and DPRI initiated the IIASA–DPRI Integrated Disaster Risk Management Forum Series, which continued over 8 years, helping to build a scholarly network that eventually evolved into the formation of the International Society for Integrated Disaster Risk Management (IDRiM Society) in 2009. The launching of the society was promoted by many national and international organizations.

The volumes in the IDRiM Book Series are the continuation of a proud tradition of interdisciplinary research on integrated risk management that emanates from many scholars and practitioners around the world. In this foreword, we briefly summarize the contributions of some of the pioneers in this field. We have endeavored to be inclusive but realize that we have probably not identified all those worthy of mention. This foreword is not meant to be comprehensive but rather indicative of major contributions to the foundations of IDRiM. This research area is still in a continuous process of exploration and advancement, several of the outcomes of which will be published in this series.

Japan

Disaster Prevention Research Institute

The idea of framing disaster prevention in risk management terms was still embryonic even among academics in Japan when Kobe and its neighboring region were shaken by the Great Hanshin–Awaji Earthquake (GHQ) in 1995. For example, Okada (1985) established the importance of introducing a risk management approach to reduce flood and landslide disaster risks. Additionally, it was not until late 1994 that the Disaster Prevention Research Institute (DPRI) of Kyoto University

Table 1 Conventional disaster plan vs. 21st century integrated disaster planning and management

Reactive	Proactive
Emergency and crisis management	Risk mitigation plus preparedness approach
Countermeasure manual approach	Anticipatory/precautionary approach
Pre-determined planning (if known events)	Comprehensive policy-bundle approach
Sectoral countermeasure approach	Adaptive management approach
Top-down approach	Bottom-up approach

had reorganized to add a new cross-disciplinary division of Sogo Bosai, or "integrated disaster management."

The new division of DPRI undertook a strong initiative among both academics and disaster prevention professionals to substantiate what is meant by integrated disaster management and to communicate to society why it is needed and how it helps. Many of these efforts were based on evidence and lessons learned from the GHQ. Japan's disaster planning and management policy changed significantly thereafter. Table 1 contrasts the approaches before and after that cataclysmic event. The current approach stresses strategies that are proactive, anticipatory, precautionary, adaptive, participatory, and bottom-up. The rationale is that governments in Japan had been found to be of relatively little help immediately after a high-impact disaster. Lives in peril had more often been saved by the actions of individuals and community residents than by official governmental first responders.

To understand a significant change in disaster planning and management in Japan, one must understand the contrasts among Kyojo ("neighborhood or community self-reliance"), Jijo ("individual or household self-reliance"), and Kojo ("government assistance"). Realizing limitations in the government's capacity after a large-scale disaster, Japan has shifted more toward increasing both Kyojo and Jijo self-reliance roles, and to depend less on the former, which in the past was the major agent to mitigate disasters.

One of the additional lessons learned after the 1995 disaster was to address the need for a citizen-led participatory approach to disaster risk reduction before disasters, as well as for disaster recovery and revitalization after disasters.

International Collaboration

In 2001, the International Institute for Applied Systems Analysis (IIASA) and DPRI started to join hands in fostering a new disciplinary area of integrated disaster risk management. That year, IIASA and DPRI agreed to initiate the IIASA–DPRI Integrated Disaster Risk Management Forum Series. Eight annual forums were held under this initiative, helping to build a scholarly network that eventually evolved into the formation of the IDRiM Society in 2009.

These activities, which were designed to be cross-disciplinary and international, have seen synergistic developments. Japan's accumulated knowledge, led by DPRI, became merged with IIASA's extensive expertise and became connected with inputs from the USA, the UK, other parts of Europe, Asia, and other countries and regions.

Major Research Contributions

Among many, the following contributions merit mention:

Conceptual Models Developed and Shared for Integrated Disaster Risk Management Okada (2012) proposed systematic conceptual models for understanding the Machizukuri (citizen-led community management) approach. Figure 1 illustrates the multilayer common spaces (an extension of the concept of infrastructure) for a city, region, or neighborhood community as a living body (Okada 2004). This conceptual model has been found to be useful to address multilayer issues of integrated disaster risk management at various scales. For example, in the context of this diagram, Machizukuri is more appropriately applied on a neighborhood community scale rather than on a wider scale, such as a city or region. Applied to a neighborhood community in the context of a five-storied pagoda model, it starts with the fifth layer (daily life), followed by the fourth (land use and built environment) and the third (infrastructure). By comparison, Toshikeikaku (urban planning) focuses mainly on the fourth and third layers. Another point of contrast is that Machizukuri requires citizen involvement to induce attitudinal or behavioral change, while this issue is not essential for Toshikeikaku.

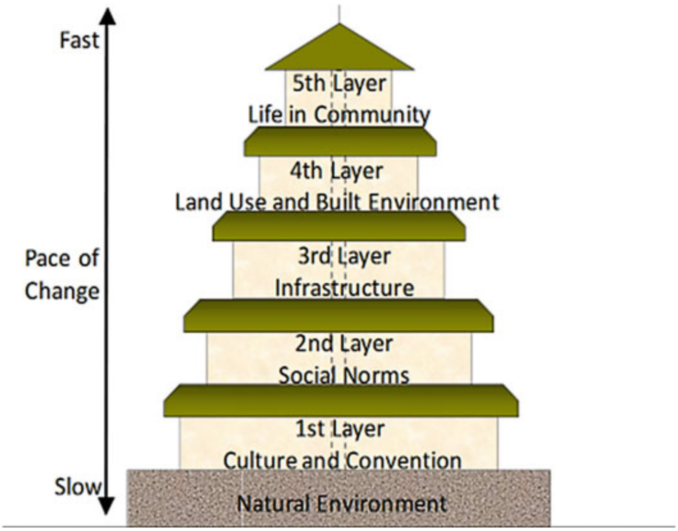

Fig. 1 Five-storied pagoda model (Source: Okada 2006)

Economic Modeling of Disaster Damage/Loss and Economic Resiliency Extensive research has been carried out by Tatano et al. (2004, 2007) and Tatano and Tsuchiya (2008) to model and analyze economic impacts of disruptions to lifelines and infrastructure systems caused by a large-scale disaster. For instance, simulating a hypothetical Tokai–Tonankai earthquake in Japan, a spatial computable general equilibrium (SCGE) model was constructed to integrate a transportation model that can estimate two types of interregional flows of freight movement and passenger trips. Kajitani and Tatano (2009) investigated a method for estimating the production capacity loss rate (PCLR) of industrial sectors damaged by a disaster to include resilience among manufacturing sectors. PCLR is fundamental information required to gain an understanding of economic losses caused by a disaster. In particular, this paper proposed a method of PCLR estimation that considered the two main causes of capacity losses as observed from past earthquake disasters, namely, damage to production facilities and disruption of lifeline systems. To achieve the quantitative estimation of PCLR, functional fragility curves for the relationship between production capacity, earthquake ground motion, and lifeline resilience factors for adjusting the impact of lifeline disruptions were adopted, while historical recovery curves were applied to damaged facilities.

Disaster Reduction-Oriented Community Workshop Methods The Cross-Road game developed by Yamori et al. (2007) proceeds as follows. During a game session, a group of five players read 10–20 episodes that are presented on cards one at a time. Each episode is derived from extensive focus group interviews of disaster veterans of the GHQ and describes a severe dilemma that the veterans of Kobe actually faced. Individual players are required to make an either/or decision (i.e., yes or no) between two conflicting alternatives in order to deal with the dilemma.

The Yonmenkaigi System Method (YSM) by Okada et al. (2013a, b) is a unique participatory decision- and action-taking workshop method. It is composed of four main steps: conducting a strength–weakness–opportunity–threat (SWOT) analysis, completing the Yonmenkaigi chart, debating, and presenting the group's action plan. The YSM is an implementation- and collaboration-oriented approach that incorporates the synergistic process of mutual learning, decision-making, and capacity building. It fosters small and modest breakthroughs and/or innovative strategy development. The YSM addresses issues of resource management and mobilization, as well as effective involvement and commitment by participants, and provides a strategic communication platform for participants.

Collaborative Research and Education Schemes Based on the Case Station-Field Campus (CASiFiCA) Scheme Acknowledging that diverse efforts have been made for disaster reduction, particularly in disaster-prone areas (countries), many professionals have been energetically and devotedly engaged in field work to reduce disaster risks. They recognize also that more community-based stakeholder-involved approaches are needed. A crucial question arises as to why we cannot

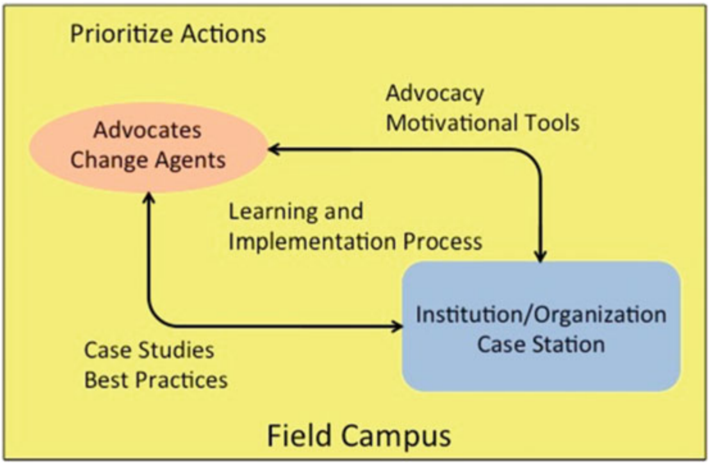

Fig. 2 Case Station-Field Campus scheme

conduct field work more creatively. One promising solution might be the CASiFiCA scheme originally proposed by Okada and Tatano (2008). As diagrammed in Fig. 2, the CASiFiCA scheme is characterized by a set of local case stations and field campuses and their globally networked linkages that are expected to operate synergistically to achieve the following objectives: promotion of IDRiM education at all levels, multilateral knowledge sharing and knowledge creation, and implementation of knowledge and gaining knowledge from implementation.

Europe

Integration via Regulation: European Union Experience

The integrated risk management of technological and natural hazard-triggered technological accidents (known as Natechs) has been a major theme addressed during the IIASA–DPRI Integrated Disaster Risk Management Forum Series since the first forum in 2001. In 2007 and 2008, the forum was hosted by the Major Accident Hazards Bureau at the Joint Research Centre of the European Commission in Italy, further strengthening the need for integration across natural and technological disaster risk management.

Integration was not (and, generally, still now *is not*) a self-evident concept when the first European Union Conference on Natural Risk and Civil Protection was launched in 1993, in Belgirate, Italy (Horlick-Jones et al. 1995). As the rapporteur-general wondered:

> Whilst one objective of the conference was to encourage dialogue between researchers and practitioners, it quickly became clear that the group structure was rather more complex than simply comprising natural scientists and civil protection experts. The 'tribes' present included natural hazard scientists, civil protection theorists – mostly social, behavioural and management scientists, industrial risk specialists, protection administrators and civil protection practitioners. The hazards and civil protection 'community' included a number of professional groups with distinct traditions and cultures. The term 'tribe' is used in an attempt to capture some sense of how strong is this divide.

Communication between the groups was rather difficult and most surprising for people not directly involved in scientific disputes. The discovery of the strong opposing views existing between different research directions within the same "hard" discipline (e.g., in seismology the debate on earthquake predictability) made even the agreement on an agenda for the conference challenging. These difficulties were unanticipated, because previous events concerning industrial hazards—organized in a similar manner on emergency planning (Gow and Kay 1988) and risk communication (Gow and Otway 1990)—found a rather cooperative atmosphere.

Despite the fact that the organization of the conference involved three directorate-generals of the European Commission (Research and Education, Environment, and Joint Research Center), natural hazards activities were not covered by an institutional legal basis. Also, at the time, there was no mutual assistance/compensation agreement in the case of a natural disaster, but only an initial exchange of experiences among emergency response services of EU member states. On the other hand, the existence of a sound regulatory process that obliged the different actors to be involved in the risk management framework was the reason for the successful cooperation in the latter mentioned events.

The new regulatory process for chemical accident prevention is an example. The process was reactive rather than anticipatory. It was triggered by a number of major accidents—e.g., the dioxin release at Seveso (Italy) in 1976 and the explosion at Flixborough (UK) in 1974. These had in common the features that local authorities did not know what chemicals were involved and in what quantities. They did not know enough about the processes to understand what chemicals/energy could be produced or released under accident conditions, and there was a general lack of planning for emergencies. Given this background, the first 1982 Seveso I Directive (82/501/EEC) was largely concerned with the generation and the control of an adequate and sufficient information flow among the different actors in the risk management process (Otway and Amendola 1989). This covered industrial activities that handle hazardous materials and introduced an integrated risk management scheme with identification of the actors and their obligations (control/licensing authorities—operators) or rights to know (the public). It requires that potential major accidents involving hazardous materials be identified, adequate safety measure be taken to prevent them, and on-site emergency plans be implemented. The competent authorities (CAs) have to control the adequacy of such measures and provide for external emergency plans. The public should be "actively" informed of the safety measures and how to behave in the event of an accident. The operator is required to report any major accident to the CAs, and the CAs have to notify the European Commission, which keeps a register of accidents so that member states can benefit from this experience for the purposes of prevention of future accidents.

The Seveso I Directive was the background for further discussions at the international level, such as the Organisation for Economic Co-operation and Development (OECD) and the United Nations Economic Commission for Europe (UNECE), which resulted in further recommendations and conventions on trans-boundary effects related to major accidents (United Nations 1992).

Reacting to the tragedy in Bhopal, India and other issues identified during its implementation, the need for a revision was identified, particularly concerning the lack of provisions for land-use planning (De Marchi and Ravetz 1999), resulting in the Seveso II Directive (96/82/EC). It completed the transparency process, beginning with the obligation of disseminating information to the public on how to behave in case of an accident, and, in a relatively short time, changed the "secrecy" in most countries surrounded by chemical risks into unprecedented transparency (for the "evolutionary construction of a regulatory system" for an extensive discussion of all Seveso II requirements, see Amendola and Cassidy 1999). It established that the public should be consulted for land-use planning and emergency planning with respect to accident risks and therefore should be more directly involved in risk management decisions. Furthermore, the safety report and accident reporting systems became accessible by the public.

The Seveso II Directive focused much more on the socio-organizational aspects of the control policy:

- The concept of an industrial *establishment* was introduced, characterized by the presence of dangerous substances. The focus is on the interrelations among installations within such an establishment, especially those related to organization and management. Further, attention is given to situations liable to provoke so-called *domino effects* between neighboring establishments. This led to integrated assessments of industrial areas. Furthermore, it implicitly called for the analysis of external threats, such as natural hazards.
- The socio-organizational aspects of an establishment were strongly affected by the introduction of the obligation for a major accident prevention policy (MAPP), to be implemented by means of safety management systems (SMS) (Mitchison and Porter 1999). These provisions were introduced after the awareness that most of the major accidents of which the commission was notified over the years under the major accident reporting system (MARS) had root causes in faults of the management process (Drogaris 1993).
- The introduction of the obligation for a *land-use planning policy* with respect to major accident hazards has had important socio-organizational consequences, as a broader body of authorities, especially those dealing with local urban planning, are becoming involved in decisions about the compatibility of new development with respect to existing land use (Christou et al. 1999). This has been integrated with the requirement that the public shall be consulted in the decision-making process. This has also led to integration of planning policies with respect to other kinds of hazards, such as natural ones, assuring that appropriate distances are

kept between establishments, residential areas, and areas of particular "natural sensitivity."

- The provisions for *emergency planning* and *public information* have been reinforced, as the *safety report* becomes a public document, and the public must be consulted in the preparation of emergency plans.

The Seveso II Directive also approached management as a continuous process, because it did not limit the regulatory action to providing a license or a permit to operate. Instead it assigned the obligation to the operator to adopt management systems as a continuous process for feedback in the procedures relating to operating experience and managing the changes over time. Also, land-use planning addresses not only "siting" a new establishment but also considers the compatibility of major changes with the existing environment as well as the control of urbanization around an establishment. Furthermore, it promoted common efforts among authorities, operators, and risk analysts to improve the risk assessment procedures and achieve better risk governance processes (Amendola 2001).

As mentioned above, the Seveso II Directive called for the analysis of external hazards as part of the hazard assessment process. Both domino effects and land-use controls are of particular importance when addressing the risk reduction of chemical accidents triggered by external natural hazard events (Natechs). In fact domino effects may be more likely during natural disasters than during normal plant operation (Cruz et al. 2006; Lindell and Perry 1997). Their likelihood will depend on the proximity of vulnerable units containing hazardous substances, and the consequences will undoubtedly increase with the proximity of residential areas. The European Commission published guidelines to help member states fulfill the requirements of the Seveso II Directive (see Papadakis and Amendola 1997; Mitchison and Porter 1998; Christou and Porter 1999). However, the guidelines do not provide specific actions or methodologies that should be taken to prevent, mitigate, or respond to Natechs (Cruz et al. 2006).

In 2012, the European Commission published the Seveso III Directive, which amended and subsequently repealed the Seveso II Directive. The major changes included in the Seveso III Directive included strengthening of a number of areas such as public access to information and standards of inspections. Furthermore, the latest amendment now explicitly addresses Natech risks and requires that environmental hazards, such as floods and earthquakes, be routinely identified and evaluated in an industrial establishment's safety report (Krausmann 2016).

International Institute for Applied Systems Analysis (IIASA)

"Risk" has been part of IIASA's activity profile since the institute's foundation. This theme is critical, as the prospect of unintended consequences from technological, environmental, and social policies continues to stir intense debates that shape the future of societies across the world. Relying on probability calculations, risk became a theoretical focus designed to bolster a scientific, mathematically based approach toward uncertainty and risk management.

Early controversies in the 1970s and 1980s on nuclear power, liquid natural gas storage, and hazardous waste disposal—all early research topics at IIASA—made clear to the expert community, however, that probabilistic calculations of risk, although essential to the debates, are not sufficient to settle issues of public acceptance. In response, IIASA has pioneered research on risk perception (Otway and Thomas 1982), objective versus subjective assessments (Kunreuther and Linnerooth 1982), systemic cultural biases (Thompson 1990), and risk and fairness (Linnerooth-Bayer 1999).

As a critical part of this history, IIASA is widely recognized for its advances in stochastic and dynamic systems optimization (e.g., Ermoliev 1988), treating endogenous uncertainty and catastrophic risks in decision-making processes (reviewed in Amendola et al. 2013) and advancing statistical methods for probabilistic assessment (e.g., Pflug and Roemisch 2007). The hallmark of IIASA's risk research is the integration of these multiple strands of mathematical and social science research.

One important in-house model taking an integrated perspective in the RISK program at IIASA is the so-called Catastrophe Simulation (CatSim) Model, which focuses on the government and its fiscal risk in the face of natural disaster events. It is a mainstay of the program's methodological and policy research and was first developed to aid public officials in developing countries to assess catastrophic risks from natural hazards and analyze options to enhance their country's financial resiliency. The model takes a "systems approach" by integrating catastrophe risk modeling with financial and economic modeling. It enables users to explore the impact of traditional and novel financial instruments, including reinsurance and catastrophe bonds, in terms of the costs of reducing the risk of a financing gap. CatSim has proven useful in other contexts as well, e.g., for allocating climate adaptation and development funds to support disaster resilience in the most vulnerable countries. Based on the model framework, assessed exposure and financial vulnerability to extreme weather events on the global scale can be performed as well (Hochrainer-Stigler et al. 2014).

Beyond modeling, IIASA has pioneered the exploration of novel financing instruments to provide safety nets to vulnerable communities and governments facing climate risks (Linnerooth-Bayer and Amendola 2000). These instruments now feature prominently on the agendas of development organizations and NGOs, and they are also gaining attention in the climate change adaptation community (Linnerooth-Bayer and Hochrainer-Stigler 2015). In an early influential policy paper, IIASA scientists argued that donor-supported risk-transfer programs, some based on novel instruments, would leverage limited disaster-aid budgets and free recipient countries from depending on the vagaries of post-disaster assistance (Linnerooth-Bayer et al. 2005).

As a final mention, IIASA's contributions to integrated disaster risk management have included the design and implementation of new forms of bottom-up governance, most notably stakeholder processes which co-design policy options with experts and explicitly recognize large value differences.

The USA

Multidisciplinary Center for Earthquake Engineering Research

The National Center for Earthquake Engineering Research (NCEER) was established at the State University of New York at Buffalo in 1986, with funding from the US National Science Foundation (NSF), the state of New York, and industrial partners. NCEER's original vision focused on multidisciplinary research and education aimed at reducing earthquake losses. Although the Center's main priority was to support research in structural, civil, and geotechnical engineering, it also provided funding for research in the fields of economics, urban planning, regional science, and sociology. Despite NCEER's ambitious vision, much of the research conducted during the 10-year period of initial grant support remained discipline-specific, although with the passage of time there was greater integration across disciplines, particularly in areas such as earthquake loss estimation, which required collaborative approaches.

When NCEER leaders decided to enter a new competition for NSF funding in the mid-1990s, there was general agreement that investigators should step up their multidisciplinary collaborative efforts based on an understanding that earthquake risk reduction and risk management require contributions from a range of areas of expertise beyond traditional engineering fields. This was made explicit when the leadership decided to change the Center's name to the Multidisciplinary Center for Earthquake Engineering Research (MCEER). Participation in multidisciplinary teams was strongly encouraged as MCEER investigators increasingly tackled problems that were beyond the scope of individual disciplines. Experts in remote sensing and in structural engineering worked together on the development of building inventories and, later on, rapid post-earthquake damage assessment methods using remotely sensed data. Engineers, economists, and sociologists worked on improving earthquake loss estimation methods, focusing, for example, on estimating potential damage to urban lifeline systems as well as resulting direct and indirect economic losses. Collaborating teams developed earthquake recovery models and explored the economic, political, and institutional obstacles that stand in the way of adopting and implementing risk reduction policy. Researchers studied hospitals both as critical physical systems and as organizations. A multidisciplinary group consisting of engineers, policy experts, and decision scientists developed decision-support tools designed to help facility owners make informed choices about alternative seismic risk reduction measures.

In the late 1990s, another team of researchers from various fields began a series of projects focused on the conceptualization and measurement of earthquake (and general disaster) resilience. Recognizing that resilience itself is a multidisciplinary and even a transdisciplinary concept, researchers surveyed a wide range of studies in fields ranging from ecology to psychology, identified common concepts and indicators, and developed one of the first frameworks that applied the resilience concept to natural hazards. One early product resulting from that collaboration was the article "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of

Communities" (Bruneau et al. 2003). Authors of that paper represented the fields of civil, geotechnical, and structural engineering, operations research, economic geography, decision science, and sociology.

These successful collaborations were the result of several factors. Research activities were problem focused, and the researchers involved recognized that the earthquake problem is multidimensional. Methodological tools such as geographic information systems were useful in bringing about integration across disciplines. The longevity of NCEER and MCEER was also important; long-term funding made it possible for investigators to engage with one another over prolonged periods. This also meant that over time, researchers came to better understand and appreciate the approaches and methods employed by their counterparts in other disciplines. Additionally, the intent of the funding source was a significant influence; NSF made it clear that it was looking for research that was capable of overcoming disciplinary silos.

A major example of integrated research at MCEER was the first New Madrid (Earthquake Zone) electricity lifeline case study (Shinozuka et al. 1998), which focused on the site of the largest earthquake to strike North America in its recorded history. The study team was composed of engineers, geographic information scientists, economists, regional scientists, planners, and sociologists. They addressed the complexity of the interaction of various systems in the Memphis Tennessee Metropolitan Area. This included the vulnerability of the lifeline network, business response to physical damage and production disruption, estimation of direct and indirect losses in the region and throughout the USA, and policy analysis and implementation. At the core of the research were models of economic, social, and spatial interdependence, such as input–output analysis, multisector mathematical programming, and social accounting matrices (all precursors of the now state-of-the-art approach of computable general equilibrium analysis). This research was performed around the same time as the development of FEMA's loss estimation software tool HAZUS (FEMA 1997, 2016), which was another example of an integrated assessment model (see also Whitman et al. 1997). The capabilities included in HAZUS had to be simplified in order to be incorporated into a decision-support system that could be used by a wide spectrum of emergency managers and analysts on a desktop PC. In contrast, the MCEER research was intended to advance the state of the art in improving the scope and accuracy of hazard loss estimation. As such, it proved valuable in future extensions and upgrades of HAZUS and informed other research and public and private decision-making. One of its major points was the prioritization of electricity service restoration according to various societal objectives such as minimizing lost production and employment. As one of the study authors noted: "Not taking advantage of such opportunities results in an outcome as devastating as if the earthquake actually toppled the buildings in which the lost production would've originated" (p. xvii).

MCEER was directed by Masanobu Shinozuka, George Lee and Michel Bruneau. Researchers who contributed to the integration of various disciplines under its umbrella, in addition to the directors, included Barclay Jones, Kathleen Tierney, Tom O'Rourke, Bill Petak, Charles Scawthorn, Detlof von Winterfeldt, Stephanie Chang, Ron Eguchi, and Adam Rose. Two sister centers of MCEER were established with NSF Funding in the mid-1990s: the Pacific Earthquake Engineering Center (PEER), headquartered at the University of California, Berkeley, with a focus on performance-based engineering; and the Mid-American Earthquake Center (MAE), headquartered at the University of Illinois, Urbana, with a focus on a multi-hazard approach to engineering.

Natural Hazards Center

The Natural Hazards Research and Applications Information Center at the University of Colorado Boulder—now called the Natural Hazards Center (NHC)—was founded in 1976 by Gilbert F. White, a geographer, and J. Eugene Haas, a sociologist. Center activities were built upon the foundation that White and his collaborators from many disciplines had already established, as outlined in the books *Natural Hazards: Local, National, and Global* (White 1976) and *Assessment of Research on Natural Hazards* (White and Haas 1975). In the *Assessment*, White and Haas argued that efforts to prevent and reduce disaster losses relied far too much on technological approaches, without taking into account research in the social sciences. Their position was that such research could offer important insights into societal responses to hazards and disasters while also shedding light on whether technological approaches aimed at reducing losses were likely to produce their intended outcomes. Early research assessments focused on "adjustments" to hazards that communities and societies can adopt either singly or in combination: relief and rehabilitation, insurance, warning systems, technological adjustments such as protective works, and land-use management. In the view of the founders, a key task for researchers was to better understand the conditions under which particular adjustments would be adopted and their subsequent impact on disaster losses. Early in its history, the NHC produced its own series of books, monographs, and special reports, many of which focused on findings from US National Science Foundation-sponsored research carried out by investigators in the social, economic, and policy sciences. That practice was discontinued as specialized journals began to proliferate and an increasing number of academic and commercial publishers began to show an interest in publishing research monographs and textbooks in the disaster field.

From its inception, the NHC has had a dual mission. First, it serves as a clearinghouse and information provider for social science research on hazard mitigation, preparedness, response, and recovery, again with an emphasis on alternative adjustments to hazards. The idea of an information clearinghouse arose out of recognition of the difficulties associated with getting research applied in real-world settings. Clearinghouse activities include the production and distribution of the NHC newsletter, the *Natural Hazards Observer,* library and information services, and the annual NHC workshop, which has grown over the years. From the beginning, the annual workshop was designed to bridge communication gaps among researchers and graduate students from a variety of physical, social science, and engineering disciplines, government decision-makers, and emergency management practitioners. The NHC also administers a small-grant quick-response research program that enables researchers and students to go into the field immediately following disasters and then publishes the results of those studies. Second, NHC faculty and graduate students conduct their own research, with support from the National Science Foundation and other sponsors.

Both the activities associated with the production of the original *Assessment* and subsequent center activities involved the training of young researchers from a variety of social science disciplines. The first generation of center graduate trainees included well-known researchers such as Harold Cochrane (economics); Eve Gruntfest and John Sorensen (geography); Dennis Mileti, Robert Bolin, and Patricia Bolton (sociology); and Michael Lindell (psychology).

During the 1990s, the NHC conducted the second assessment of research on natural hazards under the leadership of director Dennis Mileti. The second assessment, which involved contributions from approximately 120 researchers, students, agency personnel, and other public officials, resulted in five books and numerous published articles and reports, again reflecting a range of social science perspectives (e.g., Mileti 1999). Like its predecessor, the second assessment provided training for another generation of researchers.

Since the early 2000s, the NHC has been increasingly involved in multidisciplinary research projects. Examples include collaborations with computer scientists and other social scientists on new technologies for emergency management, with economists on post-disaster business and economic resilience, with researchers from the National Center for Atmospheric Research on warning systems, with investigators from a number of social science disciplines on homeland security-related issues, with engineering researchers on recovery from the 2004 Indian Ocean tsunami, and with engineers, earth scientists, and policy scientists on the problem of induced earthquakes.

The NHC has served under the able directions of its founders and successor directors geographer William Riebsame (now William Travis), sociologists Dennis Mileti and Kathleen Tierney, and, beginning in January 2017, sociologist Lori Peek.

Center for Risk and Economic Analysis of Terrorism Events (CREATE)

Soon after the September 11, 2001, terrorist attacks in the USA, the nation's National Academy of Sciences performed an assessment of how the scientific community, broadly defined, could contribute to reducing the terrorist threat. One of their recommendations was to establish university centers of excellence (COEs) in research and teaching. The first of these was the Center for Risk and Economic Analysis of Terrorism Events (CREATE), established in 2004 and headquartered at the University of Southern California but being a geographically distributed entity with more than a dozen affiliates at other universities and research organizations throughout the USA and some overseas. These faculty affiliates came from the

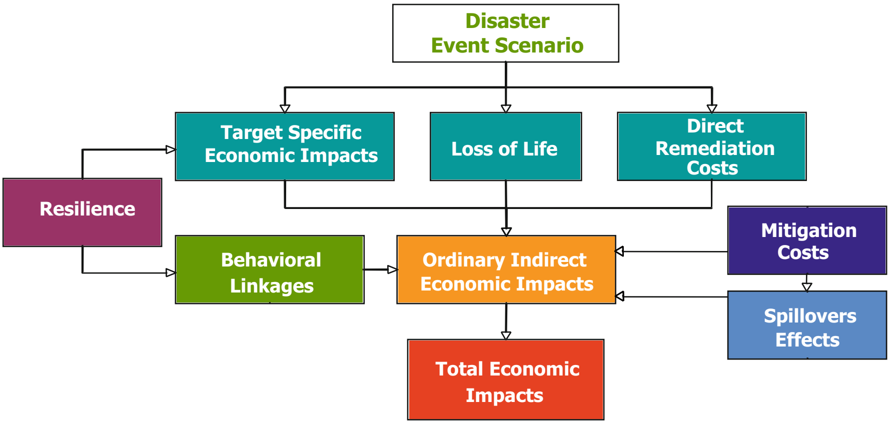

Fig. 3 CREATE economic consequence analysis framework

disciplines of decision analysis, risk analysis, psychology, economics, business, regional science, planning, operations research, public policy, public administration, public health, computer science, and communications. Founding directors were Randolph Hall and Detlof von Winterfeldt; subsequent directors were Stephen Hora and Ali Abbas, with von Winterfeldt returning after serving as director of IIASA.

Despite the restrictive nature of its title, CREATE was intended to be an "all hazards" center, although research in areas other than terrorism has been in the minority. CREATE was initially based on three themes: risk assessment, economic consequence analysis (and related topics in economics), and risk management. Risk communication was later inserted into the base of the framework. Much of the research has been multidisciplinary and some of it interdisciplinary.

One of the major interdisciplinary contributions was the development of a comprehensive framework for economic consequence analysis (ECA), as depicted in Fig. 3. This framework expanded ordinary economic impact analysis and hazard loss estimation substantially, first, by incorporating resilience. Building on his research at MCEER, Rose refined the concept of economic resilience into its static and dynamic versions, which are analyzed in the context of business interruption (BI), and focused the research on the demand, or customer, side, in terms of how businesses, households, and government agencies utilize remaining resources more efficiently and recover more quickly (see, e.g., Rose 2009 and this volume in the IDRiM Book Series). CREATE researchers performed many case studies using the operational metric that resilience effectiveness of any given strategy was equal to the averted BI as a proportion of the total potential BI in the absence of implementing the strategy. A major example was the finding that 72 % of the potential BI losses stemming from the destruction of the World Trade Center were averted by the rapid relocation of its business and government tenants (Rose et al. 2009).

Subsequent research has established the basis of an economic resilience index based on actionable variables (Rose and Krausmann 2013).

Another innovation was to incorporate "behavioral linkages," primarily off-site, post-disaster responses caused by such phenomena as the social amplification of risk and stigma effects. Many of these reactions are related to fear, as exemplified by the large BI following 9/11 from the decline of airline travel and related tourism (von Winterfeldt et al. 2006; Rose et al. 2009). A more in-depth and integrated analysis was undertaken to examine the BI losses from a simulated dirty bomb attack on the Los Angeles Financial District (Giesecke et al. 2012). This study examined the costs of potential wage and investor rate of return premia and customer discounts needed to attract people back to the targeted areas and inserted these costs in the state-of-the-art tool of economic consequence analysis—computable general equilibrium (CGE) modeling. The study results indicated that behavioral effects were 15 times larger than the ordinary direct and indirect economic impacts typically measured.

More recently, the framework has been "transitioned" to a user-friendly software tool known as E-CAT (Rose et al. 2017—a forthcoming volume in the IDRiM Book Series). A further extension of ECA on a parallel track to enhance the US government's terrorism risk assessment capability is being completed by Dixon and Rimmer (2016).

Other examples of interdisciplinary research at CREATE include work on adaptive adversaries, risk perceptions, risk messaging, and the value of information in risk management. This includes numerous case studies for academic and policy advising purposes that have been undertaken by CREATE researchers. One set of these has been the collaborative efforts between CREATE and the US Geological Survey (USGS) on analyzing disaster scenarios, such as a catastrophic earthquake, severe winter storm, tsunami, and massive cyber-disruption (see, e.g., Porter et al. 2011).

CREATE is one of a dozen COEs, with others involved in interdisciplinary research being the Consortium for the Study of Terrorism and Responses to Terrorism (START) and the Coastal Hazards Center. The centers have involved major researchers in the USA on both terrorism and natural hazards, such as Dennis Mileti, Kathleen Tierney, Susan Cutter, and Gavin Smith. An example of pioneering research is that on community resilience by Norris et al. (2008).

Low-Income Countries

It is difficult to pinpoint the beginning of academic research on natural hazards and disasters in low-income countries. The humanitarian system has deep historical roots, but the emergence of a humanitarian knowledge community is more recent and began to accelerate in the 1970s (Davey et al. 2013: 29). The 1970s and 1980s saw significant attention given to food emergencies and famine (Comité d'Information Sahel 1973; Sen 1981) and also to floods and cyclone impacts (White

1976). The rapid growth of academic research in the 1970s and 1980s was arguably driven by the greater visibility and political saliency of disasters such as the famines in the West African Sahel and Ethiopia, huge loss of life in Bangladesh due to cyclones, and deadly earthquakes in Guatemala and China (Kent 1983; Wisner and Gaillard 2009). However, it was only in what the British call "development studies" that disaster vulnerability became a core concern during this early period, with, for instance, Chamber's introduction of the concept of vulnerability in the context of "integrated rural poverty" (1983) and theme issues of the *Bulletin of the Institute of Development Studies* devoted to problems of seasonality and to food security and the environment (Lipton 1986; Leach and Davies 1991). The international, interdisciplinary journal *Disasters* was launched in 1976. Geographers, political economists, anthropologists, students of international relations, and community health specialists were among the early contributors. Epidemiologists and other public health researchers were active in defining disasters as a new focus of research at about the same time (de Ville de Goyet 1976); however, they worked alone or in small groups. The large academic center devoted to interdisciplinary, integrated approaches to understanding and managing disasters in low-income countries is a more recent development.

National Interdisciplinary Centers in the Global North

In the early twenty-first century, dedicated research centers now exist whose staff and collaborators span disciplines from the earth science and geoinformatics, social work, engineering, and public health to psychology, economics, sociology, politics, and geography, among others. Their approach is generally applied to and focused on the policy and practice of management of disaster prevention and risk reduction, warning, response and relief, and recovery. Two examples are the IRDR at University College London and IHRR at Durham University.

The Institute for Risk and Disaster Reduction (IRDR https://www.ucl.ac.uk/rdr) at University College London draws from a wide range of the University's institutes and departments, including the Institute for Global Health, Development Planning Unit in the Bartlett School of Architecture, Faculty of Engineering Sciences, the Leonard Cheshire Disability and Inclusive Development Centre, and departments of earth science and psychology, among many others. IRDR affiliates conduct research on the public perception of risk and how diverse societies deal with disaster, understanding health risks and pandemics, the study of extreme weather and the climate forcing of geological hazards, innovative design and construction, planning and design codes, and issues of resilience and recovery. One UCL partner with IRDR, the UCL Hazard Centre, has placed Ph.D. student researchers in nongovernmental development organizations (NGOs) in order to enhance NGO effectiveness (https://www.ucl.ac.uk/hazardcentre/ngo).

The Institute of Hazard, Risk and Resilience (IHRR https://www.dur.ac.uk/ihrr/) covers a similar range of research topics and also engages staff and research students across many disciplines at the University of Durham. IHRR plays a central role in the Earthquakes Without Frontiers research program in a number of countries in the Alpine–Himalayan Belt. This work involves earth scientists, social scientists, a historian, and a professor of social work and seeks to understand secondary earthquake hazards such as landslides, as well as risk governance and perception of earthquake risks by stakeholders at a number of scales (http://ewf.nerc.ac.uk/). IHRR researchers are also investigating such health aspects of disaster management as the effectiveness of respiratory protection during volcanic eruptions and economic questions such as how well small and medium enterprises recover from flooding.

International Centers

Because the elimination of poverty and promotion of security for people from food shortage, disease, and natural hazards are among the mandates of a number of UN organizations and international organizations, it is not surprising that research on integrated disaster risk reduction and management also takes place in these institutional homes. The World Bank and United Nations Development Programme (UNDP) are keenly aware of risk and are active on issues of human security (World Bank 2014; UNDP 2014). The World Health Organization (WHO) and the World Food Programme (WFP) also commission and conduct research on the early warning and management of epidemics and food emergencies, respectively (WHO 2016; WFP 2016). The Intergovernmental Panel on Climate Change (IPCC) has addressed the impacts of climate change on poor people in poor countries, particularly in its major report on climate-related disasters (IPCC 2012).

Also at the international scale, a good deal of the work of IIASA has been important in shaping policy and practice of risk management in low-income countries, for example, in the area of disaster insurance. The Center for Research on the Epidemiology of Disasters at the Catholic University of Louvain (CRED) in Belgium has evolved from a collector and repository of disaster data into a multifunctional academic institution that also produces occasional reports of relevance to integrated disaster risk management. One example is its 2016 report on poverty and disaster deaths (CRED 2016).

The International Council for Science has launched an initiative on the integrated study of disaster risk (http://www.irdrinternational.org/). Based in Beijing, China, the program of Integrated Research on Disaster Risk (IRDR) is active worldwide, especially in the Global South. It encourages young scientists, and it is currently engaged in an international assessment of integrated research on disaster that may lead to the IRDR's becoming the hub of a community of practice for such work. Its other research areas include knowledge sharing on the assessment of disaster loss and of the factors involved in the ways that people make decisions regarding disaster risk. In all of these functions, the emphasis is on serving a networking and facilitating function among researchers.

Another major program at IRDR has been to develop a framework for the forensic analysis of disasters called Forin (IRDR 2015). It seeks to focus researchers' attention on the root causes of disaster that go beyond the physical triggering phenomena and simple human exposure. Forin is grounded in a theory of social construction of disaster risk (Wisner et al. 2004, 2016; Tierney 2014). While keenly aware of physical and biological processes that manifest as hazards, Forin focuses on the process of development itself as a locus of risk creation (Oliver-Smith et al. 2016).

The forensic approach of the IRDR's Forin framework is not unusual. For many researchers who come to disaster risk from a background of work on poverty and marginalization in low-income countries, disaster is understood as a manifestation of failed or distorted development (Lavell et al. 2012) and the accumulation of risk in everyday life (Bull-Kamanga et al. 2003). Data collected beginning in the early 1970s shows that marginalized and excluded social groups in formerly colonized and other low-income countries are more severely impacted by natural hazards (Wisner et al. 2004). Women die in greater numbers in floods and coastal storms. Small farmers and fishers end up losing their land and boats to more wealthy neighbors and money lenders and find it more difficult to reestablish viable livelihoods.

The perspective of research grounded in daily realities of the urban and rural poor has also revealed that local knowledge and ways of adapting to hazards have been overlooked by planners and managers. In the last two decades, there has been much research on how local knowledge of hazardous environments can be brought together with outside specialist knowledge (Wisner 1995, 2010, 2016). The concept and practice of community-based disaster risk management (CBDM) or risk reduction (CBDR) have become common among both academic researchers and a large number of nongovernmental organizations, and collaboration between civil society and academia has begun in this domain (Wisner et al. 2008; Kelman and Mercer 2014).

National and Regional Centers in the Global South

Interdisciplinary research is also being conducted by institutions within low- and medium-income countries themselves. In the Americas, the network of researchers known as La Red was a pioneer (http://www.desenredando.org/). Created in 1992, La Red has a relationship with FLACSO, the graduate faculty of social sciences shared by ten Latin American countries. La Red publishes a journal, *Sociedad y Desastres* (http://www.desenredando.org/public/revistas/dys/), suspended for a time, but now relaunched, and has incubated some of the world's most innovative work on participatory action research for disaster reduction and on deep analysis of the links between development and disaster. Many of these innovations, while originally focused on the region and published in Spanish, have taken on an international role in shaping how disaster is understood and measured. A disaster monitoring and inventory tool known as DesInventar (http://www.desinventar.org/) was created by associates of La Red. It makes use of sub-national media and civil society sources to catalogue small- and medium-scale hazard events that have been shown to have a major impact on livelihoods and human security. Since its earliest application in Colombia, it is now used in many parts of the world.

In South Africa, Stellenbosch University and North-West University have interdisciplinary centers devoted to disaster risk management. At Stellenbosch, the Research Alliance for Disaster Risk Reduction (RADAR) began in 2013 to build on 17 years of research and networking on the continent when the director was based at Cape Town University. A large body of work on urban disaster risks such as shack fires and risk management in South Africa has resulted, as well as work on flooding. In addition, Peri Peri University is coordinated from a base in RADAR (http://www.riskreductionafrica.org/partners-and-programmes/stellenbosch-university-stellenbosch-south-africa/). Peri Peri U is a network of 11 universities in sub-Saharan Africa that share knowledge on disaster-focused pedagogy and research methods. North-West University is home to the African Centre for Disaster Studies (ACDS http://acds.co.za/). Established in 2002, ACDS conducts research on disaster risk governance, gender and disasters, water-related risks, and climate change. It is also home to a peer-reviewed, open-access journal, *Jàmbá: Journal of Disaster Risk Studies* (http://www.jamba.org.za/index.php/jamba).

In South Asia, a group of researchers pulled from civil society, journalism, and academia produces the occasional *South Asia Disaster Report* (e.g., Practical Action 2010) coordinated by the NGO called Duryog Nivaran and facilitated over the years by the INGO, Practical Action.

Many of the participants in these various research efforts in the Asia-Pacific region, the Middle East, Africa, Latin America, and the Caribbean have collaborated over the years with research into local, lived realities of disaster risk and risk reduction. The Global Network of Civil Society Organisations for Disaster Reduction (GNDR www.gndr.org) has in this way been able to mount large surveys that involved 800 civil society organizations in 129 countries, tapping the knowledge of more than 85,000 respondents in its Views from the Frontline series (http://www.gndr.org/programmes/views-from-the-frontline/vfl-2013.html), as well as even more detailed studies of local risk perception and action in its Frontline and Action at the Frontline series (Gibson and Wisner 2016).

Summary

The examples provided above are not exhaustive. Groups of researchers in many universities, civil society organizations, and government departments in low- and medium-income countries carry out work on disaster risk, albeit some of it more and some less integrated and interdisciplinary, given differences in the history of relations among academia, news media, and government and differences in bureaucratic flexibility within higher education and government. The important takeaways from this brief overview are that:

- A vital and growing focus on disaster risk in low- and medium-income countries has emerged
- A consensus is growing that disaster risk in such countries is to a great degree a manifestation of failed development
- The applied focus on practice and policy leads such research toward an integrated management approach
- Systemic changes in governance and in the relations among academia, civil society (including the media), and government are necessary if research on integrated risk management is to flourish in low- and medium-income countries themselves, and elsewhere in the Global South, as opposed to relying primarily on work within rich-country institutions and international organizations in the Global North

Other Contributions

The brief summaries of research contributions on integrated disaster risk management presented above are not all-inclusive. They focus to a great extent on work performed through major research institutions. As such, they omit contributions by several who have contributed to the IDRiM cause before the formation of the organization and since. Some examples are noted below.

The interrelationship between disasters and development was given a significant boost by the establishment of a program in disaster and development studies at Northumbria University (UK) in 2000 (see also the Department of Geography/Disaster and Development Network, DDN). This also co-emerged with integration of more specialized fields such as health and well-being-centered disaster risk reduction and communities and resilience, all of which are based on integrated approaches. Early work by Andrew Collins and others focused specifically on infectious disease risk management, bringing together microbial ecology, socio-behavioral, and contextual analyses to identify best-integrated risk management practices in Mozambique and Bangladesh (see http://www.ukcds.org.uk/the-global-impact-of-uk-research/communities-against-disasters). A broader set of universities are involved in the UK Alliance for Disaster Research (UKADR) (www.ukadr.org).

In Austria, BOKU University has a long tradition in the research of water resources, including current involvement in the South East Europe (SEE) project CC-WARE (Mitigating Vulnerability of Water Resources Under Climate Change). It is led by the forest section of the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management and includes 17 partners from 10 countries. The main objective of CC-WARE is the development of an integrated transnational strategy for water protection and mitigating water resources vulnerability as a basis for the implementation of national and regional action plans (http://www.ccware.eu/). See also Löschner et al. (2016).

DPRI, with funding from the government of Japan under its GCOE Human Security Engineering (HSE) initiative, promoted field-based research projects on disaster risk management in Asian megacities. The Mumbai project, 2009–2013, focusing on vulnerable hot-spot communities, was established with the objective of evolving scientific methodology on participatory grassroot-level disaster risk management. The project, a first of its kind in India and one among a few globally, was undertaken in collaboration with the Mumbai city government (MCGM); School of Planning and Architecture, New Delhi; the Tata Institute of Social Science; IIT Bombay; and JJ School of Architecture, Mumbai. One outcome is a breakthrough in process methodology that empowered the two hot-spot poor communities to play the lead role in what is known as community-based disaster risk management (CBDRM). IDRiM founding member Bijay Anand Misra served as the senior adviser and coordinator of the project (see Misra 2013).

IDRiM member Manas Chatterji has overlapped research on integrated disaster risk management with work on conflict management and peace science (see, e.g., Chatterji et al. 2012).

Several research centers working on aspects of integrated disaster risk management operate in Iran, such as the International Institute of Earthquake Engineering and Seismology, under the founding and long-term leadership of Professor Mohsen Ghafory-Ashtiany, who also serves as the Chairman of the SP Insurance Risk Management Institute.

As one major example of research in China, in 2011, the Risk Governance Group of the Chinese National Committee on International Dimensions Programme on Global Environmental Change (CNC-IHDP) launched its Integrated Risk Governance (IHDP-IRG) Project. As a ten-year international cooperative research effort, its mission is to improve the governance of new risks that exceed current human coping capacities by focusing on the transitions in and out of the occurrence of relevant risks in the global climate changes. Under this project Beijing Normal University, with the leadership of Peijun Shi and others, has led comprehensive scientific research that included the several case studies, a community risk governance model, and a proposed paradigm of catastrophe risk governance in China. See, e.g., Shi et al. (2013) for a comparative study of the Wenchuan Earthquake and Tangshan Earthquake, centering on hazard, exposure, disaster impacts and losses, disaster rescue and relief, and recovery and reconstruction.

Limitations of space restrict us from mentioning all those working on the topic of resilience, but, in addition to the people and organizations mentioned above, we note the following whose research is in the spirit of integrated disaster risk management: Erica Seville, co-Leader of the Resilient Organisations community in New Zealand, Stephane Hallegatte of the World Bank, and Swenja Surminski of the Overseas Development Institute.

Conclusion

Further efforts needed in the future to advance integrated disaster risk management include:

- Extending research perspectives and constructing new conceptual models
- Developing new methodologies
- Exploring yet uncovered and newly emerging phenomena and issues
- Engaging in proactive field studies in regions that face high disaster risks, but, where investigations have not yet been undertaken, performing field studies that incorporate research advances in disaster-stricken regions

Obviously, the above approaches are rather interdependent, and thus integrated disaster risk management is best promoted by combining them. For instance, emerging mega-disasters, which are caused by an extraordinary natural hazard taking place in highly interconnected societies, may require a combination of both the second and third points above, such as mega-disaster governance based in part on mathematical models of systemic risks. Also, long-range planning for societal implementation of integrated disaster risk management inevitably requires encompassing most of the above approaches.

The IDRiM Book Series as a whole intends to cover most of the aforementioned new research challenges.

Nishinomiya, Japan — Norio Okada
Milan, Italy — Aniello Amendola
Laxenburg, Austria — Joanne Bayer
Uji, Japan — Ana Maria Cruz
Laxenburg, Austria — Stefan Hochrainer
Los Angeles, CA, USA — Adam Rose
Boulder, CO, USA — Kathleen Tierney
Oberlin, OH, USA — Ben Wisner

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Preface

The twenty-first century has been ushered in by unprecedented disasters throughout the world. We have witnessed known events occurring with higher frequency and/or severity, as well as new forms of disasters. The September 11, 2001 terrorist attacks in the United States used commercial airliners as a weapon to wreak havoc on human lives and our collective psyche, with the additional intent to cause extensive economic harm. Hurricane Katrina's wind and flood damage were unprecedented in US history, as was the failure of the government response at all levels. The Deep Water Horizon oil spill greatly damaged fragile eco-systems along the Gulf Coast and led to a dramatic drop in tourism and fishing activities. We can add to this the increase in the number and magnitude of tornadoes and wildfires in recent years. Other parts of the world were also hit by especially devastating disasters, such as the Wenchuan China earthquake of 2008, the Chilean earthquake of 2010, and the Thai floods of 2011. Most devastating of all was the compound event of the Tohoku earthquake, ensuing tsunami, and subsequent Fukushima nuclear reactor meltdown in Japan in 2011. On the horizon is the prospect of the accelerating threats stemming from climate change and space weather. As our world becomes increasingly interconnected, we also become more vulnerable to widespread cyber disruptions.

Decision-makers in the private and public sectors need information on the economic consequences of these disasters and others. This will allow them to better allocate resources across multiple disasters for mitigation and resilience capacity-building prior to the events, and to reallocate resources and provide recovery assistance during their aftermaths. Ideally, these estimates would be accurate, quick, and comparable across multiple threats. This volume presents the development of advanced economic modeling methods and their transition into a user-friendly software system for this purpose. The modeling involves several stages, but the major ones are the identification of a broad range of drivers of many types of direct impacts, refinement of a state-of-the-art approach to economy-wide modeling that can incorporate the drivers and estimate the ripple effects, conversion of the complex modeling results into a reduced-form statistical equation, and incorporation of these equations into a user-friendly software system.

The research presented in this volume is the culmination of 10 years of work at the Center for Risk and Economic Analysis of Terrorism Events (CREATE), an independent Center of Excellence in Research and Education originally established by major funding from the US Department of Homeland Security (DHS) Office of University Programs (OUP). This research has involved the broadening of economic consequence analysis, enhancement of economy-wide modeling, and application to dozens of case studies, all of which have been vetted in the peer-reviewed literature.

A foundation of the research is the CREATE Economic Consequence Analysis (ECA) Framework (Rose, 2015). A few decades earlier, hazard loss estimation was formulated, primarily by engineers and statisticians, with an emphasis on loss of life and property damage emanating from physical damage. A major advance in the 1980s was the consideration of direct impacts on gross domestic product (GDP) and employment, as well as the estimation of ordinary indirect, often referred to as multiplier, effects (see, e.g., Gordon and Richardson, 1992; FEMA, 1997; Rose et al., 1997; Shinozuka et al., 1998). CREATE researchers first added resilience to their framework. While this concept had been studied by hazards researchers for a decade (see, e.g., Chang et al. 2001; Bruneau et al., 2003), I developed a rigorous definition and an operational metric grounded in economic principles (Rose, 2007), and, together with my research team, applied it most notably in a study of the economic impacts of 9/11 (Rose et al., 2009) and in subsequent analyses of disruptions to water and power systems (Rose et al., 2011a), epidemics (Dixon et al., 2010; Prager et al., 2016), earthquakes (Rose et al., 2011b), port shutdowns (Rose and Wei, 2013), and tsunamis (Rose et al. 2016a).

The second major addition was behavioral responses, primarily stemming from fear, that have the potential to greatly exacerbate the consequences. Rose et al. (2009) found that the rapid relocation of businesses and government agencies housed in the World Trade Center reduced business interruption (BI) by 72 %, but that 80 % of the remaining BI was due to a nearly 2-year reduction in airline travel and related tourism. Subsequent research by Giesecke et al. (2012) and Rose et al. (2016b) found that behavioral effects could increase ordinary BI by 1–2 orders of magnitude.

Finally, large expenditures on decontamination and remediation after major oil spills and chemical/biological/radiological/nuclear (CBRN) threats were brought into the CREATE ECA Framework. Here ECA differs from benefit–cost analysis (BCA) in that it does not automatically relegate such expenditures to the cost side of the ledger, but instead uses modeling to determine the bottom-line effects on GDP and employment, in the context of whether the economy is operating at full employment or not (Rose 2015).

The major recent innovation in the CREATE ECA Framework relates to the identification of a comprehensive set of impact drivers for any disaster. There are generally two approaches to loss estimation or consequence analysis. One is a detailed examination of a few major drivers, while the other undertakes less-detailed examination of a broader range of them. For major disasters, it is our premise that the latter is likely to result in greater overall accuracy. We developed an approach that enumerates all of the potential drivers and thus provides a comprehensive check-list of factors that need to be considered (Rose et al., 2015; Prager et al., 2016).

The next major innovation was to transform the results of a complex economic simulation model into a form that could be incorporated into a software system to be used by non-experts. Computable General Equilibrium (CGE) models, our major model of choice, contain thousands of equations reflecting relationships within, among, and between businesses, households, and various institutions. What we have done for this volume is to develop a "reduced-form" approach by which we run at least 100 simulations for each threat type, varying drivers and parameters according to a sophisticated sampling system, to yield synthetic data to which we apply regression analysis to yield a single estimating equation. The equation is then entered into an Excel Visual Basic Applications (VBA) platform as the core of the user-friendly E-CAT software system that yields rapid estimates of consequences on GDP and employment presented in the context of various depictions of uncertainty.

This volume owes a debt to many people and institutions. I was indeed fortunate to have an outstanding research team to further refine the CREATE ECA Framework and models and to transition them into a software system over the past 2 years. The other three senior authors, especially, made this volume possible.

Fynn Prager led the latest round of refinements of the US CGE Model and its update. He coordinated a good deal of the work on the research with special emphasis on overseeing the quantitative scoring of the enumeration tables for many of the threats, linking the enumeration table impact categories with CGE model drivers, and translating them into user interface variables. He also led the work on the influenza CGE analysis, which served as a template for the work on other threats. He is the lead author of Chaps. 4 and 5 and of the CGE model description in Appendix A.

Zhenhua Chen worked closely with Fynn on the CGE model refinement and updating, as well as on the development of the user interface variables. He was the lead on the programming and execution of the complex reduced-form analysis and the programming of the E-CAT User Interface, as well as carrying out the validation tests. He is the lead author of Chaps. 6 and 9 and of the E-CAT Software Tool in Appendix C.

Sam Chatterjee led the output uncertainty design and analysis, as well as the input sampling procedure. He was the lead programmer and architect of the initial E-CAT User Interface prototype, and also designed the major validation test. He is the lead author of Chap. 7.

The associate authors Dan Wei, Nat Heatwole, and Eric Warren contributed to key aspects of the volume. All three participated in the design of the threat scenarios and the identification of the upper and lower bound cases in the enumeration tables and their quantitative scoring. Dan Wei did extensive work on the detailed underpinnings of the influenza threat scenario in Appendices 4A and 4B. Nat Heatwole performed an analysis of the nuclear threat, the details of which cannot be presented

because of their sensitive nature. Eric Warren took the lead on the quantification of the enumeration of several other threats.

I am also indebted to the long line of pioneers in the hazard loss estimation field. I have benefited greatly from them in general and through my affiliation with the U.S. National Science Foundation-sponsored Multidisciplinary Center for Earthquake Engineering Research (MCEER). These include Masanobu Shinozuka, Stephanie Chang, Kathleen Tierney, Ron Eguchi, Bill Petak, and Tom O'Rourke, and my graduate students at Penn State University, primarily Debo Oladosu, Shu-Yi Liao, Gauri Guha, Dongsoon Lim, and Juan Benavides.

At the University of Southern California (USC), my research accelerated by my affiliation with CREATE. I am grateful especially to Detlof von Winterfeldt, who has served two terms as Director and who established an atmosphere of independent research and a high-quality standard. I also thank CREATE Director Steve Hora and CREATE Research Director Isaac Maya for encouraging the reduced-form approach and to Erroll Southers, CREATE Director for Transition, who supported the final leg of the relay. I must say that I resisted the suggestion for quite some time because I questioned its ability to generate new research advances. I am however happy to say that it has done so in addition to yielding the obvious practical decision-support tool.

I am also grateful to Debra Elkins, formerly of the DHS Office of Policy, which commissioned E-CAT in the first place, and to Joseph Simon, for their guidance, and to Scott Farrow, CREATE Coordinator for Economics, for his guidance and input as well in the formative stages of this research. I also thank several professional colleagues at CREATE with whom I have collaborated on ECA research, most notably Peter Dixon, Maureen Rimmer, James Giesecke, Dan Wei, and Peter Gordon, and those in related areas such as Bill Burns, Paul Slovic, and Heather Rosoff. Post-docs and graduate students, some of whom are co-authors of this volume, made valuable contributions, including Fynn Prager, Zhenhua Chen, Sam Chatterjee, Nat Heatwole, Misak Avetysian, Noah Dormady, Bumsoo Lee, and JiYoung Park. Other able research assistants not listed as co-authors include Noah Miller and Joshua Banks, who contributed to the quantification of the enumeration tables, and Lillian Anderson, who undertook the tedious tasks of proofreading and reformatting the manuscript.

I also thank others who have supported or encouraged this research, especially Matt Clark, Director of OUP, and Gia Harrigan, the most recent CREATE program manager, as well as Tony Cheesebrough of the DHS National Protection and Programs Directorate (NPPD). The transition of the aforementioned tool to the E-CAT Tool was supported by the U.S. Department of Homeland Security under Grant Award Number 2010-ST-061-RE0001-05.

Finally, I thank my many IDRiM colleagues who have provided valuable feedback of an interdisciplinary nature on my research at annual conferences. These include Norio Okada, Hiro Tatano, Elisabeth Krausmann, Joanne Bayer, and Ana Maria Cruz, among others.

Los Angeles, CA, USA Adam Rose
July 26, 2016

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