Risk Reduction in Natural Disaster Management Through Information Systems: A Literature review and an IS design science research agenda

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Abstract

Natural disasters, including earthquakes, Tsunamis, floods, hurricanes, and volcanic eruptions, have caused tremendous harm and continue to threaten millions of humans and various infrastructure capabilities each year. In their efforts to take countermeasures against the threats posed by future natural disasters, the United Nations formulated the "Hyogo Framework for Action", which aims at assessing and reducing risk. This framework and a global review of disaster reduction initiatives of the United Nations acknowledge the need for information systems research contributions in addressing major challenges of natural disaster management. In this paper, we provide a review of the literature with regard to how information systems research has addressed risk assessment and reduction in natural disaster management. Based on the review we identify research gaps that are centered around the need for acquiring general knowledge on how to design IS artifacts for risk assessment and reduction. In order to close these gaps in further research, we develop a research agenda that follows the IS design science paradigm.

Keywords:

Natural Disaster Management, Risk Reduction, Hyogo Framework, IS Design Science, Literature review

Introduction

Natural disasters, including earthquakes, Tsunamis, floods, hurricanes, and volcanic eruptions, have caused tremendous harm and continue to threaten millions of humans and various infrastructure capabilities each year. For example, according to the World Disaster Report of the International Federation of Red Cross and Red Crescent Societies (IFRC, 2010), the megathrust earthquake centered near Sumatra on December 26, 2004, generated a tsunami that resulted in more than 220,000 deaths and caused total damages amounting to 9.2 billion US$, the tropical cyclone Nargis on May 2, 2008, lead to almost 140,000 deaths and 4 billion damages, and the Haiti earthquake on January 12, 2010 caused more than

220,000 deaths. Overall, the estimated number of people killed and the estimated damage caused by natural disasters amounted to almost 1 million and 1,000 billion $US, respectively, over the period 2000-2009. These statistics do not appropriately reflect the millions of people whose lives were indirectly disrupted by the economic impact of natural disasters. Their ability to raise a modest income is reduced and the prospect of escaping poverty is postponed (UN/ISDR, 2004a). Unfortunately, the trend during the last three decades shows an increase in the number of both natural disasters and affected populations (UN/ISDR, 2004a; p. 3).

In their efforts to take countermeasures against the threats posed by future natural disasters, the United Nations adopted “Guidelines for Natural Disaster Prevention, Preparedness and Mitigation and its Plan of Action” (UN/ISDR, 1994) by providing guidance on reducing disaster risk and the impacts of disasters. The review of progress made in implementing the Yokohama Strategy (UN/ISDR, 2004b) led to the formulation of the “Hyogo Framework for Action” (HFA) for the decade 2005-2015 (UN/ISDR, 2005), which identifies three strategic goals for the coming years in ensuring more systematic action to address disaster risks in the context of sustainable development and in building resilience: (a) The integration of disaster risk reduction into sustainable development policies and planning. (b) The development and strengthening of institutions, mechanisms and capacities to build resilience to hazards. (c) The systematic incorporation of risk reduction approaches into the implementation of emergency preparedness, response and recovery programmes.

In order to operationalize the strategic goals of the HFA and to strive for “risk reduction”, the HFA also contains key activities required, which indicate the multidisciplinary nature of future challenges in NDM. For example, the creation and deployment of national institutional and legislative frameworks requires research activities in the political science, legal studies, cultural studies and sociology; the assessment of existing human resource capacities for disaster risk reduction and the allocation of resources for the development and the implementation of disaster risk management policies calls for research activities in the organization and management sciences; also the need for facilities to record, analyze, summarize and disseminate statistical information on disaster occurrence, impacts and losses, the maintenance of information systems as part of early warning systems, and the promotion of the use of information and communication technologies and related services to support the dissemination of information to citizens clearly reveals that information systems research (ISR) is among the scientific disciplines that can substantially contribute to reducing risk.

The need for ISR contributions in addressing major challenges of NDM is also acknowledged in a global review of disaster reduction initiatives of the UN (UN/ISDR, 2004a). The report concludes that the innovative use of information, technology and applied research in support of comprehensive disaster risk management is central to strategic areas and that greater public use of information systems can lead to more access to risk management information tailored to the needs of specific users.

While the relevance of information systems (research) for NDM has been acknowledged and we identified more than 70 academic publications in the NDM field, we are not aware of any survey that reviews the literature with regard to how ISR has addressed risk reduction in NDM. We argue that such a review is particularly useful in two regards: First, it shows how well the strategic goals as formulated in the HFA by the UN/ISDR have been supported. The results provide guidance for post HFA activities as already being planned in the “Post-2015 Framework for Disaster Risk Reduction” (UN/ISDR, 2013). Second, the review allows for identifying research gaps and suggesting future research paths where both the disaster management and the IS communities can jointly help close the gaps. We provide such a joint research agenda that might help bridge the gap between the IS community and the disaster management community. We see such a gap because our literature search reveals that in the most prominent IS outlets only a few papers have been published during the past ten years.

The remainder of this paper is structured as follows: In Section 2, we frame our discussion by defining core concepts in NDM and by deriving key challenges in NDM based on the Hyogo framework (UN/ISDR, 2005). In Section 3, we review the literature of both the disaster management community and the IS community regarding how well the identified challenges have been addressed by which academic disciplines, and we derive research gaps. In Section 4, we suggest a research agenda. Finally, we present our conclusions in Section 5.

Framing the Discussion

Natural Disaster Management

Events that have a massive negative large-scale impact on people have been inconsistently named “emergency”, “hazard”, “catastrophe”, “incident”, “disaster”, and “crisis” in the literature. Being consistent with the terminology of the International Federation of Red Cross and Red Crescent Societies (IFRC, 2010), the U.S. Federal Emergency Management Agency (FEMA) and the UN International Strategy for Disaster Reduction (UN/ISDR, 2004a), we use the term “disaster” in the following sense (IFRC, 2010): “A disaster is a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community’s or society’s ability to cope using its own resources.” The types of events that are covered by the IFRC disaster definition are broad and include natural, manmade, and technological disasters.

Natural disasters are naturally occurring physical phenomena caused by onset events which can be geophysical (earthquakes, landslides, tsunamis and volcanic activity), hydrological (avalanches and floods), climatological (extreme temperatures, drought and wildfires), meteorological (cyclones and storms/wave surges) or biological (disease epidemics and insect/animal plagues). Technological disasters comprise industrial accidents, transport accidents, nuclear accidents, among others. Man-made hazards include famine, food insecurity, displacement of populations, environmental degradation, pollution, and terrorism (IFRC). Some disasters may be connected to or caused by each other, as the recent 2011 Japanese earthquake, the tsunami, and the nuclear accident show.

In this paper, we focus only on natural disasters for two reasons:

(1) The Hyogo Framework for Action (UNISDR, 2005) formulated by the UN in the context of an “International Strategy for Disaster Reduction” and used in this paper to derive challenges for future research focuses on disasters of natural origin.

(2) Much information on disasters is related to natural disasters. For example, the World Disasters Reports of the International Federation of Red Cross and Red Crescent Societies (IFRC, 2010) provides data mainly for natural disasters.

Based on the understanding of the IFRC (2010), we define the management of natural disasters (NDM) as the organization and management of resources and responsibilities for dealing with all humanitarian aspects of disasters, in particular preparedness, response and recovery in order to lessen the impact of disasters. There is broad consensus in the literature that challenges and activities of disaster management can be classified along the pre-disaster phase (preparedness), the during disaster phase (response), and the post disaster phase (recovery) (IFRC, 2010, Chen et al., 2008; Turoff, 2002; Hale, 1997; Ajami and Fatahi 2009), which can be arranged in a life-cycle (Chen et al., 2008). Among these phases, the preparedness phase is focused in the UN International Strategy for Disaster Reduction (UN/ISDR, 2004a) with “risk assessment and reduction” being identified as the core future challenge in building resilience against natural disasters, where risk is regarded as the probability of harmful consequences, or expected losses, and resilience is regarded as the capacity of a system, community or society potentially exposed to disasters to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. Table 1 provides an overview of the key terms introduced above.

Table 1. Terms and definitions in NDM

Challenges in Natural Disaster Management

Based on the “Guidelines for Natural Disaster Prevention, Preparedness and Mitigation and its Plan of Action” (UN/ISDR, 2004b), the UN published their “Hyogo Framework for Action”

(HFA) for the decade 2005-2015 (UN/ISDR, 2005), which identifies key challenges and actions required in the preparedness phase of NDM in order to address disaster risks in the context of sustainable development and in building resilience. The HFA stresses the importance of disaster risk reduction being underpinned by a more pro-active approach to informing, motivating and involving people in all aspects of disaster risk reduction in their own local communities. Specific challenges, priorities for action, and key activities required are identified in the following five main areas: (a) governance: organizational, legal and policy frameworks; (b) risk identification, assessment, monitoring and early warning; (c) knowledge management and education; (d) reducing underlying risk factors; and (e) preparedness for effective response and recovery. We use these requirements in order to identify those areas and academic disciplines, including information system research that should be linked to meet the above challenges.

Table 2 summarizes the challenges and key activities that the UN formulated in the HFA as core components of an "International Strategy for Disaster Reduction" (UNISDR, 2005). These components are centered around the identification, communication and the reduction of risk, thus making "risk" the key dependent variable in future research activities that need to be conducted in multidisciplinary fields, including political science, legal science, cultural studies, sociology, management science, organization science, computer science, and information systems research, in order to comprehensively address future challenges in NDM. We argue that each of these disciplines needs to compile its own research perspective for framing and guiding their future research activities, before interdisciplinary research perspectives can be developed. The purpose of this paper is to provide such a research perspective for the information systems discipline.

As Table 2 shows, the challenges of future NDM are of multidisciplinary nature, and no single academic discipline can solve all the remaining problems. The purpose of the remainder of this paper is to focus on those challenges and activities required where information systems research can substantially contribute. Extracting these areas from Table 2 leads to the identification of the following three challenges in NDM for the IS discipline:

Table 2. Multidisciplinary challenges and key activities required in Natural Disaster Management Research, based on (UN/ISDR, 2005)

- Challenge 1 (Risk Assessment): Record, analyze, summarize and disseminate statistical information on disaster occurrence, impacts and losses, on a regular bases through international, regional, national and local mechanisms.
- Challenge 2 (Risk Reduction, Information provisioning to citizens): Provide easily understandable information on disaster risks and protection options, especially to citizens, including the development of user-friendly directories, inventories, and

information-sharing systems and services for the full and open exchange of information on good practices at international, regional, national and local levels.

- Challenge 3 (Risk reduction, Development of people centered early warning systems): Maintain information systems as part of early warning systems with a view to ensuring that rapid and coordinated action is taken and that people be warned in cases of disasters; strengthen the coordination and cooperation (processes) among actors in the early warning chain.

We use these challenges in the next section to structure our literature review.

Literature Review

Methodology

As stated in the introduction, the purpose of our literature review is twofold: (1) identification of how well the literature has addressed IS-related challenges of risk reduction as formulated in the Hyogo framework; (2) revealing of the particular contributions of the disaster management and the IS communities in order to derive research gaps and potential for joint research contributions. In order to address these goals we apply a matrix-based presentation and analysis of the literature findings (see Figure 1).

The two-dimensional structure shown in Figure 1 reflects both a challenge-centric perspective and a discipline-centric perspective. While the challenge-centric perspective is based on the Hyogo framework and represents the concept that guides our literature review (Webster and Watson 2002), the discipline-centric perspective allows for identifying the contributions of the disaster management literature and the information systems literature. As we found in our literature search also research contributions of disciplines other than the disaster management and information systems disciplines, we also provide these results and refer to these as results of “other literature”.

We searched the literature using two types of data sources. First, we conducted a title search in pertinent journal and conference databases, namely Business Premier Source, EconLit, and ACM Digital Library. We used the search string “*Disaster and ([risk OR citizens OR warning OR knowledge management] OR [(management OR system OR information) AND design])”*. The design of the search string was driven by the three challenges mentioned above. We explicitly included the term “knowledge management” in our search string based on the argument of Sobel and Leeson (2007, p. 520), who argue that *“[…] effective natural-disaster relief management, just like successful social coordination in ‘normal’ circumstances, must solve Hayek's knowledge problem.”* We limited the search period to “before 01/01/2013”. Second we performed a search of the table of contents of journals and conference proceedings for the period 2000-2012. In contrast to the aforementioned search of databases, we conducted a community-based search: a) Key outlets of the disaster management community include the proceedings of the International Conference on Information Systems for Crisis Response and Management (ISCRAM) and the journals International Journal of Emergency Response, International Journal of Information Systems for Crisis Response and Management and Disaster Prevention and Management. We searched the proceedings and table of contents, respectively, for the period 2000-2012. b) We considered the following premier outlets in the IS community: European Journal of Information Systems, Information Systems Journal, Information Systems Research, Journal of the AIS, Management Information Systems Quarterly, and Journal of the Management of Information Systems. Again, we searched the table of contents for the period 2000-2012.

Figure 1. Matrix-based framework of the presentation and analysis of literature findings

Results

Consistent with the two dimensions of our framework, we follow a two-phase procedure in presenting our findings and proposing a compendium on the application of IS for risk reduction. In phase 1, we focus the discipline-centric perspective and show the results for each of the disciplines separately, with structuring the presentation for each discipline along the three challenges. In phase 2, we focus challenges and synthesize the discipline findings for each of these.

Phase 1

Tables 3 to 5 show our findings of the disaster management literature, IS literature and other literature. Each literature contribution we found is presented with regard to a) the artifact(s) studied, such as information processes, information models or specific information systems b) methodologies and models applied, and c) key results obtained.

Table 3. Contribution of the Natural Disaster Management literature

As Table 3 shows, the disaster management literature

- focuses on risk assessment and neglects the challenges “information provisioning to citizens” and “develop people centered early warning systems,
- only rarely addresses artifacts,
- uses surveys and experiments as predominant methodologies, and
- mainly provides results on how risk assessment is affected by various factors, including countries and cultural factors, addressees at the individual level and administrative layers at the organizational level, and type of information provided.

Table 4 reveals that the information systems literature

- focuses on risk assessment and neglects the challenges “information provisioning to citizens” and “develop people centered early warning systems”,
- does not address artifacts in most studies,
- uses fuzzy-set and probability based models and methodologies as predominant basis, and
- mainly provides or applies models for risk computation, or provides specific (geographical, decision support and executive) information systems.

Table 5 shows the results that other literature suggests. The findings indicate that the literature

- focuses on risk assessment and the development of people centered early warning systems, and neglects the challenge “information provisioning to citizens”,
- does not address specific artifacts in most studies,
- uses surveys and various statistic methods as predominant methodologies, and
- mainly addresses insurance issues, risks of economic losses, risk assessment for particular types of natural disasters, including geological disasters, floods and hurricans, and perceptions of risk depending on the attention paid to different types of capital and depending on the type of information in the context of risk assessment, and
- stresses the importance of using technical devices, such as mobile phones and sirens, and teaching appropriate responses to warnings in the context of the development of people centered early warning systems.

The review of the literature of the disaster management discipline, information systems disciplines and other disciplines reveals both commonalities and differences. With regard to the former, all disciplines focus on risk assessment in terms of methods (prescriptive perspective) or perceptions (descriptive perspective) and only very rarely develop artifacts, such as processes, systems and models, for concrete cases or generic ones. Beyond this neglect of the development of artifacts, also knowledge on how to design such artifacts, e.g. expressed with principles and rules, is essentially missing. Differences occur in terms of a) challenges addressed and b) methodologies used, whereas the latter phenomenon applies to risk assessment as we did not find a sufficiently large number of papers for other challenges. Regarding difference a), both the disaster management literature and the information systems literature provide very few contributions to the challenges “information provisioning to citizens” and “develop people centered early warning systems”, in contrast to other literature which focuses on technical and educational issues. Regarding difference b), the IS literature mainly uses uncertainty modeling with fuzzy sets and probabilities for prescriptive purposes, while the disaster management and other literature predominantly use surveys and experiments for descriptive purposes.

Table 4. Contribution of the Information Systems literature

Table 5. Contribution of the other literature

Phase 2

While in phase 1 we described the results of the various disciplines in detail, in phase 2 we synthesize these findings along the identified challenges. The challenge of assessing risks is addressed by all disciplines. There is a substantial body of literature, which identifies determinants of risk perceptions, analyzes risk-based economic impacts of natural disasters, and suggests models for risk computations. Many of these studies focus on particular types of natural disasters. While the literature is dominated by analytical studies, only a few studies are design-oriented and provide artifacts as results. Those studies that suggest artifacts mainly target specific types of natural disasters and/or particular information systems. As a consequence, the overall picture of the design of artifacts (e.g., processes, models, information systems) is fragmented and lacks knowledge on how to design such artifacts.

The challenge of providing provisioning information to citizens is hardly addressed in the literature; overall we found only eight references. As a consequence, we know only little about the design of processes, models and information systems, about their deployment, and – based on the aforementioned deficiencies – we also have no experience of how the provision of information on natural disasters and of appropriate response behavior can reduce risk.

With regard to early warning systems we found three references of the disaster management literature and three references of the information systems literature. All papers of both disciplines suggest various artifacts, such as models, concepts and systems. In contrast, the references of the other literature are mainly analytical und do not suggest artifacts. Similar to the case of risk assessment, the literature is silent on knowledge on how to design early warning systems.

Research gaps

Based on the results of our literature review we now derive research gaps. The identified gaps are based on both the challenge-based perspective and the discipline-based perspective. We use these gaps in the following section to suggest future research paths.

Research gap 1: Need for construction-oriented research and design of artifacts

The scanned literature shows the large potential of using IS for risk reduction. Before IS can be used, it first needs to be developed so that a key research task is the development of information processes, information infrastructures, information models and information systems, which we refer to as “IS artifacts”. Generally speaking, NDM has a construction problem with the aforementioned IS artifacts being those to be constructed. However, research in the natural disaster domain does not focus on construction problems and the design of artifacts. For example, as Basolo et al. (2006, p. 255) note “there is virtually no research on the development of local governments' web sites for hazard preparedness or the usability of this information technology by community residents.” We identify this lack in research for all challenges and for all analyzed disciplines.

Research gap 2: Need for generic, abstract, and more general design knowledge

Second, although the analyzed disciplines provide some design-oriented contributions and many evaluation-based contributions for the three challenges, the papers contributions focus on disasters of a specific type and/or region, and/or focus on specific IS artifacts, such as early warning systems for Tsunamis in the Indian Ocean region. Furthermore, current research usually either builds or evaluates artifacts, and does not apply an iterative “build-and-evaluate” approach. This approach would allow generating general design knowledge based on the construction and evaluation of prototypic artifacts, thereby implementing the “learning through building” paradigm. This paradigm is regarded as the core of all constructivist methods, which, in turn, “[…] excel at the investigation of incompletely understood problems where the variables of study are inextricably confounded or have not yet been fully explicated by theoretical studies” (Kuechler and Vaishnavi ,2011; p. 166), as it is the case in NDM. As a consequence, research has widely ignored the development of reusable design products, and design rules and guidelines. What research widely lacks is generic, abstract, and more general design knowledge.

Research gap 3: Need for the development of people-centered early warning systems

Third, research has largely neglected the use of IS to provide information to citizens (challenge 2) and to use people-centered early warning systems (challenge 3).

Research gap 4: Need for knowledge on model building and on risk assessment factors

Fourth, while the IS discipline provides or applies several models for risk computation, or provides specific information systems, the disaster management literature mainly provides results on how risk assessment is affected by various factors, thereby identifying and using valuable domain knowledge. The joint use of model building knowledge and risk assessment factors would be a promising area of collaboration of the IS and the disaster management discipline.

Apparently, the identified gaps are centered around the need for acquiring general knowledge on how to design IS artifacts for risk reduction with regard to all three challenges. Therefore we develop a research agenda that targets the design of IS artifacts for risk identification and risk reduction.

Research Agenda

The identified needs for a focus on IS artifacts and for gaining abstract design knowledge calls for the application of the design science research paradigm, “[t]he mission of [which] is to develop knowledge for the design and realization of artifacts, i.e. to solve construction problems” (van Aken, 2004; p. 224). Through its “building and learning” approach (constructivist science), design science research is capable of generating general and abstract design knowledge. Its constructivist nature makes it particularly appropriate for “wicked” problems, which are difficult, multi-faceted and exhibiting emergent aspects that become visible only during attempted solution of the problem (Pries-Heje and Baskerville, 2008; Hevner et al., 2004; Kuechler and Vaishnavi, 2011). NDM shows these characteristics, as its complexity is enhanced through the involvement of several organizations across different cultural, national, and jurisdictional boundaries (Chen et al., 2009), at various administrative levels (Becerra-Fernandez et al., 2008), and with their own systems and services.

Beyond the potential to effectively address the identified challenges, we also see a strong advantage of using ISDS in its acceptance by the IS community. Applying ISDS can help bridge the gap that exists between the disaster management and the IS community.

The IS discipline has adopted, further developed, and applied the design science paradigm (Walls et al., 1992, March and Smith, 1995, Walls et al., 2004, Hevner et al., 2004, Peffers et al., 2007, Vaishnavi and Kuechler, 2008, Baskerville et al., 2011), but it has not been applied to in the NDM context, despite its large potential to generate general design knowledge on IS artifacts. We now unfold the potential of IS design science thinking to address the identified research gaps by first providing the ISDS framework that we use in order to structure our research agenda. We then apply the framework to each of the three challenges, thereby providing a design-oriented research agenda for future NDM research.

ISDS-based framework of research agenda

The previous section revealed the principle appropriateness of ISDS thinking to address the research challenges that we identified for the NDM domain. We now draw on the well-accepted ISDS guidelines suggested in the seminal paper of (Hevner et al., 2004) in order to present the framework of our research agenda. The authors establish seven guidelines to assist researchers to understand and meet the requirements for effective design-science research. The adoption and extension of these guidelines in the NDM context is shown in Table 6.

Table 6: ISDS guidelines for future research in Natural Disaster Management, based on (Hevner et al., 2004; p. 83)

Challenge-specific research paths

Applying the adapted ISDS guidelines to the NDM context, we now develop research paths for the three challenges.

Challenge 1: Risk assessment

Guideline 1 [Design as an Artifact]. Recording, analyzing, summarizing and disseminating information on disaster occurrence, impacts and losses on a regular basis are key activities in natural disaster risk assessment. In contrast to organizational contexts where policies on the type, content, and representation of available information may be applied and enforced and where information distributed over the organization may be consolidated, information on disasters are maintained in many organizations, at various organizational levels, in various countries with different cultural and legislative backgrounds, and with different information systems. For example, international aid organizations, national and local authorities of vulnerable regions, and enterprises including insurance companies store different information depending on their different goals when being involved in natural disasters. In order to exploit the potential of merging the distributed information, key tasks are the generation and implementation of information collection processes, information analysis processes, and information distribution processes. These information processes are components that are required in risk assessment. Other components are (distributed) information systems that connect and merge various information sources, analyze the sets of information, and distribute the aggregated information. As in the case of information processes, such information systems span national, organizational, cultural, and legislative boundaries. Although knowledge on both types of components are essential in natural disaster risk assessment, it is not known how they should look like (design product) and how they can be generated (process of design). Thus, knowledge on both the product (information process and information system) design and the process of design needs to be researched. These are the artifacts of interest in natural disaster risk assessment. This understanding of artifacts is consistent with the understanding of (Walls et al, 1992; Markus et al., 2002, Hevner et al., 2004).

Guideline 2 [Problem Relevance]. Collecting, consolidating, analyzing, and distributing information on disasters are prerequisites to assess the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and to assess the ways in which vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge (UN/ISDR, 2005). Thus, risk assessment is classified highly relevant in the Hyogo framework.

Guideline 3 [Design Evaluation]. The evaluation of designed artifacts for risk assessment is multi-faceted as inter-organizational information flows in communication channels, multiple information sources with different syntax and semantics, and information systems of various organizations need to be included. We suggest that the overall technical architecture of the suggested distributed information system is evaluated in an architecture analysis, which studies how well the local information systems are embedded and connected in the generated overall risk assessment infrastructure. Dynamic issues, such as information flows, can also be evaluated analytically by drawing on process modeling and evaluating methods, such as Petri nets. Beyond this analytical evaluation, observational evaluation using case studies and field studies are necessary in order to demonstrate the usefulness and applicability of the suggested information processes and distributed information system. Finally, the usefulness of information aggregation and information analysis needs to be evaluated. As usefulness of an artifact always depends on the context in which it is used, we suggest that field studies and case studies with aid organizations, and national and local authorities be applied. These participating organizations finally have to evaluate whether the suggested artifacts enhance their capabilities of risk assessment.

Guideline 4 [Research Contributions]. The contributions of ISDS thinking in risk assessment are manifold. They include (relational or multidimensional) data models that are capable of synthesizing the many local data models, information storages including databases and data warehouses, information collection processes, such as extract-transform-load (ETL) processes used in data warehouse contexts, information analysis methods including data mining methods, an information system architecture that connects the various information pools and organizations with centralized information processing units, and knowledge management techniques, including the use of wikis and communities of practice. As noted in (UN/ISDR, 2004a; p. 221), the greater public use of information systems can lead to more access to risk management information tailored to the needs of specific users. The applications offered by the latest information technology provide powerful interactive tools for the disaster risk management community. Other advanced technological applications could be developed to enhance information about disasters and risks. GIS, remote sensing data and satellite imagery in particular can help considerably in assessing vulnerabilities, enhance mapping, and monitor threatened areas systematically.

Guideline 5 [Research Rigor]. Research rigor can be achieved through drawing on a variety of well-established methodologies. The collection and aggregation of distributed information can be supported by concepts of data warehouses (e.g., multi-dimensional data modeling and ETL processes). The modeling and analysis of information flows can be based formally on Petri nets, and semi-formally on the Unified Modelling Language (UML), for example. Information analysis can be widely supported by data mining and artificial intelligence techniques. Research can also draw on established concepts in communication protocols and information systems architectures. A particular useful design science methodology is to learn from one-time design of individual instances of artifacts and to show

how one could turn the findings into more general design knowledge for NDM. One example is the Information Technology Centre for Africa (ITCA), conceived as a central node in the networking landscape. It will focus initially on establishing various databases derived from data maintained by existing networks, and creating a web-based directory of African web sites that promote networking activities (UN/ISDR, 2004a). A second example is the Earthquakes and Megacities Initiative (EMI), which promotes the establishment of comprehensive city-wide disaster management systems. It encourages the development of tools for disaster risk assessment and management. It includes information technology that enables megacities to understand their risks and then to take actions to reduce their exposure to hazards (UN/ISDR, 2004a). Research rigor also needs to account for cross-cultural cultural differences in risk perceptions of disasters. As (Gierlach et al., 2010) show, there is a significant difference among cultures in levels of perceived risk that do not correspond to actual exposure rates.

Guideline 6 [Design as a Search Process]. What is important for all of the three identified challenges in NDM is the enhancement of risk assessment capabilities while satisfying cultural, legislative, technical, and inter-organizational requirements. Thus, build-and-evaluate cycles need to be applied in order to evaluate to what extent the needs of different aid organizations and authorities are actually addressed.

Guideline 7 [Communication of Research]. The results of ISDS research in the NDM must be presented effectively to both the IS community and NDM-oriented audiences. This remains a challenging issue as our literature search reveals that the IS community and the NDM community are not very well connected and adopt different perspectives on natural disasters. We suggest that NDM communities, such as the International Conference on Information Systems for Crisis Response and Management (ISCRAM), and ISDS communities, such as the International Conference on Design Science Research in Information Systems and Technology (DESRIST) mutually open their platforms in order to inform each other on their perspectives and solutions. The particular challenges for both communities are discussed in more detail in the research perspective section.

Challenge 2: Information provisioning to citizens

Guideline 1 [Design as an Artifact]. A substantial way to reduce risk is the provision of easily understandable information on disaster risks and protection options, especially to citizens. Important artifacts are information and communication systems, including user-friendly directories, inventories and information-sharing systems and services for the full and open exchange of information on good practices at international, regional, national and local levels, and training systems. Knowledge on how to build such systems appropriately is scarce. As these systems are intended to be used by audiences that are heterogeneous in terms of age, cultural background, language, and access to information and communication technology, their effectiveness largely depends on how well they target the specific audiences. For example, it is important to gain knowledge on how different children and adults use such systems, and which information technology is available in developing countries, especially in rural areas.

Guideline 2 [Problem Relevance]. The risk of natural disasters can be substantially reduced if people are well informed and motivated towards a culture of disaster prevention and resilience, which in turn requires the collection, compilation and dissemination of relevant knowledge and information on disasters, vulnerabilities and capacities. Thus, risk reduction through information provisioning is a key concern in future NDM research.

Guideline 3 [Design Evaluation]. The evaluation of artifacts that help provide information to citizens needs to be audience-centric, being consistent with their audience-specific nature. Field studies and controlled experiments with homogenous audiences are appropriate design evaluation methods in order to assess the usability of systems and the knowledge gain of users.

Guideline 4 [Research Contributions]. The contribution of ISDS research on risk reduction through information provisioning includes design knowledge on how to build audience-specific and media-specific information provisioning and communication systems. For example, being able to build effective training systems applications, such as Internet-based electronic conferencing and distance learning systems, allows the immediate sharing of documents and data on demand, increasing the efficiency, timeliness and overall utility of information available to a larger number of people.

Guideline 5 [Research Rigor]. Natural disaster information provisioning systems target heterogeneous groups of citizens and are thus socio-technological systems, the effectiveness of which is not only determined by its technological design, but also by the way how issues of human computer interfaces (HCI) and usability are addressed. Thus, rigor research can largely benefit from concepts of socio-technical design (Carlsson et al., 2011; Avgerou et al.,2004; Bostrom and Heinen, 1977; Cherns, 1976; Clegg, 2000; Land, 2000), including the areas of HCI and information systems usability. Research rigor can also be achieved through learning from one-time design of individual instances of artifacts. For example, a UN report (UN/ISDR, 2004a) lists the “Association Prévention 2000”, which aims at raising awareness and promoting education on natural hazards, particularly among schoolchildren in France and Nicaragua. Many of its activities revolve around disaster mitigation and exploring innovative uses of the Internet and information technology to promote the understanding and techniques of disaster reduction. Its main instrument is an

Internet site with considerable documentation on natural disasters, considered by many as one of the pre-eminent sources of French-language information on natural disasters.

Guideline 6 [Design as a Search Process]. (see Challenge 1)

Guideline 7 [Communication of Research]. (see Challenge 1)

Challenge 3: Risk reduction (development of people centered early warning systems)

Guideline 1 [Design as an Artifact]. The development, deployment, and appropriate use of early warning systems play a substantial role in reducing risk and avoiding harm. Developments in information and communication technology, especially the variety of new terrestrial and satellite-based wireless technologies, will give additional protection to key communication channels in the event of disasters. Information systems as parts of early warning systems strengthen the coordination and cooperation among actors in the early warning chain. Thus, knowledge on how to design early warning systems, how to embed information systems, and how to use different media, including mobile devices, social networks, and web sites is required for effective early warning systems. As in the case of risk information provisioning to citizens, socio-technical requirements apply. Overall, the artifacts of interest are the architecture, the socio-technical design, and the information flows in early warning systems and their embedded information systems.

Guideline 2 [Problem Relevance]. The development and deployment of people centered early warning systems is apparently one of the key unsolved challenges in effective NDM. For example, many of the 220,000 lost lives could have been saved during the 2004 tsunami in the Indian ocean if effective early warning systems would have been in place.

Guideline 3 [Design Evaluation]. The evaluation of early warning systems artifacts is a critical issue as most of the design evaluation methods do not work. Early warning systems are complex in nature as they involve many subsystems, communication technologies, inter-system information flows and human behavior. Thus, analytical and observational methods are inappropriate due to the high complexity and non-applicability in practice, respectively. However, implemented early warning systems can be assessed after natural disasters when monitoring is in place. An appropriate means of design evaluation are simulations, where the artificial artifact is executed with artificial or historic data. As a consequence, we do not only need design knowledge on how to build early warning systems but also (methodological) knowledge on how to evaluate the constructed system.

Guideline 4 [Research Contributions]. As the previous discussion shows, the contribution of ISDS thinking does not only include knowledge on the design of people centric early warning systems and embedded information systems as socio-technical systems, but also on methodologies for the simulation of these systems. The comprehensiveness of such artifacts stressed by (Yifeng, 2009), who states that early warning system needs to be constructed on the basis of both the digital technologies and the legal, institutional, fund, personnel and material guarantees of the system.

Guideline 5 [Research Rigor]. As in the case of risk reduction through information provisioning to citizens, research rigor can benefit from socio-technical design theories. Research rigor can also be achieved through learning from one-time design of individual instances of artifacts, such as those proposed in (Escalaras and Register, 2008; Teshirogi et al., 2009; UN/ISDR, 2007).

Guideline 6 [Design as a Search Process]. (see Challenge 1)

Guideline 7 [Communication of Research]. (see Challenge 1)

Table 7 summarizes the suggested research agenda.

Conclusion

Our literature review reveals research gaps that are centered around the need for acquiring general knowledge on how to design IS artifacts for risk identification and risk reduction. Based on this ERKENNTNIS we develop a research agenda by adopting ISDS paradigm, with which the disaster management community and the IS community may come closer together and may jointly help solve natural disaster management problems as formulated through the Hyogo framework challenges. In order to foster symbiotic research and to exploit the discussed synergies between IS research and the NDM domain, researchers of the two communities should be informed about the potential synergies, the existing need and ways to exploit them, and the added value for their respective disciplines.

Table 7 ISDS-based research agenda for risk reduction in NDM

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Term	Definition	Reference guiding our conceptualization
Disaster	A disaster is a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources.	(IFRC, 2010)
Natural Disaster	Natural disasters are naturally occurring physical phenomena caused by onset events.	(IFRC, 2010)
Natural Disaster Manage-ment	The organization and management of resources and responsibilities for dealing with all humanitarian aspects of disasters, in particular preparedness, response and recovery in order to lessen the impact of disasters.	(IFRC, 2010)
Prepared-ness	Activities and measures taken prior to disasters, including risk assessment, set up of early warning systems and procedures (Gasparini et al., 2007; Zschau and Küppers, 2002; UN/ISDR, 2007), and evacuation planning (Nisha de Silva 2001; Sherali et al., 1991).	(Chen, 2008)
Response	Activities and measures taken during a disaster, including the coordination of the allocation and scheduling of resources (Fiedrich et al. 2000; Rolland et al. 2010), and activity recording and tracing of rescue and response (Lorincz et al. 2004).	(Chen, 2008)
Recovery	Activities and measures taken after a disaster in order to return to normalcy of the impacted region and people, including data analysis for further improvements and controlling (GAO, 2006).	(Chen, 2008)
Risk	The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from disasters.	(UN/ISDR, 2004a, Annex A)
Resilience	The capacity of a system, community or society potentially exposed to disasters to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure.	(UN/ISDR, 2004a, Annex A)

Table 1. Terms and definitions in NDM

Key activities required	Scientific disciplines responsible
Challenges/Priorities for action: Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation	
Rationale: Countries that develop policy, legislative and institutional frameworks for disaster risk reductions have greater capacity to manage risks and to achieve widespread consensus for disaster risk reduction measures.	
Creation and deployment of national institutional and legislative frameworks	Political science, Legal science, Cultural studies, Sociology
Putting emphasis on resources: (i) Assess existing human resource capacities for disaster risk reduction (ii) Allocate resources for the development and the implementation of disaster risk management policies, programmes, laws and regulations	Organization science, Management science
Promotion of community participation in disaster risk reduction	Cultural studies, Sociology, Marketing science
Challenges/Priorities for action: Identify, assess and monitor disaster risks and enhance early warning.	
Rationale: The starting point for reducing disaster risk lies in the knowledge of the hazards and the vulnerabilities to disasters, and of the ways in which hazards and vulnerabilities are changing.	
Risk assessment (i) Develop, update and disseminate risk maps and related information. (ii) Develop systems of indicators of disaster risk and vulnerability. (iii) Record, analyse, summarize and disseminate statistical information on disaster occurrence, impacts and losses.	Management science, **Information Systems Research**
Address early warning (i) Develop and establish early warning systems (ii) Establish, periodically review, and maintain information systems as part of early warning systems (iii) Establish institutional capacities to ensure that early warning systems are integrated into governmental policy and decision-making processes and emergency management systems (iv) Strengthening of coordination and cooperation among all relevant actors in the early warning chain	Management science, **Information Systems Research,** Computer Science, Geophysics, Oceanography, Meteorology, Biology
Capacity provisioning (i) Support the development and improvement of databases and the promotion of dissemination of data (ii) Promote the application of space-based earth observations, space technologies, remote sensing, geographic information systems, hazard modelling and prediction, weather and climate modelling and forecasting, communication tools and studies of the costs and benefits of risk assessment and early warning (iii) Establish and strengthen the capacity to record, process and disseminate information on hazards mapping, disaster risks, impacts, and losses	**Information Systems Research,** Computer Science, Meteorology Space research, Engineering, Management science

Table 2. Multidisciplinary challenges and key activities required in Natural Disaster Management Research, based on (UN/ISDR, 2005)

Key activities required	Scientific disciplines responsible
Challenges/Priorities for action: Use knowledge, innovation and education to build a culture of safety and resilience at all levels.	
Rationale: Disasters can be substantially reduced if people are well informed and motivated towards a culture of disaster prevention and resilience	
Information management and exchange (i) Provide easily understandable information on disaster risks and protection options, especially to citizens (ii) Promote the use of information and communication technologies and related services to support training and dissemination of information (iii) Develop user-friendly directories, inventories and information-sharing systems and services for the exchange of information on good practices, cost-effective and easy-to-use disaster risk reduction technologies, and lessons learned on policies, plans and measures for disaster risk reduction. (iv) Update and widely disseminate international standard terminology related to disaster risk reduction in all official United Nations languages	**Information Systems Research,** Computer Science, Cultural studies, Sociology
Education and training (i) Promote disaster risk reduction knowledge in school curricula (ii) Develop training and learning programmes in disaster risk reduction	Cultural studies, Sociology, Communication studies
Public awareness: Promote the engagement of the media in order to stimulate a culture of disaster resilience	Cultural studies, Sociology, Communication studies
Challenges/Priorities for action: Reduce the underlying risk factors.	
Rationale: Disaster risks related to changing social, economic, environmental conditions need to be addressed in sector development planning	
Environmental and natural resource management (i) Encourage the use and management of ecosystem (ii) Implement integrated environmental and natural resource management approaches (iii) Promote the integration of risk reduction into strategies for the reduction of disaster risk	Environmental science, Management science
Conduct social and economic development practices	Economics, Sociology
Conduct land-use planning and other technical measures	Environmental science, Engineering
Challenges/Priorities for action: Strengthen disaster preparedness for effective response at all levels.	
Rationale: At times of disaster, impacts and losses can be substantially reduced if authorities, individuals and communities in hazard-prone areas are equipped with the knowledge and capacities for effective disaster management.	
(i) Strengthen policy, technical and institutional capacities (ii) Promote and support dialogue, exchange of information and coordination (iii) Strengthen and develop coordinated regional approaches (iv) Prepare or review and periodically update disaster preparedness and contingency plans and policies (v) Promote the establishment of emergency funds (vi) Develop specific mechanisms to engage the active participation an ownership of relevant stakeholders	Political science, Cultural studies, Management science

Table 2 (cont'd). Multidisciplinary challenges and key activities required in Natural Disaster Management Research, based on (UN/ISDR, 2005)

Reference	Artifact studied Methodologies/ Models	Key results
Challenge: Risk assessment		
Ajami & Fattahi, 2009	Earthquake information management systems (EIMSs) Survey, criteria rating technique, Delphi technique	EIMSs in Japan, Turkey and Iran are decentralized; information system can only influence decisions if relevant, reliable and available for the decision makers in a timely fashion
Becker, 2012	– Semi-structured interviews	High discrepancies between accounts on different administrative levels concerning key functions of their system possible
Gierlach et al., 2010	– Experiment	Cultural factors may have a greater influence on risk perception than social exposure
Ho et al., 2008	– Survey	General public concerned about hazards that might affect their residential area; negative associations between the sense of controllability and the perceived impact is high for landslide victims, but not for flood victims; disaster type, gender, and previously experienced disasters are good predictors of victims' attitudes toward natural disasters
Hsieh, 2004	– Data-analytic method	Data-analytic method to forecast the severity of next record insured loss to property
Ibem, 2011	– Survey	Identification of factors militating against the adoption of effective disaster vulnerability reduction strategies: most critical were faltering institutions and governance, weak infrastructure base and a low level of disaster education.
Jennex, 2010	Crisis Response Systems –	Exploration of issues affecting social media adoption by organizations for crisis response; proposition of the use of knowledge management strategy as a process for mitigating these issues and guiding organizations in adopting social media into their crisis response plans.

Table 3. Contribution of the Natural Disaster Management literature

Reference	Artifact studied Methodologies/ Models	Key results
Challenge: Risk assessment		
Masys, 2012	– Red teaming and scenario planning	Red teaming, within the context of scenario planning, facilitates the exploration of factors creating uncertainty and the emergence of black swans
Rahm and Reddick, 2011	– Survey	Misperception of risk among chief administrative officers (CAOs) from the largest US cities
Sharma et al., 2012	– Fuzzy AHP	Identification of forest fire risk zones
Challenge: Information provisioning to citizens		
Ahrens and Rudolph, 2006	– –	Institutional failure is the root cause for underdevelopment and susceptibility to disasters
Sutton et al., 2011	– –	Online information exchange behaviors of federal and state organizations: patterns of posting and information on following network
Challenge: Develop people centered early warning systems		
Abon et al., 2012	Watershed models Experiment; flood model development scheme	Development of watershed models for different rainfall events
Lendholt and Hammitzsch, 2011	Concepts of generic information logistics for distant early warning system –	Development of concepts of generic information logistics
Lendholt et al., 2012	Large scale, ocean-wide warning infrastructures –	Development, reference implementation and test of a communication model

Table 3 (cont'd). Contribution of the Natural Disaster Management literature

Reference	Artifact studied / Methodologies/ Models	Key results
Challenge: Risk assessment		
Chen et al., 2009	– / Support vector machine	Natural disaster risk assessment model
Grolinger et al., 2013	– / Case study	Knowledge as a Service (KaaS) framework is proposed for disaster cloud data management
Hailin et al., 2009	– / Joint use of space analysis and GIS	Estimates of flood-risks for areas in the Hubei Province
Huang & Inoue 2007	– / Fuzzy probabilities	Soft risk map
Iliadis & Spartalis, 2005	Decision support system estimating forest fire risk / Risk estimates based upon fuzzy sets	Design of a system which supports a protection and prevention policy
Liu et al., 2010	Geographical information systems / Information diffusion-based methodology	Geographical Information Systems for risk analysis of grassland fire disaster to livestock production in the grassland area of northern China
Park et al., 2011	– / –	Application of an Enterprise Risk Management ERM framework to disaster risk management
Ruyan & Shijun, 2009	– / Pattern recognition/fuzzy clustering	Assessment index system to appraise the disaster risk degree
Simard and Eenigenburg, 1990	Executive Information System / –	Executive information system to support federal wildfire disaster declarations
Tsai et al., 2011	Knowledge management system / –	Description of the expansion of the natural knowledge space through the use of a spatial mediator included in a dynamic visual topic map.
Tseng et al., 2006	– / Probabilistic computation	Probability model for risk control decision making under uncertainty
Yi et al, 2007	– / Fuzzy mathematics theory of information diffusion	A frequency analysis method of flood disaster loss is for flood disaster risk analysis

Table 4. Contribution of the Information Systems literature

Reference	Artifact studied Methodologies/ Models	Key results
Challenge: Risk assessment		
Yifeng, 2009	Geographic information system platform –	Primary assessment for flood risk in Hubei Province
Zhang et al, 2002	– –	Knowledge management framework that integrates multiple information technologies to collect, analyze, and manage information and knowledge for supporting decision making in HA/DR.
Zheng & Zhang, 2008	– Fuzzy set theory, Information distribution method	Models to calculate fuzzy random risk on the basis of incomplete data
Zischg et al., 2004	– Monte Carlo simulation, fuzzy logic	Approximations of risk parameters can be represented transparently and systematically when vagueness associated with numeric quantities occur; uncertainties in risk analysis have a significant influence on the subsequent procedures in risk management
Zou et al., 2011	– Fuzzy risk analysis	Diffused-interior-outer-set model to evaluate flood risks
Challenge: Information provisioning to citizens		
Iyer & Mastorakis, 2006	– –	Description of phases of disaster management and stakeholder coordination
Khatwani, 2012	Mobility assisted disaster management systems –	Mobile applications provide an opportunity to assist the identification of natural disaster victims
Youhai & Yuan, 2010	Earthquake disaster reduction information management system –	Earthquake disaster reduction information management system for risk analysis
Challenge: Develop people centered early warning systems		
Lee et al., 2011	– –	Customized disaster information search service based on a map and suggestion of a disaster information notification service based on an application user interface
Teshirogi et al., 2009	Early warning system –	Tsunami warning system using information services on mobile phones.
Yifeng, 2009	– –	Phases for the construction of early warning systems

Table 4 (cont'd). Contribution of the Information Systems literature

Reference	Artifact studied Methodologies/ Models	Key results
Challenge: Risk assessment		
(Dilley et al., 2005)	Indexes of disaster risk –	Indexes of disaster risk-mortality risks, risks of total economic losses, and risks of economic losses expressed as a proportion of the GDP
(Fowles et al., 2009)	– Linear regression model, OLS	Earthquake risk matters in determining the interest costs for municipalities issuing debt
(Jametti and von Ungern-Sternberg, 2010)	– Equilibria	Model of reinsurance in a natural-disaster insurance market
(Kaklauskas et al, 2007)	– Multiple criteria decision making theory	Knowledge Model for Post-disaster Management
(Lall & Deichman, 2012)	– Review of empirical work and discussion	Exposure to natural hazard risk in urban areas is large and increasing; cope-mitigate-transfer framework of risk management applies to different types and sizes of cities in a country's urban system; hazard risk reduction in cities requires good general urban management; collection and public disclosure of information on hazards helps people and businesses make better choices on where to live and where to invest.
(Liangqun, 2010)	– Natural disaster risk index method, AHP, weighted comprehensive analysis	Model of risk assessment of geological disasters
(Maliska, 2006)	– –	Design of an architecture for risk assessment, consisting of SOA, data management services, a workflow management system and portal technology
(Miles and Morse, 2007)	– Elaboration likelihood model	Future perceptions of risk due to natural hazards will reflect the attention paid to each capital (four capital types, natural, human, social, and built) in media coverage
(Mozumder et al., 2009)	– Survey-based contingent valuation method	Median estimated willingness to pay for the provision of a wildfire risk map is around U.S. $12

Table 5. Contribution of the other literature

Reference	Artifact studied / Methodologies/ Models	Key results
Challenge: Risk assessment		
(Raman et al., 2011)	Knowledge management system / Action research	KM systems can support DPR efforts by providing vital information and assist the overall coordination and planning efforts for the organization.
(Rød et al., 2011)	– / Survey	Different Perceptions of value of risk information types; dialogues with a diversity of publics are suggested to fully understand the nature of risk communication responses
(Rød et al., 2012)	– / Survey	Determinants of the willingness of the target population to adhere to evacuation instructions; trusted relationships with experts, socio-demographics and psychological individual differences do not add anything significant
(Skees et. al, 2008)	Insurance products / –	Demonstrates how a pool of index insurance products could be carefully regulated while also developing the needed structure to introduce micro-CAT bonds
(Västfjäll et al., 2008)	– / Experiment, statistic methods	Natural disasters have an effect on risk perceptions and future time perspective
(Xiu-li et al., 2009)	Flood disaster prevention decision support system / –	Design of a system which supports flood disaster decisions based on rainfall data
(Zahran et al., 2011)	– / Statistical analysis/ regression	Hurricane exposure increases the expected count of poor mental health days; count of poor mental health days is sensitive to hurricane intensity; measurability of mental health resilience as a two-dimensional concept of resistance capacity and recovery time
Challenge: Information provisioning to citizens		
(Basolo et al., 2006)	World-wide web / –	Virtually no research on the development of local governments' web sites for hazard preparedness or the usability of this information technology by community residents
(López-Peláez & Pigeon, 2011)	– / Comparative analysis of two case studies	Disaster prevention policies encourage an increase in urbanization

Table 5 (cont’d). Contribution of the other literature

Reference	Artifact studied Methodologies/ Models	Key results
Challenge: Information provisioning to citizens		
(Tsai & Chen, 2011)	– Case study	Necessary information for several stakeholders to make decisions about the best courses of action to take when disasters do occur; a basis for the design of effective risk-management strategies and the reduction or transfer of losses
Challenge: Develop people centered early warning systems		
(Escalaras and Register, 2008)	Early warning system Negative binomial regression model	Early warnings are quite effective in reducing deaths
(Hallegatte, 2012)	– Cost-benefit analysis	Large potential of investments in hydro-meteorological services and early warning and evacuation schemes to reduce the human and economic losses
(Liu et al., 1996)	Sirens/early warning systems Survey	Installing sirens, providing access to shelter and teaching appropriate responses to warnings are important elements of an effective disaster prevention system
(Samarajiva & Waidyanatha, 2009)	– –	Mobile phones are reliable, effective, and affordable solutions for alerting last-mile communities with significant mobile penetration; coordination mechanisms are suggested.
(UN, 2007)	Framework –	Framework for strengthening early warning systems in the Indian Ocean region

Table 5 (cont'd). Contribution of the other literature

Guideline	Description, adapted to the NDM context
Guideline 1: Design as an Artifact	Design-science research must produce an information process and/or information system oriented artifact (construct, model, method, or instantiation), which supports risk assessment and/or risk reduction
Guideline 2: Problem Relevance	The objective of design-science research is to develop socio-technology-based solutions to assess and to reduce risk in NDM.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions for the assessment and reduction of risk in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying cultural, legislative, and inter-organizational requirements in NDM.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to the IS community as well as NDM-oriented audiences.

Table 6: ISDS guidelines for future research in Natural Disaster Management, based on (Hevner et al., 2004; p. 83)

Guidelines	Challenges in Risk Management of Natural Disaster Management		
		Reduction of risk	
	Risk assessment	Information provisioning to citizens	Development of early warning systems and processes
Design as an artifact	Artifacts are inter-organizational information processes and distributed information systems.	Artifacts are information and communication systems, including user-friendly directories, inventories and information-sharing systems and services for the exchange of information on good practices at international, regional, national and local levels, and training systems.	Artifacts of interest are the architecture, the socio-technical design, and the information flows in early warning systems and their embedded information systems.
Problem relevance	Collecting, consolidating, analyzing, and distributing information on disasters are prerequisites to assess the physical, social, economic and environmental vulnerabilities to disasters.	Disasters can be substantially reduced if people are well informed and motivated towards a culture of disaster prevention and resilience.	Development and deployment of people centered early warning systems is apparently one of the key unsolved challenges in effective NDM.
Design evaluation	Architecture analysis; process modeling and evaluating methods; case studies; field studies.	Field studies and controlled experiments with homogenous audiences in order to assess the usability of systems and the knowledge gain of users.	Early warning systems can be assessed after natural disasters when monitoring is in place; appropriate means of design evaluation are simulation runs.
Research contributions	(Relational or multidimensional) Data models; information storages including databases and data warehouses; information collection processes, such as extract-transform-load (ETL) processes used in data warehouse contexts; information analysis methods including data mining methods; information system architecture.	Design knowledge on how to build audience-specific and media-specific information provisioning and communication systems.	Knowledge on the design of people centric early warning systems and embedded information systems as socio-technical systems, and on methodologies for the simulation of these systems.
Research rigor	Modeling and analysis of information flows (Petri nets, UML); ETL processes and multi-dimensional data modeling; deriving design knowledge from instances.	Research rigor can largely benefit from concepts of socio-technical design; deriving design knowledge from instances.	Research rigor can largely benefit from concepts of socio-technical design; deriving design knowledge from instances.
Design as a search process	Enhancement of risk assessment capabilities while satisfying cultural, legislative, technical, and inter-organizational requirements; use of build-and-evaluate cycles.		
Communication of research	ISDS community and the NDM community are not very well connected and adopt different perspectives on natural disasters; community outlets should inform each other.		

Table 7. ISDS-based research agenda for risk reduction in NDM

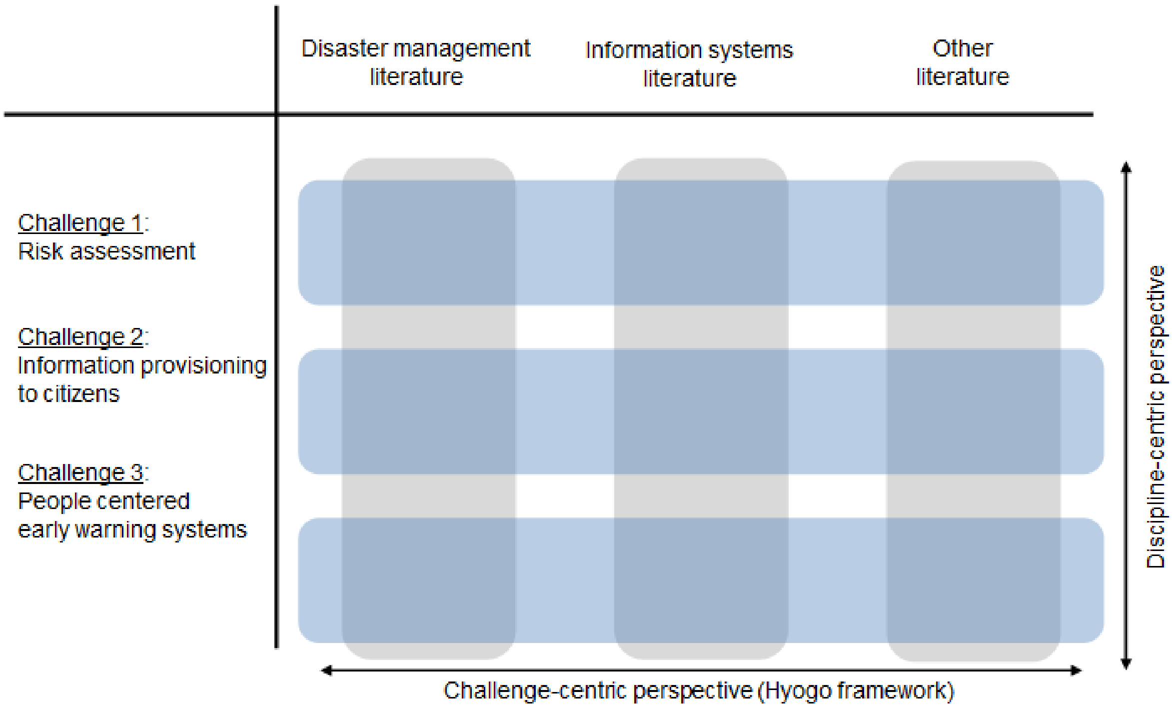

Figure 1. Matrix-based framework of the presentation and analysis of literature findings