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PREPARING FOR COMPLEX INTERDEPENDENT RISKS: A SYSTEM OF SYSTEMS APPROACH TO BUILDING DISASTER RESILIENCE

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Abstract

In a disaster, risks connect beyond the boundaries of individual emergency management organizations. These organizations depend on each other as well as on governments, communities, partner institutions and individuals, all of which are subject to evolving environmental conditions. Disaster resilience thus depends on the whole interconnected system and not simply on individual organizations.

The uncertainty posed by natural and human-made disasters arises from both known risks and a range of unforeseeable risks, some of which may be novel, not having been observed before. These interconnected risks may evolve over short periods of time and may feed into one another. In a network of multiple causes and effects, such risks may not be foreseeable at the disaster preparedness level, and may only be observed at the time of disaster response. This creates a higher level of complexity and requires new approaches with individual organizations and members needing to make decisions outside predefined frameworks and hierarchical command-control structures while still operating in the ethos of their organizations.

This study advocates the need for disaster preparedness strategies to go beyond linear approaches to risk management. This is necessary in order to better address complex interdependent risks where such risks may be novel or unforeseen and which may connect in a cascading manner. The resulting causal network needs to be addressed with a networked approach in order to enrich existing linear approaches by recognizing the need for an interconnected holistic approach to deal appropriately with interconnected risk factors.

Systems theory, System of Systems (SoS) and complex systems thinking were used in the study to explore networked approaches to support the community in building resilience in preparation for future unexpected disaster risks.

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Introduction

The Hyogo Framework for Action (HFA, United Nations 2005) and subsequent national strategies such as the Australian National Strategy for Disaster Resilience (NSDR 2011), highlight the importance of assessing risks and preparing for them (Childs et al. 2013).

This study is based on a research project, which was funded by the Australian Natural Disaster Resilience Grant Scheme, an Australian government initiative to enhance disaster resilience building. The Australian National Strategy for Disaster Resilience (NSDR) in particular has encouraged research beyond the borders of individual organizations, to focus on the empowerment of communities to increase their resilience in response to disasters. This strategic goal was formulated in response to bushfires, cyclones and floods that have recently intensified in Australia due to climate change (Steffen 2013). The intent of the NSDR is to promote collaboration between disaster management practitioners and local communities to build disaster resilience.

Disaster preparedness strategies are deployed to mitigate disaster risks and to build community resilience. Therefore, there is a strong connection between disaster resilience, disaster preparedness and risk management.

Current disaster preparedness strategies often focus on building resilience for known disaster risks. However, disasters are characterized by interdependent and systemic risks that can trigger cascading effects (Lorenz, Battiston & Schweitzer 2009) which are hard to predict. The 'unexpected' is already part of the life of many communities. For this reason, there is an urgent need to investigate ways to prepare for what we are not able to predict or to communicate.

Drawing on complexity theories, we provide a sense-making framework on preparing for the unexpected by creating networks capable of building general resilience, that is, resilience to unknown risks.

Risk Assessment today

The majority of risk assessments take the approach of ISO 31000[1] (Leitch 2010), which defines risk as 'the effect of uncertainty on objectives'. This standard is based on the assumption that risk identification is the first step in managing risks. Therefore, many people use the ISO 31000 process of identifying a series of individual risks, assessing their individual likelihoods and consequences, and then comparing these. They then calculate the individual risks, either by qualitative or quantitative measures, evaluate their potential impact (as a product of likelihood and consequence) and finally sort them by severity of impact. Normally only the highest rated risks are addressed.

[1] ISO 31000 - Risk management http://www.iso.org/iso/home/standards/iso31000.htm and ISO/TR 31004:2013 for *Risk management - Guidance for the implementation of ISO 31000.*

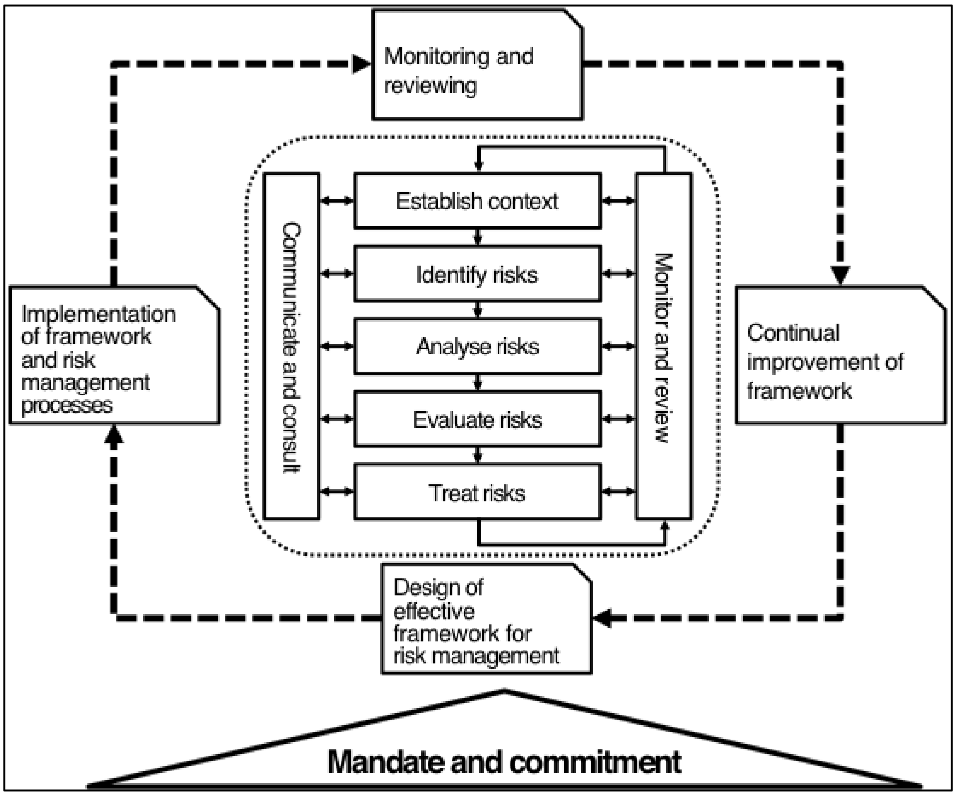


Figure 1: Risk management scheme in Australia (National Emergency Management Committee 2010, p. 7) based on ISO 31000.

This approach is valuable in the case of traditional projects where problems, or, in this case, risks, can be broken down into their components and strategies can be created to deal with them. Unfortunately, linear risk assessments fail to take into account the impact of unpredicted risks. This has become particularly significant as we confront climate change and the uncertainty of its effects on environment and populations (Van Aalst 2006).

ISO 31000 has clarified the steps to manage risks and has thus opened the way for risk management to be implemented in and by public organizations and governments. This has led to better informed decisions and more robust policies in terms of disaster preparedness. This approach has been used, for example, in areas of Australia that are prone to bushfires, by targeting community preparedness campaigns to raise awareness of risks and consequences; and in the Philippines, where local governments are working to prepare for typhoons, earthquakes and volcanic eruptions (Arman 2013).

While there seems to be a robust basis for programs and research around how best to prepare the community for identified risks, disasters show increasingly unprecedented consequences. For example, typhoon Yolanda struck with unprecedented wind strength in the Philippines in November 2013 (Daniell et al. 2013). A further example is the Fukushima disaster in Japan in March 2011. An unprecedented chain reaction involved an earthquake and a tsunami triggering a nuclear disaster: the blackout of cooling systems to reactors of the Daiichi nuclear power plant led to meltdowns and the release of radioactivity (Oi 2012).

Often when disasters cause heavy losses, a lack of preparation and information is blamed. However, modern disasters have shown that more information does not always correspond to higher safety or preparedness levels, especially where unanticipated events occur. For example, in the case of the previously discussed Fukushima disaster, the Japanese government, the Nuclear Safety Commission (NSC) and the company at the centre of the nuclear disaster, the Tokyo Electric Power Company (TEPCO) were aware of seismic, tsunami and nuclear risks (Funabashi & Kitazawa 2012; The National Diet of Japan 2012). Despite this, the Nuclear Safety Commission (NSC), which oversees the Nuclear and Industrial Safety Agency (NISA) did not put in place adequate regulations and these in turn were not imposed on TEPCO. For example, outages were addressed as temporary risks, because they could have been quickly solved as they occurred. Consequently, TEPCO addressed the crisis inadequately and even contributed to its worsening (Hatamura et al. 2011).

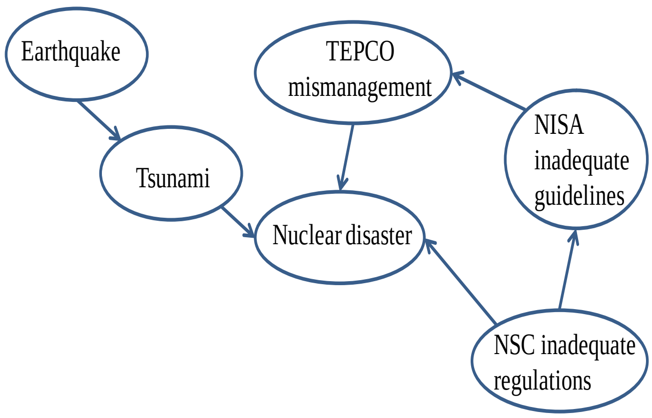


Figure 1 : A partial risk network of the Fukushima Daiichi disaster (Cavallo & Ireland 2012).

The underlying assumption of this analysis may be to suggest that stricter well implemented regulations would benefit the disaster severity. However, appropriate international regulations existed already at the time of the disaster, but TEPCO did not abide by them. This leads to a question on the effectiveness of international control and monitoring institutions and regulations, since government, nuclear authorities and TEPCO knew about them, but they did not put them into place (Cavallo & Ireland 2012).

An increased level of knowledge does not necessarily mean better disaster management. Disasters are often emergences. The word 'emergence' refers to the formation of new system properties as the result of evolutionary behavior (Boardman & Sauser 2008). In this sense, disasters trigger unique events that have never occurred before and that may never happen again with the same characteristics.

Statistical and modelling approaches to the complexity of systemic resilience have increased our understanding of past events. However, modern disasters have shown a number of unanticipated emergent and cascading effects. For this reason, there is a strong need to investigate new ways to prepare for unexpected interdependent risk events which trigger cascading effects (Helbing 2013).

The prediction of cascading failures can be particularly difficult for two reasons. First, information is often scarce or insufficient to use approaches such as robust Bayesian methods (Ruggeri et al 2005), which are normally drawn on when the degree of uncertainty is considered very high and unmanageable without modelling support (Comes & Cavallo

2013). Second, public awareness of risks as identified by disaster prevention agencies is limited, leaving the rest of the population unprepared. Consequently, the challenge for regulators and practitioners is to design policies and disaster preparedness strategies that align with the capacity of, for example, individual communities and businesses.

Research around disaster preparedness has been mainly linear in approach, focusing on known risks. However, this approach is limited, with sometimes inadvertently serious consequences, when for example:

- The interactions between different risks are not considered, e.g. earthquake, tsunami and nuclear disaster in Japan
- The gradual worsening of environmental conditions is neglected, e.g. increased number of natural disasters or sea level rise
- After disasters, lessons learned focus on actions specified in existing regulations rather than on an analysis of the disaster's development and changed conditions. As a result, lessons learned do not provide appropriate interconnected guidance for future risk and disaster preparedness
- 'Extreme weather' has been planned for as an exceptional condition, something that happens rarely; however, natural disasters have become so frequent that they are increasingly part of a community's routine
- Information fails to reach communities
- Information is not specific to the community's context

Even though many disaster risks cannot be predicted, there is potential to prepare for them (Gilpin & Murphy 2008). Unknown risks can be managed.

Why system thinking in disaster preparedness

Risks are often described as linear cause-effect relationships. They are compiled on a risk register, evaluated and addressed individually. This process has brought important outcomes such as information sharing with the wider community and awareness raising campaigns.

However, in some cases such as those already discussed, risk assessments of this kind fail to reflect the actual risk situation. This is the case when relatively unrelated systems affect each other. Examples are: the economic and broader impacts of asset price collapse, regulatory failure, illicit trade, global governance failures, migration driven by economic disparity, terrorism, weapons of mass destruction, chronic diseases, increasing storms and cyclones due to climate change, inadequate governance of ocean management, corruption, and other causes (Helbing 2013).

Systemic failures result from chain reactions and cascading effects across different systems and are triggered by the highly interconnected systems that emerge or have been created to increase efficiency. An example is open markets. Hyper-connected systems like these result in networked and interdependent risks, which can spread globally. Events such as the U.S. sub-prime mortgage crisis have an effect well beyond one country's borders. Risks like these are not to be seen as confined to a certain geographic area. The sociologist Beck (2011) conceptualizes these as risk societies ('Risikogesellschaften'), that is to say, groups of people sharing the same risks.

Furthermore, risk assessments are sometimes not seen in their context, which may lead to a clash with local contexts. For instance, corruption can dramatically reduce the impact of risk assessment procedures when local government self-interestedly allows new buildings in flood prone areas against recommendations emerging from risk assessments. Worse, the public interest may not be the focus of assessment, rather private interests have priority. There is a need for public dissemination of risk related information to be networked and viral rather than being delivered through top-down processes. Therefore, a challenge exists to address these concerns more transparently, to undertake comprehensive risk assessments and to contextualise them appropriately.

Each community and household has particular vulnerabilities and is subject to conditions that are impossible to take into consideration a priori. For this reason, we suggest that even linear risk assessments need to be fact and situation based, to avoid being based on idealized and static system conditions. A system is an abstract concept used to indicate, for example, a community, a state, a nation, a social network. A system can describe any set of interconnected parts (Yasmin & Peter 2011).

Risk assessments should address the difficulties in implementing action plans and factor in community assets that can contribute to resilience under local conditions.

Contextualizing risks in their network can provide a different perspective, which goes beyond linear risk assessments by including events that may be otherwise considered impossible. Future disasters will be an emergence for most affected people. In this sense, lessons learned from the past need to be integrated with approaches that support preparation for future unanticipated disaster events.

This is significant as, after the event, possible causal paths to disasters can be identified. Nonetheless, it is hard to clearly determine and isolate all the concurrent causes, which generate and flow from disasters such as Fukushima, hurricane Katrina or typhoon Yolanda. Causes can be multiple and hard to classify, for example, natural disaster, complacency, corruption, ignorance, religious misbeliefs. When analyzing lessons learned, we have a bias to favor the causal paths that we already know and can recognize.

One of the causes may be the assumption that general safety is a function of the safety of individual components (Leveson 2011). This can also be adopted in resilience thinking, where there may be a misconception about the fact that individual and community resilience are the same, in the sense that one is directly proportional to the other. Safety and resilience directly relate to successful disaster preparedness and response strategies. Like safety, community resilience is not simply the sum of resilient people living in a community. It refers to the whole system and not to its individual components. This is also the case with disaster preparedness strategies. Different organizations may take the optimal decision for a specific situation or for their organization. However, their decision will have an impact on the other organizations, as well as of course, on the entire accident dynamics, i.e. the overall system.

The need to consider a disaster as a whole (Salmon et al. 2012), rather than taking a series of partial perspectives on the event, acknowledges that disasters are not simply the sum of their component parts. Disasters involve different independent systems, which are all dependent on each other. Therefore, a disaster can be considered as a system of systems (SoS). Systems of systems are networked, all-integrated systems, which are composed of autonomous independent systems, which to an extent operate separately. Additionally, systems belonging to a SoS are heterogeneous and contribute to the evolution of the SoS towards unpredictable states or conditions (Boardman & Sauser 2008).

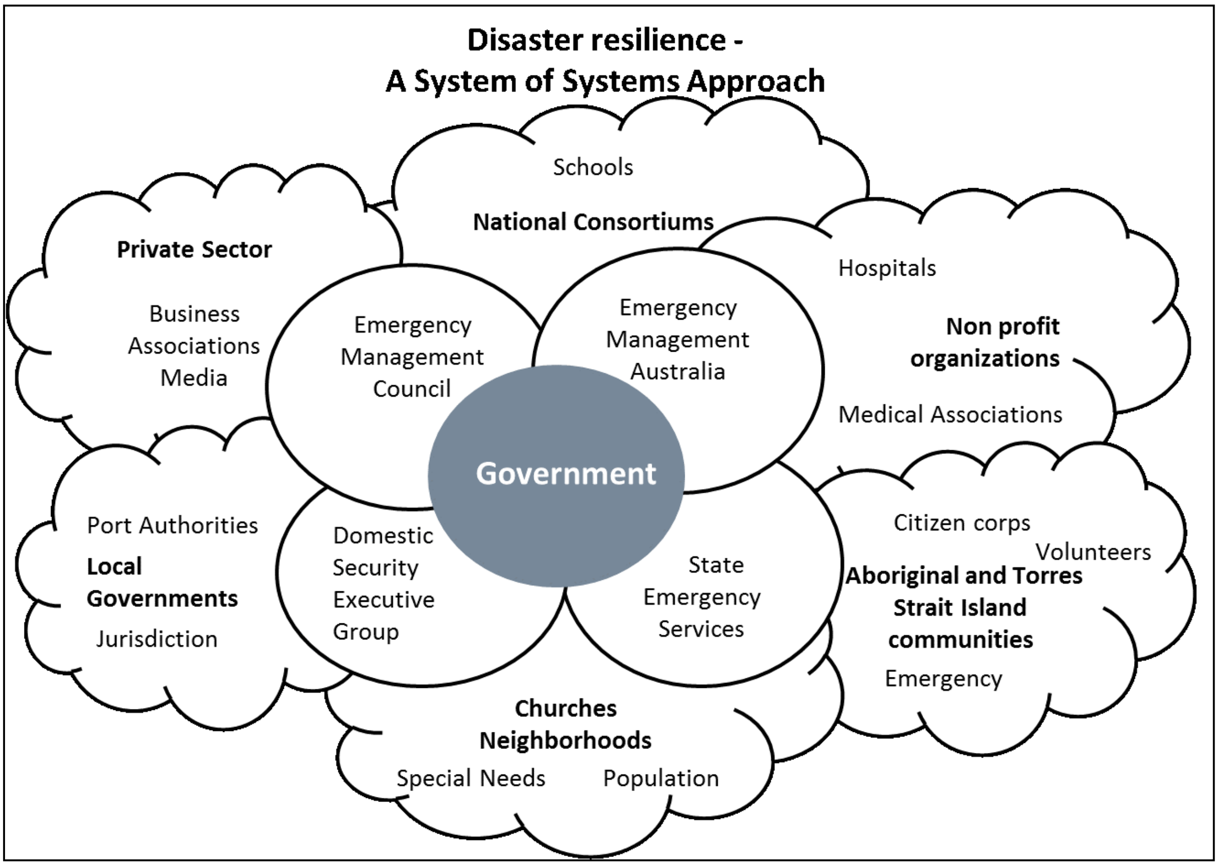


Figure 2: Disaster Resilience in a System of Systems.

Figure 2 gives an example of a SoS for disaster resilience in Australia. As we illustrate later in this paper, the impact that community groups and religious institutions, for example, can have on building a community's resilience are at least as important as information provided by federal and local government.

As the HFA encourages research on community resilience, systems theory offers a global vision of disasters and their management from the very first steps of preparedness. In this paper, we focus on a holistic approach in terms of existing systems, but also acknowledge the challenge of thinking holistically in terms of time. Risk networks are subject to causal relationships that are spatial (e.g. environment, other stakeholders, competing systems) and temporal. Systems belonging to the same system of systems can influence each other both in space and time.

Disaster preparedness planning should take this into consideration, as the adoption of a system of systems approach to disaster resilience would better address the complex challenges of climate change and increase the general level of readiness for unexpected acts such as the 9/11 terrorist attack or the 2004 tsunami disasters.

Complex and systemic risks

Linear causal relationships constitute only a part of the risk network that emerges when disasters strike. We argue that, from a cognitive point of view, in a disaster, there are at least two types of risks. Complicated risks are characterized by cause-effect relationships that can be understood in advance, before the risk event occurs. Bush fires can be considered as an example. Stochastic approaches are appropriate for many complicated risks, where information is available from past disasters.

Complex risks are different in nature (Loch, DeMeyer & Pich 2006). Cause-effect relationships can often only be understood in hindsight (De Rosa et al. 2008), after disasters occur. At the outset, it can be difficult to identify clearly the area in which the risk could emerge. In this case, there is a perceived 'problematical situation' (Checkland & Poulter 2006), but causes and/or solutions cannot be identified.

In complicated systems, cause and effect can be identified in advance, whereas in complex systems the correlation between causes and effects is only clear in retrospect (Snowden & Boone 2007). Complicated systems can be broken down into their components, whereas complex systems involve interactions and interdependencies, which cannot be separated, i.e. the sum of the components does not equal the whole.

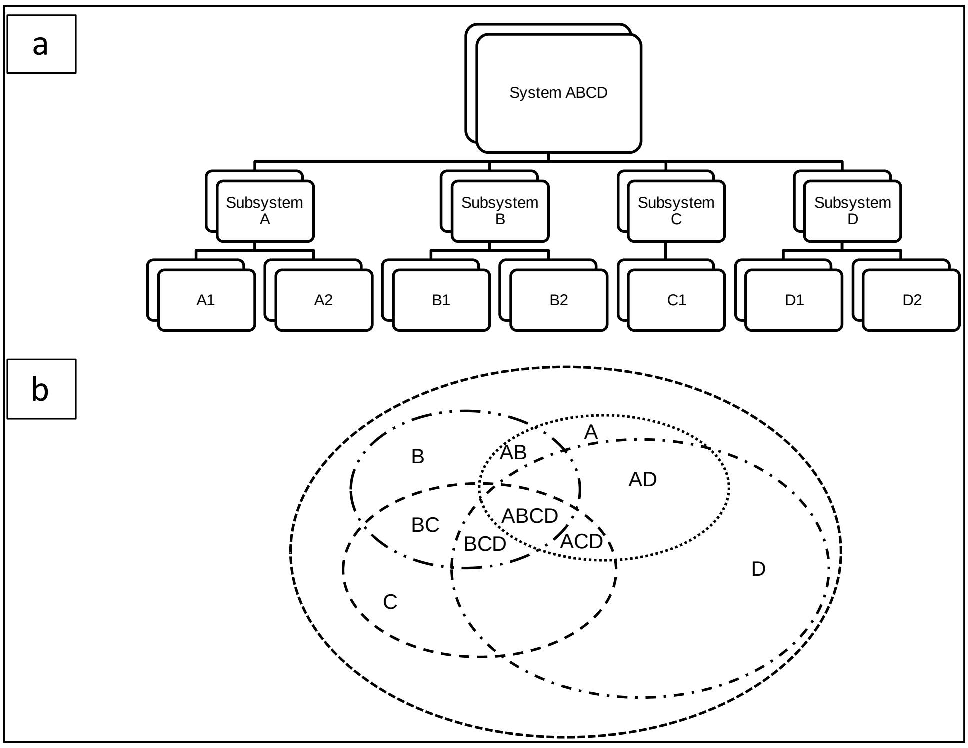


Figure 3: Difference between a complicated (a) and a complex system (b) (Williams 2002 in Cavallo 2010)

An example is the outbreak of major bushfires in Sydney, Australia in October 2013. A number of relatively unrelated systems combined to result in thousands of hectares of land burnt and over 200 homes destroyed. The interacting systems on that day included:

Climate

- A previous winter which was 1°C warmer than average;
- A winter with low rainfall;
- A maximum temperature of 38°C on the day;
- Winds of over 80 km/h on the day;
- Lightning strikes starting fires;
- Ignition of some fires due to sagging power lines due to the high temperatures before the fire

Geography

- The topography in some of the national parks, of fires occurring in the valley and then racing up very steep cliff faces;
- Excess fuel and inadequate clearing of fallen timber in National Parks;

Governance

- Australian Defence Forces testing munitions - there were no warnings that this was not allowed;
- Inability to fight the fire due to unexploded ordinance remaining in the 'testing zone';
- Inadequate construction of housing, due to inadequate local government requirements, and inadequate clearing of land around houses to resist intense fires, with flames exceeding 10 m in height.

Networked effects are very different to effects in hierarchical systems and generally follow power laws (Strogatz 2001; Barabasi 2002). Power failures in the United States of America in 2003 and 2011 illustrate the vulnerability of interlinked systems, where the failure of one component cascaded through several levels (or scales) leading to a global system failure (Guckenheimer & Ottino 2008).

The notion of power law relationships is well described by Pareto, who concludes that in general terms, 80% of the effects occur from 20% of the causes. However, two concepts of risk, that is systemic versus systematic risk, display different statistical properties (Andriani & McKelvey 2010). The 20% of events responsible for 80% of the outcomes, traditionally a systematic risk, follow a Gaussian distribution, which is approximately normal, and hence linear and reasonably predictable. However, the 80% of events responsible for 20% of the outcomes follow a power law set of relationships in which inputs and outputs are related by a power law. This power law relationship means that the outcomes are not in proportion to the inputs and are more difficult to predict. These are the systemic risks, which Helbing calls networked risks (2013).

Systemic risks show a 'high degree of heterogeneity and distributed interdependence leading to extreme variance' (Andriani & McKelvey 2010). It is argued that the Paretian approach makes sense of an entire class of phenomena, which "are difficult or impossible to explain via Gaussian" approaches based on finite variances such as extreme events (West & Deering 1995). The population in cities follows a power law relationship when ranked by population, as does the structure of the Internet, an aspect which was identified by Barabasi (2002). If different statistical behaviors demonstrate power laws, then traditional methods of analysis, such as regression techniques, are not applicable for non-Gaussian statistical behavior. Therefore, systemic processes are required.

Resilience thinking

Resilience. This ancient word - Cicero used it in his Orations (Alexander 2013) - has been used to mean different things over the years and across a plethora of disciplines such as engineering, social sciences and, more recently, disaster risk reduction. It is also something of a buzzword requiring its usage here to be made clear.

Characteristics

Resilience is often defined through the characteristics of a resilient system. For example, "Your community will prove resilient in the event of a severe emergency or disaster when members of the population are connected to one another and work together, so that they are able to:

- function and sustain critical systems, even under stress;
- adapt to changes in the physical, social or economic environment;
- be self-reliant if external resources are limited or cut-off; and
- learn from experience to improve over time" (TRI 2012).

Strong relationships are normally seen as positive drivers of resilience. Community members share their physical, cultural and emotional assets by living in 'networks of relationships'. This can be summarized as 'social capital', which is seen as an important catalyst for community resilience. Nevertheless, resilience is also considered as an emergent property of system components, which being connected through loose relationships, are more autonomous than strongly connected system components (Ramalingam et al 2008). For this reason, they are believed to recover more easily from a change in the system whereas strongly connected elements are impacted more intensely. As a result, the loosely connected system components can embrace change more easily because these do not have an important impact on the system as a whole.

For example, after Hurricane Katrina in August 2005, New Orleans neighborhoods with a high level of civic participation (measured through percentage of people going to vote) and a strong identity, would not accept temporary housing in their areas (Aldrich 2012). They did not accept what they thought did not belong to their community identity. This caused significant delays in the recovery process.

Definitions

By its very nature, resilience is a dynamic system property. Therefore, a finished and complete definition of resilience is difficult to formulate. We acknowledge that resilience and its products can be very diverse determined by specific system characteristics. Depending on particular vulnerabilities and strengths, people's reactions to emergencies can be very different.

There are many definitions of resilience. The most common is probably "the ability to bounce back" (Zolli and Healy 2012). Unfortunately, this is also amongst the least useful when talking about interdependent risks. 'Bouncing back' in the event of disaster is not a linear process, just as the cause-effect relationships are complex, so too is recovery. What we are really aiming for is drawing on community and individual resources, and those available from outside the system, to 'bounce forward'.

One definition which reflects complex systems and acknowledges uncertainty is "Community resilience is the existence, development, and engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability, and surprise" (Magis 2010, p. 402). 'To thrive' is aspirational rather than realistic and itself could be the subject of significant discussion.

While this definition addresses the ever-changing nature of resilience and the exposure of the community to external shocks, it fails to address the openness of the community as an important factor in preparation for disasters. This definition suggests that in such situations, a community should recover based only on its internal assets, without relying on external help. Furthermore, the interconnectedness of the risks underlying this definition is not taken into consideration.

In practice

The process of building resilience needs to be a networked process incorporating community assets rather than solely identified risks.

The dynamic nature of resilience makes it difficult to address in policies or frameworks such as HFA2. However, building resilience can be considered as a complex project, where there is no set beginning, rather a natural continuation of systemic conditions; no set end point and the actual outcome cannot be clearly defined (Cavallo 2010).

The fact that resilience is complex should not prevent us from engaging in practices and policies aimed at building disaster resilience. We assert that current approaches to disaster preparedness primarily reflect our experience of response to past disasters. Much of what we do is evidence-based. Statistical projections or modelling start from past information of the system's behavior. These approaches are fundamental in making communities more resilient. However, they have the limitation of neglecting the level of uncertainty that future disasters will involve and which make defining resilience so complex.

Uncertainty relates, for example, to the degree of preparation of the wider community; individuals' reactions to emerging risks; unpredicted cascading effects; unknown risks. Additionally, when modelling interdependent cascading risks, it is only possible to identify a number of potential causal paths yielding sets of possible scenarios; we cannot be sure that all possible causal paths have been identified; nor can we be sure of communities' reactions to emerging risks.

Current disaster preparedness approaches have significantly aimed to build resilience to known risks in the community. Typically, these approaches are tailored around the highest rated risks identified in a geographic area, for example, flooding, earthquakes and bush fires. Depending on the risks identified and on the subsequent action plans, committees and programs are created to respond to the need to raise awareness within the community. Interdependent risks and cascading failures are discussed in lessons learned, but they often fail to be addressed in disaster risk reduction plans.

A social-ecological perspective helps to explain. Social-ecological systems describe environmental and human/social system interactions. In the adaptive cycle pictured below, four phases are illustrated: rapid growth, conservation, release and reorganization (Walker & Salt 2006). In disaster risk reduction, a community can be seen as a system going through these four phases. At the beginning, the community can grow (rapid growth) allowing a few people to develop gradually into a bigger community with routines and stable functions (conservation). When a disaster occurs (release), the impact on the community is such that reorganization and review of fundamental community functions and routines will need to change (reorganization) to allow a new start of growth.

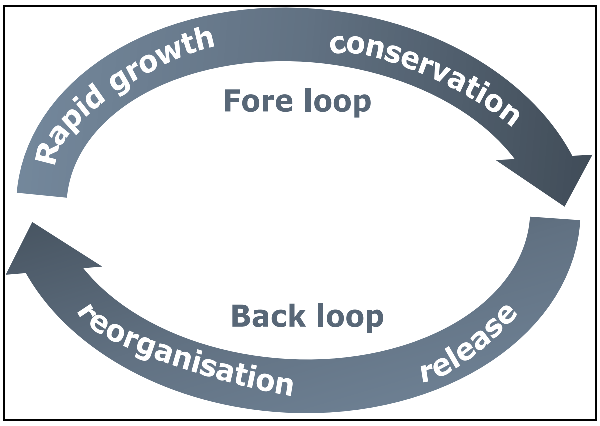


Figure 4 : Adaptive Cycle simplified (Walker & Salt 2006)

The fore loop includes rapid growth and conservation and it is characterized by stability and certainty. On the contrary, the back loop, involving release and reorganization, is characterized by uncertainty.

Addressing interdependent risks in disaster risk reduction plans is challenging and complex because of ambiguity, lack of precision and inadequate information (Comes & Cavallo 2013). Uncertainty makes us uncomfortable. Descartes found a way to systematically address what we do not know (Morin 2007). The focus of recent centuries, however has been on the fore loop of the adaptive cycle (Walker & Salt 2012). In disaster risk reduction, this corresponds to known and knowable risks. Chaos is described in hindsight, but because it cannot be controlled from the top, it is often considered as a temporary condition that will fade in the end (see Fukushima example on pp. 5-6).

As we approach higher levels of uncertainty arising from disasters, the focus of frameworks such as the HFA2 should broaden to include 'back loop research'.

Specified and general resilience

The following table illustrates the two types of approaches to resilience building that we have discussed. It should be noted that the following is a sense-making table that can support disaster risk reduction practitioners and researchers in explaining what many intuitively already know.

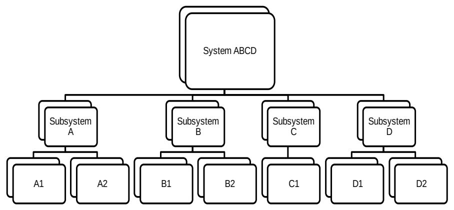
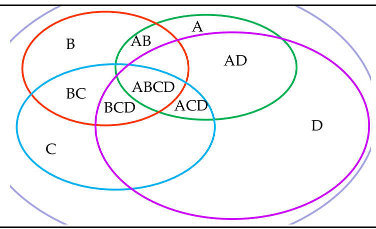
SPECIFIED RESILIENCE	GENERAL RESILIENCE
Reductionist	Abductive
	
System of subsystems (SoSS)	System of systems (SoS)
Identified risks	Unforeseen, unanticipated risks or unprepared community
Linear thinking	System thinking
Sense and respond	Probe, sense and respond
Mitigate risk of negative events	Keep a safe operating space

Table 1 : Characteristics of specified and general resilience.

Specified resilience refers to known risks, whose consequences have already been observed in the world. This is the case with many natural disasters. Action plans are normally reductionist, that is, risks are broken down into more manageable components that are addressed individually. Top-down thinking and management are usually applied to building specified resilience. Risks are addressed as 'systems of subsystems' (De Rosa et al 2008), because we assume that the sum of action plans composed makes the community more resilient. Each subsystem depends on the system above. Risk assessments are based on linear cause-effect relationships and the strategy follows a 'sense and respond' principle (Snowden & Boone 2007), in that general risk perception triggers the application of practices learned from previous disasters. The underlying philosophy is that it is possible to mitigate identified risks.

General resilience refers to the ability of a community to face unknown shocks. Approaches to build general resilience need to be bottom-up and top-down at the same time. For example, governments need to inform the community about emergency management arrangements as well as collect feedback on communities' assets and deficiencies to assess their self-organization capabilities. The complexity of these capabilities requires that these approaches follow an abductive logic, that is to say, that "hypotheses guide actions, [… and these approaches] are simultaneously tested through those same actions" (Flach 2012). The result is a 'probe, sense and respond' approach. Risks are typically interdependent and complex to assess. Network approaches are encouraged. Here, risk-reducing factors often come from programs and institutions that do not appear in disaster management plans. Examples are community gathering programs and institutions such as religious and sports groups. Additionally, communities can influence one another. Every system interacts more or less implicitly with others. However, contrary to specified resilience, most systems are autonomous and independent from one another. For this reason, they constitute a system of systems (SoS).

Unlike specified resilience thinking that aims to mitigate disaster risks by formulating specific plans, in building general resilience we are not able to specify the threat from which we are protecting the community. Hence, we focus on resources that would be critical in the event of any large-scale emergency such as hospitals and, more generally, on access to essential goods and services. In conclusion, we need to enlarge systems' resilience thresholds in order to maintain a safe operating space. Depending on communities' specific assets and weaknesses, which change over time, thresholds may vary significantly from community to community. This is why practices cannot be standardized; rather, risk reduction plans need to be conceived abductively, tested and adjusted regularly, based on the evolving feedback from communities and on their self-organization capabilities.

Specified and general resilience do not represent a dichotomy; communities need to build both because there is a trade-off between them: if we invest solely in specified resilience, the level of general resilience will drop, so that if something unexpected happens, the community will struggle to recover and move forward. Similarly, if we do not prepare enough for known risks, we risk undermining the community's ability to learn about the most likely risks and to react accordingly. At present, disaster risk reduction strategies are focusing more on building specified resilience and much work needs to be done in this space. However, as we approach a period of exposure to risks that are more highly interdependent and often unexpected, we suggest that policies should also embed principles of general resilience building.

Building general resilience starting from the community

For the purpose of this paper, we describe how we framed this research project, rather than discussing findings that are specific of the SoS studied. In the following section, we describe how we overlapped different scale views to arrive at a holistic view for interdependent and systemic preparedness to unexpected risks.

Disaster management involves a range of very different systems: governmental, political, historical, social, economic, financial, environmental, etc. For this reason, multiple lenses, theories and disciplines have to be involved to design a holistic approach, which encompasses and integrates diverse disciplines and systems. In academic terms, we may say that we took on-board the need of an 'epistemological pluralism' (Mileti 1999 in Boteler 2007).

This study drew inspiration from a range of disciplines and theories including, for example, engineering, social sciences, complex systems and social-ecological systems. In particular, we used Soft Systems Methodology (SSM) to collect data on general resilience building.

SSM was conceptualized by Peter Checkland in the 1990s. SSM offers an open methodology to deal with diverse worldviews and the difficulty of defining the problem for which a solution is being sought (Yasmin & Peter 2011). In disaster preparedness, it is important to consider different risk perceptions and perspectives; otherwise, the danger is to misinterpret community needs. For example, a great number of Indian laborers moved from rural to coastal areas after the 1977 cyclone, despite the fact that the coast was more exposed to cyclones. In absolute terms, they should have stayed in the backcountry to stay away from the risk of cyclones. Nonetheless, it was observed that they moved to the coast because their highest risk after the cyclone was starvation (Ibarraran 2009). This is also why preparing for interdependent risks requires us to acknowledge the complexity behind risk mitigation and the significant divergence of views arising from the expression of community needs. SSM allows an understanding and mapping of the multiple purposes of systems and people to develop a more widely accepted framework to address the 'problematical situation' (Checkland & Poulter 2006).

At this point, the question which may rise, is where to start with general disaster resilience? To address this question, we referred to previous studies and undertook a study in South Australia. The aim was to explore the idea of the unexpected and the related community systems' capabilities as preparedness assets. Interviews were also conducted in Östersund, Sweden, but they are not discussed in this paper.

In South Australia, interviews and focus groups involved community members, Red Cross staff and ten state government organizations responsible for prevention of the highest rated risks in South Australia.

Detailed consultations were carried out with community organizations, mid-level Red Cross officials and senior Government officials to ascertain the dynamics of their disaster prevention systems based on a System of Systems (SoS) paradigm. Each participant in these groups contributed their worldview regarding resilience building in their own system, as they perceive it, and to which they see themselves belonging.

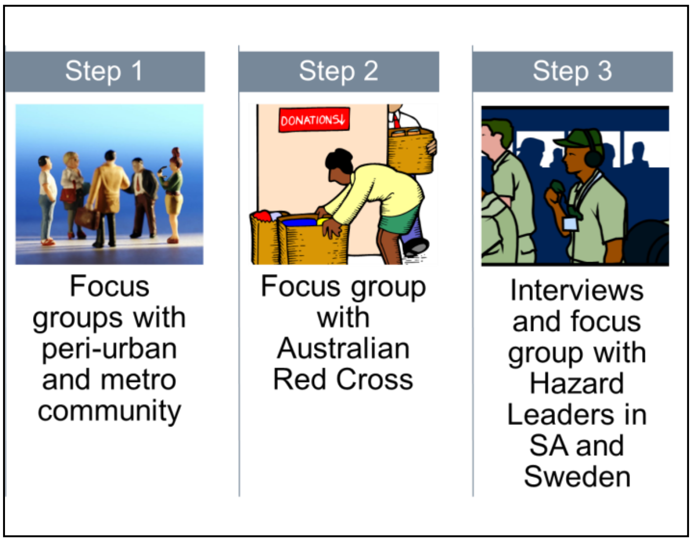


Figure 5 : The three research steps undertaken in 2013.

Community participants were introduced to the basics of complexity theories and guided in the conversation:

- to share their experience of the unexpected

- to identify current community resources supporting resilience building processes
- to identify barriers to general resilience
- to identify desirable changes to support the community in building general resilience

During focus groups, participants became increasingly aware of personal and community critical assets. We consciously avoided providing them with scenarios or with suggestions of what they should do in the event of something unexpected, which allowed participants to start from their own experience and definition of 'unexpected'. They came to appreciate the differences between supporting others in the short term, for example, immediately after a disaster has occurred, and in the long term, several months after a disaster. Finally, they reflected on existing and desirable community resources that could contribute to building general resilience.

Red Cross participants were asked to share their view on these points and to discuss current programs and their networked effects on the community. For example, the emergencyREDiPlan is an 'All-Hazard' program, where community members from the Adelaide Hills in South Australia learn how to prepare for disasters, so allowing them to share their specific vulnerabilities and doubts about the mainstream recommendations. In case of catastrophic risk of bushfires[2], vulnerable people living in the Adelaide Hills are strongly recommended to leave their house in advance. For many old people, this means taking a taxi into the city and waiting in the air conditioning of a shopping mall for the whole day. It can be an exhausting and expensive journey, which is not sustainable considering the increasing number of catastrophic fire risk days in a row. However, one of the network effects of the emergencyREDiPlan program was the following. One of the participants expressed discomfort about the suggested action to take in case of bush fire risk. She even said that she would not do it again, because last time, nothing had happened. However, another old person, who participated in the same session, suggested that next time a catastrophic day was announced, the other woman could go to her house and her son would pick them up and they could spend the whole day at her son's place.

Facilitating, understanding and exploiting network effects such as this example of collaboration, are essential in preparation for unexpected risks. We delved deeper into network effects in the focus group with Hazard Leaders, that is, the nine government agencies responsible for the prevention of the highest rated risks in South Australia, and the South Australian Fire and Emergency Services Commission (SAFECOM), which is the overseeing authority.

[2] This corresponds to the worst conditions for a bushfire. http://www.cfs.sa.gov.au/site/fire_restrictions/fire_bans.jsp

Organization	Risk, whose mitigation, they are responsible for
Primary Industries and Regions South Australia (PIRSA)	Animal and Plant Disease
Country Fire Service (CFS)	Bushfire
Department for Planning, Transport and Infrastructure (DPTI)	Earthquake
Safework SA	Escape of Hazardous Materials
State Emergency Service (SES)	Extreme Weather
Department for Environment, Water and Natural Resources (DEWNR)	Flood and Riverbank Collapse
Department of Health (SA Health)	Human Disease
Metropolitan Fire Service (MFS)	Urban Fire
SA Police (SAPOL)	Terrorism

Table 2: Hazard Leaders in South Australia (SEMP 2013).

Hazard Leader representatives were briefed about complexity theories on which this study is based and were invited to share their views on integration possibilities for risk assessment and disaster risk reduction in South Australia.

Every focus group was conducted in a manner that encouraged participants to express their personal views and to refer to their personal experience, rather than the 'ideal picture'. In this way we could discuss specific needs, strengths and vulnerabilities, rather than referring to best practices that sometimes can be taken out of context.

At the conclusion, we mapped different worldviews emerging from the focus groups conducted across the three groups (community, Red Cross and Hazard Leaders). This led to a series of important findings and to a much better understanding of:

- community routines into which general resilience related processes should be built;
- current and potential community capabilities on which to build general resilience
- cross-scale effects among different disaster stakeholders and across different systems
- possible points of contact and gaps in communication across different systems

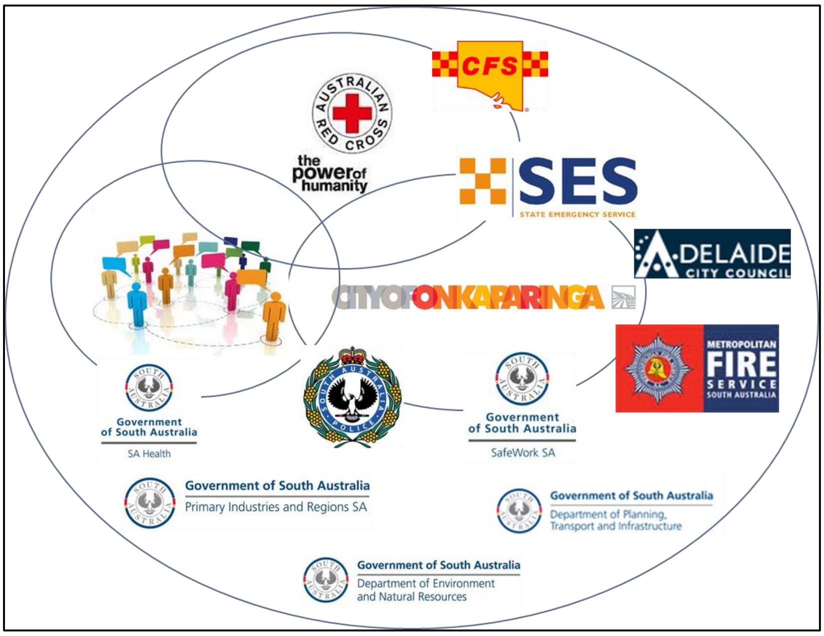


Figure 6 : A part of the System of Systems (SoS) in South Australia.

Finally, this study clearly confirmed the usefulness of complexity theories to build systemic general resilience.

Conclusion

Natural and human-made disasters are increasingly posing a threat to many communities. Areas that have not previously been affected by disasters are increasingly at risk. Disaster risks have been principally assessed following linear methods that neglected to consider risks in their causal networks. Recent disasters have drawn attention to the cascading effects of disaster risks that emerge in every disaster. Cascading effects of interdependent risks are challenging to model and predict.

The social-ecological distinction between specified and general resilience is used to assess strengths in current disaster risk reduction strategies and to suggest potential for improvement. Specified resilience refers to known risks, whereas general resilience refers to unknown risks. Disaster risk reduction strategies should address both in order to prepare the wider community for both predicted and unexpected risks.

Approaches to building specified resilience tend to be top-down approaches that aim to mitigate identified risks. As a result, specified resilience has been observed to be increasing over time (Childs et al. 2013). Continuing challenges remain however, due to the unpredictability of future disasters and difficulties in ensuring that the wider community has access to risk specific information.

All-hazard approaches have contributed to increased levels of general resilience in the community. However, the importance of 'all-hazard' approaches in areas exposed to significant specific risks has been underestimated and approaches to building general resilience have been under researched.

We suggest that a logic of general resilience may help to reach out to parts of the wider community that are currently hard to involve in disaster risk reduction activities. This may be achieved by exploiting network effects and bottom-up approaches within and beyond a community.

Unexpected cascading effects and their causes can normally be identified only retrospectively. However, applying a System of Systems (SoS) logic allows a better understanding of network effects even across unrelated systems, before the disaster. These network effects can be used a priori to prepare the community to face disaster risks – allowing better management of unknown risks.

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