Design of a Resilient Information System for Disaster Response

Completed Research Paper

Mihoko Sakurai*
Keio University
Tokyo, Japan
sakuram@sfc.keio.ac.jp

*Research Fellow of Japan Society for the Promotion of Science

Jiro Kokuryo
Keio University
Tokyo, Japan
jkokuryo@sfc.keio.ac.jp

Abstract

The devastating 2011 Great East Japan Earthquake made people aware of the importance of Information and Communication Technology (ICT) for sustaining life during and soon after a disaster. The difficulty in recovering information systems, because of the failure of ICT, hindered all recovery processes. The paper explores ways to make information systems resilient in disaster situations. Resilience is defined as quickly regaining essential capabilities to perform critical post disaster missions and to smoothly return to fully stable operations thereafter. From case studies and the literature, we propose that a frugal IS design that allows creative responses will make information systems resilient in disaster situations. A three-stage model based on a chronological sequence was employed in structuring the proposed design principles.

Keywords: Disaster management, Resilient, Information systems design, Self-organization, Municipal governments, Frugal IS

Force for Changing Perceptions

The Great East Japan Earthquake, Japan's largest in recent times, occurred in 2011 and caused severe damage to a very wide area, with the tsunami wreaking havoc beyond any prior expectations. The earthquake and subsequent tsunami revealed the vulnerability of Japan's Information and Communication Technology (ICT) infrastructure. It greatly affected the recovery process and more than likely increased the loss of life. Such massive disasters will likely become more common, as the number of natural disasters in the world is increasing.[1] There were three times as many natural disasters between 2000 and 2009 as there were between 1980 and 1989.[2] Given the importance of ICT to the functioning of modern society and its evident vulnerability, we must rethink how we design ICT systems to deal with future disaster situations.

This paper addresses issues related to the design of information systems and how the design may enhance the handling of future and unexpected disasters or similar catastrophic events. It focuses specifically on systems resilience, the measure of a system's persistence and the ability to absorb disturbances while maintaining the existing relationships between system entities (Holling 1973). Information systems (IS) research is missing, we believe, a methodology for the design of resilient systems that support the relief and recovery stages of a disaster. We have become dependent on ICT for the performance of nearly all activities in advanced economies, and disasters illustrate the fragility of this dependence. They shake our confidence in technology.

We report on two case studies completed following the Great East Japan Earthquake. The first case is based on structured interviews conducted in 13 municipalities. The second relies on a interview in Tagajo City. Both cases investigated the effects of the earthquake on ICT local administration. These analyses led us to realize that it is impossible to build a robust system that very rarely fails, and to recognize the importance of creative field responses. We need resilient systems that recover their core functions' flexibly quickly following a disaster. Such systems should enable a creative and autonomous response in the field immediately after a disaster. Embedding such a creative response in the design of an IS gives it the capability not only to recover core functions but also to meet the diversity of needs following a disaster. The notion of a frugal IS (Watson et al. 2013), we propose, supports realization of a resilient information system that can function effectively in a disaster.

This article focuses on the following topics: (1) the need for resilience in IS design, based on 13 cases of municipalities affected by the Great East Japan Earthquake, (2) the need for a creative response and data compatibility in the field revealed by the case of Tagajo City, (3) a solution design, (4) a guiding proposition (principle), and (5) conclusions. We believe development of methodologies to implement a resilient information system will contribute to an area of IS research that has rarely been discussed before.

Empirical Research

The Great East Japan Earthquake occurred on March 11, 2011. It measured 9 on the Richter scale, which made it one of the most powerful earthquakes in recorded history. The tsunami reached 40 meters in height and hit the coastline, devastating cities and towns. The Fire and Disaster Management Agency reported 18,958 deaths, 6,219 injuries, and 2,655 missing as of March 2014. It also reported 127,291 houses completely destroyed and more than one million partially destroyed.

From November 2011 to February 2012, just eight months after the earthquake, we conducted structured interviews with 13 municipal governments in the areas hardest hit by the earthquake (Sakurai et al. 2012). The authors visited Miyako City, Oozuchi Town, Kamaishi City, Rikuzentakata Town, Kesennuma City, Minamisanriku Town, Ishinomaki City, Higashimatsushima City, Sendai City, Minamisouma City, Iwaki City, and the refugee offices in Namie Town and Futaba Town. These municipalities are located in the prefectures of Iwate, Miyagi, and Fukushima. Within the administrative structure of the Japanese government, municipalities occupy the third rung, the top rung being that of the National Government,

[1] Last accessed Sep. 3rd 2014, at http://www.emdat.be/natural-disasters-trends

[2] Last accessed Sep. 3rd 2014, at http://www.accuweather.com/en/weather-blogs/climatechange/steady-increase-in-climate-rel/19974069

followed by prefectural governments (47 of them), and municipal governments (1,718 cities, towns, and villages as of April, 2014). The size of municipal governments varies enormously. Big cities such as Osaka and Yokohama each have a few million residents. Small villages have less than one thousand. There are several types of municipal government, such as cities (requiring a population of over 50,000), towns (variously defined by prefectures), villages, and special wards. The populations of the municipalities we visited vary from 2,000 to 70,000. Almost all of them are small cities. Legally, municipal governments function to provide services to citizens, but most significantly, they have the obligation of keeping resident information (i.e., the data that serve as the foundation for government). On the other hand, prefectures are defined more loosely as wide area government.

The objective of the interviews was to formulate a standard business continuity plan (BCP) for local governments so that they might be better prepared in the event of future disasters. Literature bearing on this goal recommends that emergencies be managed along four stages, namely, mitigation, preparedness, response, and recovery (McLoughlin 1985; Settle 1985; Shoaf et al. 2000). Based on these notions, the structure of the interview was decided. There were questions on preparedness, the level of damage, and the recovery process of ICT equipment including power supply, network connectivity, information systems, and related facilities.

Apart from our comparative study of the 13 municipalities impacted by the earthquake, we undertook a second case study in another city. In November 2011, a city officer of Tagajo City, located in Miyagi Prefecture, gave a presentation on the earthquake and ICT recovery process, reporting on the acute needs created by the disaster and the vital importance of an immediate and autonomous response in the field. Independently, the authors carried out a separate study of Tagajo City in August 2012, one and a half years after the earthquake.

Various problems were observed as time passed. In terms of chronological sequence, there were three key IS problems.

The *first* problem was infrastructure failure, especially power and communications. In many areas, electric power and connectivity were lost at the most critical lifesaving phase (i.e., immediately after the earthquake). Also, we discovered that up to four months were required to recover power and communications in some areas.

A *second* issue concerning the variety of IS needs surfaced after the infrastructure was restored. There was a diversity of IS needs depending on time and location. Information systems are essential to conducting immediate disaster relief operations. Based on such recognition, Japan had prior to the earthquake developed solutions in the form of package software to deal with disasters. In spite of the existence of such planned solutions, municipalities were overwhelmed by the diversity of the needs. Instead of using the planned solution, several autonomous system developments emerged that filled the needs of municipal governments to meet the various demands of the residents.

The *third* problem was the confusion created by the multiple autonomous responses. While these systems were developed to meet the immediate needs, data compatibility among these systems was lacking. This caused delays in relief efforts and subsequently hindered recovery. In other words, fragmentation of data seriously damaged the efficiency and consistency of relief efforts.

In the following section, we explain these problems in detail and discuss an IS design for solving them and realizing a resilient information system.

The Case for Resilience

As noted previously, the immediate problem after the earthquake was the failure of the supporting infrastructure needed to run information systems. In addition, the physical destruction of servers meant that residential records were lost in some areas.

The field research of 13 municipalities revealed that a uniform plan across all municipalities would not have been appropriate because the situations in different towns and cities and the requirements for dealing with the disaster were continually changing. Government buildings were generally robust and survived the tsunami. Nevertheless, their survival did not mean ICT survived.

Unexpected ICT Failure

Of the 13 municipal facilities we visited, the earthquake destroyed none, although the city office in Minamisanriku was washed away by the tsunami. Server rooms in 10 cities—except Minamisanriku, Rikuzentakata, and Otsuchi—survived the tsunami and remained functional as such; however, they were useless because of tsunami damage to power supply and network connectivity (see Table 1), a possibility that had not been considered in disaster planning.

Table 1. Status of Communication Means and Timing of Restoration (Sakurai et al. 2014)

Municipalities interviewed		**Status of usage *1 (March 11)**			**Timing of restoration (Days after the disaster)**			
		Land lines	Mobile phones*2	The Internet	Land lines	Mobile phones	The Internet	Power supply (at the municipal government office)
Iwate Prefecture	*Miyako City*	×	Δ (1)	×	Approx. 20 days	-	15 days	15 days
Iwate Prefecture	*Rikuzentakata City*	×	×	×	Details unknown	7 days	120 days at the temporary office	3 days (only areas where emergency response headquarters were set up)
Iwate Prefecture	*Kamaishi City*	×	×	×	7 days	7 days	9 days	Approx. 120 days (19 days to server room and peripherals)
Iwate Prefecture	*Otsuchi Town*	×	×	×	Approx. 45 days	9 days	Approx. 70 days	Approx. 20 days (to the Central Community Hall), approx. 45 days (to temporary office)
Miyagi Prefecture	*Sendai City*	○	Δ (2)	×	-	3 days	2 days	1 day (2days to the Information Systems Center)
Miyagi Prefecture	*Ishinomaki City*	×	×	×	15 days	15 days	15 days	15 days
Miyagi Prefecture	*Kesennuma City*	×	Δ (3)	×	10 days	Approx. 10 days	6 days	6 days
Miyagi Prefecture	*Higashimatsushima City*	×	×	×	6 days	Approx. 20 days	6 days	4 days
Miyagi Prefecture	*Minamisanriku Town*	×	×	×	Approx. 20 days	Approx. 20 days	Approx. 20 days	Approx. 80 days (at temporary office)
Fukushima Prefecture	*Iwaki City*	○	○	×	-	-	1 day	No power loss
Fukushima Prefecture	*Minamisoma City*	○ (From March 12 ×)			8 days	8 days	8 days	No power loss
Fukushima Prefecture	*Futaba Town*	○	Δ (4)	×	-	7 days	2 hours	No power loss
Fukushima Prefecture	*Namie Town*	×	×	×	Details unknown	Details unknown	80 days	1 day

*1: Could not be used: ×, Could be used: ○, Could be used with some restrictions: Δ

*2: Information on the status of usage of mobile phones is as stated by the interview respondents. The status of usage of mobile phones immediately after the disaster and the timing of restoration varies by telecommunications service provider and area.

(1) Mobile phones could be used between only a few telecommunications service providers.

(2) Varies by telecommunications service provider and area.

(3) Could be used until around 10 p.m. on March 11.

(4) Could be used only to send and receive e-mails, not to make phone calls

Electric power and connectivity were lost at exactly the most critical lifesaving phase (i.e., immediately after the earthquake). Existing information systems for operating disaster relief activities were useless because almost all of the 10 affected municipal governments had never anticipated any long-term power failure. Although emergency power generators were available, there was not enough fuel to make them functional. No municipal government in the research had thought about the need to supply power to information system facilities. Supply was also limited to lighting and emergency equipment until fuel ran out. Recovery time varied depending on the damage and state of the progress of disaster relief operations. Up to four months were required to restore the power supply to the city office in Kamaishi. Telecommunications were also disrupted as a result of the power outage. Also, many switching facilities were lost, and cables were damaged by the tsunami. Rikuzentakata, Otsuchi, and Minamisanriku were forced to move to temporary offices because city offices were damaged or washed away by intruding water. The restoration of the Internet in these areas was slow compared to other municipalities. Satellite Internet base stations were sent to these areas almost one month after the disaster. Up to four months was required to resume normal Internet connectivity in Rikuzentakata. Among individuals, a mobile phone was the most widely used communication tool. Service was available in most areas until the batteries at cell tower sites began to discharge, with most running out by the following day (March 12). Conversation was mostly impossible, but packetized email systems could be used immediately after the quake. Many municipal government officials had learned about the coming of the tsunami with TV tuners on their private phones. Mobile phones were restored more quickly than landlines (fixed communication lines), but nevertheless cell sites were out of service from a couple of days to approximately two weeks.

Need for a Creative Response

The second problem occurred after the power supply and network connectivity had resumed. Before the earthquake, Japan had developed a National Disaster Victims Support System in anticipation of major disasters. However, this system could not meet the diverse demands from the field because the actual requirements were different from those anticipated. The planned system failed.

Uselessness of Planned Solutions

The National Disaster Victims Support System is a Linux based, comprehensive post-disaster support system endorsed by the National Government. It was developed in Nishinomiya City after the 1995 Hanshin Awaji Earthquake, which killed thousands, to prepare for future similar events. It consists of seven sub-systems, each of which is related to relief operations, such as opening evacuation centers; recording victims and their families; visualization of the status of damage on the map; and management of temporary residents; disaster relief goods; destroyed housing, and people who need support. All sub-systems are based on resident information and links to other government functions. Source code for the software was made openly available to other municipal governments in 2005 and to everyone including private companies after the earthquake.

In spite of its good intentions and the investment, the system was not utilized as expected in the relief efforts. Although none of the municipalities had installed the system before March 11, 2011, Miyako, Ishinomaki, Kesennuma, Minamisanriku, and Iwaki have introduced it since then. Miyako utilizes the system to manage the distribution of relief funds; Ishinomaki for the issue of Disaster Victim Certificates; Kesennuma for the management of debris removal; and Minamisanriku to manage distribution of relief funds and occupancy of temporary housing facilities. However, some of these municipalities had to modify the original software to suit local requirements.

On the other hand, following the disaster, eight other municipalities considered the introduction of the National Disaster Victims Support System, but they were forced to defer it for the following reasons:

- There was insufficient time to learn how to operate the software in a disaster situation;

- Installation on data servers was not successful;
- Data incompatibility required cumbersome conversion;
- A drop in performance was experienced when handling large volumes of data;
- Study and modification to the system could not be completed in time;
- There were operational differences with the developer (Nishinomiya City) regarding the format of the Disaster Victim Certificate and other issues.

In hindsight, all of the municipal governments affected had to conduct ICT development work at a time when people were starving and freezing. All of the problems mentioned could have been avoided if preparations had been made during normal times to configure the system and train personnel to be able to upload resident information immediately in the event of a disaster. However, even if these problems had been solved in advance, it would have been impossible to predict all the emerging demands because the field situation was changing continuously.

Creative Response

Municipal governments that abandoned the National Disaster Victim Support System opted to use simpler measures, such as spreadsheets. There were multiple instances of fortuitous IS development amid the crisis situation revealed by the interview (see Table 2).

Table 2. System Development of 13 Municipal Governments (Sakurai et al. 2013)

Municipalities interviewed		Example of creative responses	Date
Iwate Prefecture	*Miyako City*	Modified the National system Developed original victim support system	Mid-May Late December
	Rikuzentakata Town	Developed original system for checking resident safety using open source software	Mid-March
	Kamaishi City	Developed original victim support system	Mid-April
	Otsuchi Town	Developed original victim support system	around May
Miyagi Prefecture	*Sendai City*	Modified existing tax collection system to develop victim support system	Early May
	Ishinomaki City	Modified the National system	Early May
	Kesennuma City	Developed original victim support system with Microsoft Access	Mid-April
	Higashimatsushima City	Developed original victim support system	Mid-April
	Minamisanriku Town	-	-
Fukushima Prefecture	*Iwaki City*	Developed original victim support system	Late May
	Minamisoma City	Developed original system for checking resident safety with Microsoft Access Developed original victim support system	March April
	Futaba Town	Developed original system for checking resident safety with Microsoft Excel	March
	Namie Town	Developed original system for checking resident safety with Microsoft Excel Developed original victim support system	March Late March

Open source software, Microsoft Access, and Excel were apparently widely used, as they were immediately available resources. Office staff members were already accustomed to these applications in their daily life and had less trouble customizing them for their purposes. It seems clear that information systems not used in daily life are not useful in an emergency situation.

New systems development in the 13 municipalities indicates the need for creative responses to unexpected events. Accordingly, a creative response in this paper is defined as *an autonomous reaction using available resources to regain the capability to meet key objectives*. Information systems must have modifiability, in addition to functional capability (to perform as intended) and responsive stability, to conform to organizational requirements (Ashenhurst 1972). "Well functioning" systems may still have unsatisfied clients; this highlights the importance of citizen participation in systems development (Juergens 1977). In the context of this paper, these calls for modifiability can be interpreted as calls for developing capacity among citizens to execute creative responses without external support.

The earthquake heavily damaged Tagajo, a city of about 60,000, which opened a support center for disaster victims on April 1, 2011. Its primary tasks were to identify residents' whereabouts, acquire contact information (address, phone number, etc.), and assess damage inflicted on homes and properties, as well as to provide adequate information on relief programs. The number of deaths attributed to the disaster stood at 188 in April 2012, and one third of the entire city had sunk under the tsunami. ICT challenges encountered in Tagajo City included (1) recovery of lost connectivity (Internet/telephony), (2) reinstallation of terminals and the local area network to support resident service counters, and (3) preparation of residential data and information systems to use in citizen interactions.

Tagajo lost power immediately after the earthquake and recovered it on March 14, three days later. Network connectivity was lost until March 17, as base stations were damaged. The city was isolated from the world during this period and unable to collect or deliver information.

As two weeks had passed after the earthquake, the setting up of an information system became imperative, primarily to create records of residents' consultations. These data could then be linked to resident records, which would ensure consistency and continuity of support. Requirements for the system were (1) to serve each resident with consistent information based on the integrated records of all previously given instances of advice, (2) to have an integrated and simultaneously accessible database that could be accessed from multiple help desks, and (3) to remain available in the long term as most residents would likely need continuing assistance.

The city considered the National Disaster Victims Support System and investigated other solutions such as the Sahara System, which was developed after the 2004 Indian Ocean earthquake. These open source software solutions, however, could not meet Tagajo's requirements. Thus, the city decided to develop a new system.

It took Tagajo personnel only five days to create a system. Faced with a lack of resources, including time, the city relied on downloadable open source software. Necessary adjustments and additions were made to the software modules before integrating them to meet the mounting needs. Luckily, the server room inside the city government office was not damaged, and its hardware could be utilized to run the newly developed system.

A popular customer relationship management system in the commercial world, SugarCRM, was chosen as the core engine. SugarCRM could operate on common browsers and some pieces were offered free of charge. Thus, by limiting the use of the software to narrowly defined areas (records of advice, advisory officials, and advice provided), the city could freely customize the system for use.

Other tools utilized were PHP, MySQL, Apache server software, and the Eclipse development environment, all of which are available on the Internet. As the tools were open systems that required no more than browsers and came with little installation burden, existing equipment could be used. Access rights could be granted liberally as many of the tools were also license free, without the worry of having to pay for licensing or of violating copyright.

The system was developed to operate in a series of three steps:

1. Setting up resident identification. Data were imported from city governmental resident records to be used as the key for subsequently adding and searching records of advice.
2. Input of interview records such as residents' problems. Multiple resident visits produced new records on top of previous records under a single key.
3. Issuing consultancy records to advisees. To give a sense of assurance to residents, copies of interview records and advice were handed to persons at the end of consultations. Advisees could bring their copy to subsequent consultations.

The system was put into operation on April 1, 2011, in time to coincide with the opening of the support center. One hour of training was given to the advising officials who would operate the system. No major problems occurred, and minor functional additions were made as the system became operational. As of April 30, 2012, one year after the disaster, the system had supported over 30,000 consulting occasions with 700 officials, including officials who were sent by other municipalities as relief staff.

Compatibility Need

After the newly developed system was operational in Tagajo, the integration of data across systems became a major issue. Various departments autonomously and independently developed several systems without coordination. This resulted in the lack of data compatibility among the systems (see Table 3).

Table 3. Type of Disaster Relief Operation and New Systems in Tagajo City

Type of disaster relief operation	Date of operation (2011)	Software used	Developed by
Open disaster victim support center	April 1	Open Source Software	City Officer
Acceptance of temporary residences	April 1	Excel	City Officer
Issuing disaster victim certificates	April 20	Access	Pasco ltd
Temporary repairs of residences	April 25	Excel	City Officer
Management of contributions	End of April	Access	NEC Corporation

Source: Tagajo City Office

The problem was solved in the interim by using a conversion table and by resorting to burdensome manual operations. These conditions clearly illustrate the importance of preparedness for a creative response in the field.

Findings from the Tagajo City case study can be summarized as (1) recognition of the importance of a creative response following a catastrophe, and (2) availability of standard and open (as opposed to proprietary) systems which would enable a response without concern for fees and licenses.

In a nutshell, there were three key IS problems after the earthquake (see Figure 1). First, the infrastructure failure lasted longer than anyone expected. After its restoration, new developments and modifications of existing systems, which we call a creative response, took place. Local officers used whatever available resources were in the field. These responses met imperative needs; however, they occurred independently. Yellow circles in the diagram represent a creative response, which caused another problem, namely, lack of data compatibility. There were no connections (a red X in the diagram) between these responses.

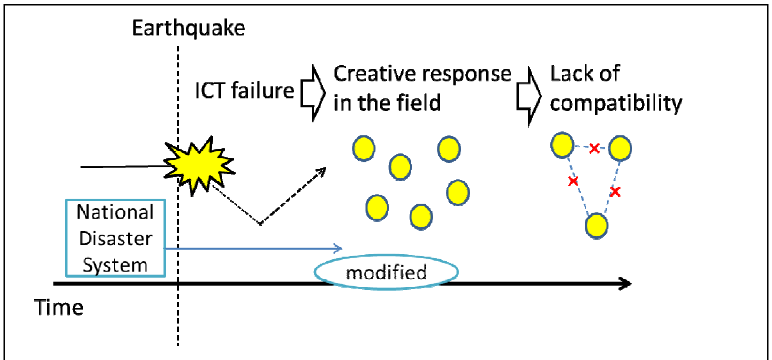

Figure 1. Key IS Problems

The Concept of Resilience in IS Field

What do experiences during the Great East Japan Earthquake teach us about resilience of information systems? Discussions in contemporary IS research appear to be mainly based on the idea that IS reliability is achieved through the use of dependable technology (Butler et al. 2006). Assuming reliability, the effectiveness of systems and processing capacity is given much attention. This focus, however, fails to account for the infrastructure needs of IS operations in unexpected and overpowering situations. No one had predicted that the power supply and network connectivity would be lost for such long periods. This outcome made it clear to us that achieving perfect reliability is improbable. Rather, we need to create resilient information systems. We define resilience as *quickly regaining essential capabilities to perform critical post disaster missions and to smoothly return to fully stable operations thereafter.*

Resilience in Emergency Management

Resilience is naturally often discussed in the context of emergency management. It has been incorporated into the international business process standard as ISO 22301 (formerly British BSI2599), which is intended to maintain business continuity at times of extraordinary stress. Discussions of resilience begin by distinguishing resilience from stability (Holling 1973). After that, the concept of resilience expands its scope to include the analysis of organizations (Horne et al. 1998), such as supply chain management (Lee et al. 2004; Ponomarov et al. 2009), engineering (Hollnagel et al. 2006), and business modeling (Gilbert et al. 2012).

All of the damage listed previously impaired the five critical missions for life saving activities following a devastating disaster, namely (1) confirming the whereabouts and safety of residents, (2) establishing and operating evacuation centers, (3) transporting and managing relief goods, (4) supporting evacuees and recording their status, and (5) issuing disaster victim certificates. Information sharing among municipal offices was mainly done by pencil and paper, which made it difficult to ask other municipal governments for help because information could not be shared readily. The slow recovery of ICT hindered all other recovery processes. Clearly, the lack of resilience in ICT proved to be a serious problem when municipalities tried to tackle disaster recovery operations. To operate disaster relief activities successfully, it is necessary to restore essential ICT infrastructure as soon as possible.

This illustrates the importance of infrastructure (especially power supply and network connectivity) in making resilient information systems work. This observation stands apart from the conventional discussion on resilience engineering thus far primarily focusing on software (Hollnagel et al. 2006).

In summary, our research findings stress the importance of flexibility in meeting needs in rapidly changing environments such as following disasters exceeding all reasonable expectations. This is the basis of our argument for resilience.

Resilience or Stability

Municipalities' disaster relief operations are quite distinct from normal daily operations and only come into focus when a disaster happens. Also, there are various demands on the systems. Before resources from outside the affected area are mobilized, municipalities have to deal with difficult disaster situations by themselves. In this phase, should we aim to just return to an equilibrium state? Rather, we should create a new IS environment to support a creative response in the field. By being 'creative', we mean the execution of responses that were not planned prior to the event, often to be carried out autonomously by staff that has to deal with impending needs in the field. Regarding this, the notion of resilience provides adaptive capacity that allows for continuous development, like a dynamic adaptive interplay between sustaining and developing with change (Anderies et al. 2004).

Numerous cases related to creative responses in a disaster situation have been reported. For example, after Typhoon Haiyan in the Philippines in 2013, more than 900 people were lending a hand remotely by collaborating on online maps, through the OpenStreetMap network, which is an open source mapping system and is available to every person on the Internet. It uses satellite technology and knowledge supplied by the public to help relief organizations, like the Red Cross, know where buildings and roads are located and how and where to best deliver supplies.[3] During the Haiti Earthquake in 2010, a phenomenon called "voluntweeters" that supported information collection and transmission to disaster victims was observed (Starbird et al. 2011). IS enabled these kinds of supports not only from outside the damaged area, but also from inside the area. After a mountain fire in California in 2007, evacuees reconnected with their communities thanks to online neighborhood-based forums (Shklovski et al. 2008). One important observation in reading through these reports is that the core mission of IS at disaster times is different from that of normal times. Even more, the mission tends to change as the recovery progresses. This discussion is quite different from the conventional one of resilience with the emphasis on maintenance of the core purpose and integrity in the face of dramatically changed circumstances (Zolli et al. 2012). Thus, IS should support various demands in the field with a degree of flexibility.

Solution Design

Based on the renewed understanding of the resilience of information systems, how should we design the future technologies and processes of information systems? To solve three key IS problems, a resilient IS design must ensure:

- Swift recovery after functions fail;
- A creative response;
- The integration of creative responses that occur independently.

Our investigation strongly suggests that we need to depart from the conventional pursuit of system design to adopt a new disaster recovery strategy and IS design principle. IS research should contribute to provide necessary knowledge to this end.

Three Stage Model

We propose a three-stage model based on the chronological sequence necessary to deal with disaster situations (see Figure 2): that is, the "in advance stage," the "initial response stage" and the "recovery stage." This model was derived from our research.

---

[3] Last accessed Sep. 3rd 2014, at http://hereandnow.wbur.org/2013/11/15/mapping-effort-philippines

Figure 2. Three Stages for a Resilient IS

Our comparative study of the disaster-hit municipalities suggests that the concept of resilience is effective as a criterion for building a new disaster recovery strategy. However, it should be discussed at a practical level because existing frameworks do not provide operational steps for designing a resilient IS (Junglas et al. 2007).

In the literature, emergency management has been categorized into four components: mitigation, preparedness, response, and recovery (McLoughlin 1985; Settle 1985; Shoaf et al. 2000). Conventional emergency management research separates mitigation and preparedness; however, based on our observation, we see mitigation and preparedness as one and the same stage. Mitigation focuses on lessening the long-term risk; on the other hand, preparedness indicates activities that develop operational capabilities for response (McLoughlin 1985). So how can we lessen the risk and develop operational capabilities in spite of the difficulties in predicting what exactly will happen in the future? This is the most important question for designing a resilient IS. Thus, we combined mitigation and preparedness into "in advance" to distinguish it from the existing situation. Furthermore, we should separate technological and operational aspects during these three stages. Technology is developed according to society needs (Bijker et al. 1987). In this regard, the technological aspects should place a priority on reducing vulnerability and then enable operational capabilities subsequently.

We also learned from the Great East Japan Earthquake experience that special attention is necessary during a response, especially the "initial response stage" when municipalities have to deal with the situation with very limited or no external support. Immediately after the disaster, municipalities have to conduct disaster relief operations with limited access to resources. These initial operations are totally distinct from normal tasks and linked directly to saving lives. Thus, we need to design systems that recover quickly and allow creative and independent efforts in the field as well. The length of the initial response depends on the scale of a disaster. Prior research reports an example in which it took 39 days after a disaster for outside help to arrive (Comfort et al. 2004). In our case studies, it took up to one month for effective IS related supports to arrive.

As the initial response stage ends and outside resources are delivered to a disaster area, the situation settles down and stabilizes, though at a different equilibrium than pre-disaster. It gradually goes into the "recovery" process. Recovery consists of short-term activities that restore vital life-support systems to minimal operating standards and long-term activities that return life to normal (McLoughlin 1985). At this time, connections are required between emergency and normal systems. In this stage, self-organization, the spontaneous reallocation of energy and action to achieve a collective goal in a changing environment (Kauffman 1993; Comfort 1994) of creative responses emerges as a new design goal. If the number of creative response occurs independently, as the case studies show, they lack compatibility, which hinders recovery. These various creative responses should be linked to avoid the friction of IS incompatibility.

Frugal IS

With the awareness that unexpected failures of IS happen, and with the recognition that preparation for a creative response to such unexpected failures is possible, we argue that the notion of frugal IS (Watson et al. 2013) is helpful in supporting creative responses and a resilient IS. A frugal IS is defined as "an information system that is developed and deployed with minimal resources to meet the preeminent goal of the client." Disaster situations typically force people to deal with situations facing limited access to resources at the initial response stage. Thus, frugality is a necessity for an IS in disaster situations. There are four u-constructs (information drives) for establishing this frugal system (see Table 4).

Table 4. Four Information Drives (Junglas et al. 2006)

Drive	**Definition**
Universality	The drive to overcome the friction of information systems' incompatibilities
Ubiquity	The drive to access information unconstrained by time and space
Uniqueness	The drive to know precisely the characteristics and location of a person or entity
Unison	The drive for information consistency

There are two aspects for realizing this frugal IS, which are technological and process. From a technological point of view, "universality" and "ubiquity" should be considered a key driving force for reducing the long-term risk.

Multi-functionality is a key concept of "universality." This encourages using open systems that can be readily integrated. City officers in Tagajo used whatever available resources they could find in the chaotic situation. They combined multiple resources to develop the system. On the other hand, the most popular tools for new developments in the earthquake were Microsoft Excel and Access. The reason why municipalities used these applications is because they use them in normal tasks and are accustomed to them. The notion of universality should incorporate people's familiarity with the tools. A smartphone is universal because the open API in today's smartphones allows many creative developers in the field to develop applications that meet local needs. Such universality also means that smartphones are multi-functional and can meet various needs of individuals in everyday life and during disasters. In reality, during the Great East Japan Earthquake, a cellular phone was the most widely used communication tool because people were already familiar with it. Nowadays, people use smartphones more than regular cellular phones.

In addition, we need "ubiquitous" network connectivity that enables access to information unconstrained by time and space. If ubiquitously available smartphones, standard PCs, and non-dedicated public Internet services can be used, the chances of creatively developing disaster relief systems with "whatever available" resources increase. This will empower stranded people to help themselves before outside help arrives. Among other alternatives, the use of drones and/or balloons to carry communication base stations is a likely candidate for regaining ubiquitous connectivity (Sakurai et al. 2014). In reality, after the earthquake, satellite Internet base stations and portable mobile phone base stations (cars) were sent to the damaged area. However, they arrived at the area a couple of weeks after the earthquake because of poor road conditions. Thus, at this time, the most reliable means for realizing ubiquitous network connectivity immediately after the disaster would be aerial solutions.

When we can develop an infrastructure that employs "universality" and "ubiquitous" features, then "uniqueness" and "unison" become operational goals for enabling a resilient IS.

Information that will likely be shared during disaster relief operations should employ the notion of "uniqueness." This means recording attributes (such as the profile and location) of a person or entity. This is essential for identifying objects. The time when a specific incident happened will frequently need to be recorded to uniquely identify events and track their relationships.

"Unison" indicates the importance of consistency of data among different locations and databases. This is an essential factor in preventing data incompatibility. This also enables people to share information through devices at any time. On the other hand, the idea of unison would become a significant challenge and might be set aside when we try to adopt creative responses, usually undertaken by autonomous individuals or groups as a solution to meet the immediate disaster relief mission.

Looking into the future, a smartphone will be the tool that meets the frugal design requirements better than any other device. First, it can be kept operational easily by a manually cranked charger. Second, a smartphone can be connected either by a cellular network or WiFi networks if the cellular network is down. WiFi is probably the most frugal and ubiquitous connectivity tool around presently and thus is likely to be the most resilient. Also we have new technology such as an aerial means for establishing WiFi networks. Third, a smartphone also employs the notion of “uniqueness” and “unison” because it carries a unique phone number and SIM card. By associating the information of individuals collected with the number of a personal smartphones, the uniqueness of the individuals is maintained. It will also be easy to link information of the same individuals collected in various locations.

Guiding Proposition (principle)

The recognition that extraordinary, special needs emerge in post disaster situations, resilience involves identifying essential missions that have to be performed under emergency situations, and applying whatever means are available to achieve the key objectives. That is quite different from trying to create a system that can perform in a stable situation under adverse conditions. Proceeding from this basis, we clearly need to focus on preparedness for creative response in any affected areas. So, we can apply this notion to the three-stage model (See the “*Future* row” of Table 5). Each stage should have different principles and strategies. Process (as opposed to technological) oriented items are italics.

<table>
<tr><th colspan="5">Table 5. Sequence of Events (Based on System Design) and Future Design Principles</th></tr>
<tr><th></th><th>In advance</th><th>Initial response</th><th colspan="2">Recovery</th></tr>
<tr><td>Expected</td><td rowspan="2">A part of power failure
Usage of The National Disaster Victim Support System</td><td colspan="3">Usefulness of emergency power supply (only to minimum functions)
Quick recovery based on a regional disaster response plan</td></tr>
<tr><td>Actual</td><td>Loss of personnel / power supply / data
Flooded of server room
Relocation of administration functions</td><td>Creative response</td><td>Data integration</td></tr>
<tr><td>Future</td><td>Manually cranked charger for universal devices
Ubiquitous network connectivity
Disaster relief application
Unison database
Fire Drills related to ICT</td><td>Universal devices
Information uniqueness (characteristics / location / time)
Creative response</td><td>Self-organizing of creative responses</td><td>Resuming normal operations
Connection to normal systems</td></tr>
</table>

With a better understanding of the post-disaster phases, can we have any “in advance” preparations to conduct initial response and recovery efficiently? Business continuity planning (BCP) plays a role in defining actions for all recovery processes uniformly. Many organizations will have BCPs (Cerullo and Cerullo 2004). None of the 13 municipalities interviewed had a particular BCP, but all had regional disaster response plans. The plans defined the chain of command and the tasks to be performed. However, unless plans can be intuitively applied during fast emerging crises, the plans will not be effective (Seville et al. 2006; Bhamra et al. 2011). Our field research reveals that the extent and diversity of damage can go far beyond any prior assumptions. This implies that even if a BCP existed, a uniformly prepared set of responses would have been insufficient to meet the diverse and rapidly changing needs of residents.

This by no means reduces the importance of planning. A system should create a balance between preparedness and resilience (Comfort et al. 2001). It is naturally useful to make predictions as to potential damage and make plans to respond to the likely situation. Determination of the chain of command is also critical, and it is wise to stock up on supplies based on a careful estimation of need. Such plans should be widely shared among all people concerned. At the same time, we recognize the importance of flexibility in decision making when executing disaster management plans (Kunreuther and Miller, 1985). To respond to changing situations, the strategic incorporation of current information is essential.

Before we can understand what needs to be done during the in advance stage, we need to look at the initial response and the recovery stage first.

Initial Response Stage

Municipal governments' operational goals in the initial response stage are to confirm the whereabouts and safety of residents, open evacuation centers (and create evacuee lists), and transport relief goods to them. Functional requirements to realize these operational goals are the identification of persons (individuals) and goods and the compilation of a disaster victim database. In addition, information sharing capability among persons who are involved in a disaster relief operation is essential.

Initially, local officials need to operate without support from outside of the damaged area. As the case studies show, since no one had assumed that power and network connectivity failures would last for such a long time, municipalities damaged by the earthquake could not respond effectively. To make the initial response effective, Japan had prepared a National Disaster Victims Support System; however, it was developed almost 20 years ago and the technology was out of date. Although it had employed an open source policy, i.e., there was room and freedom to make adjustments; it was nevertheless not efficient enough to allow staff in the field to develop new applications flexibly in response to the new reality. The National System was a closed system in the sense that it required installation of the system prior to disasters with access keys distributed by the national government. It also lacked compatibility with other widely available systems.

Instead, it was necessary to use universally available and versatile devices that require minimal resources. Consequently, an application for disaster relief operations should be run on these devices. In addition, these devices should be those that people already have and with which they are familiar in order to promote a creative response in the field. In the earthquake, a mobile phone was a universal device that most people had and used. Phone numbers or SIM IDs of mobile phones have the potential for identifying individuals.

Data that are collected during the initial response should be dynamic. These data must employ uniqueness to identify people or entities by their characteristics, location, and time. This would make it easier to understand a situation and to connect with information collected by other sites. For example, think about a case where there are four Mr. Katos in the same evacuation center. Without uniqueness, there will be confusion as to which Mr. Kato requires a specific medication or which one needs hospital treatment.

How can we measure resilience in the field? The concept of resilience is fundamentally multi-dimensional. In this paper, it is defined as *quickly regaining essential capabilities to perform critical post disaster missions and to smoothly return to fully stable operations thereafter*. Regarding this definition, "regaining essential capabilities" must be focused on in order to achieve functional requirements. In this stage, resilience should be measured by:

- Recording the length of time needed to recover minimal capability (to fulfill a functional goal);
- Recording the length of time to recover data integrity across multiple locations;
- Recording the degree to which capabilities are recovered without external resources.

Thus, resilience can be measured by the number of functions recovered without external help, or the minimal IT functions that municipal governments would likely have in emergency situations.

Recovery Stage

The initial response gradually becomes a recovery as efficient support for disaster relief arrives in an area. In our case studies, after the ICT infrastructure had been restored, creative responses were observed in several locations. However, a lack of coordination among the local efforts caused the subsequent lack of data compatibility. This led to loss of efficiency in the later stages of disaster relief. Recognition of the seriousness of the data incompatibility leads to the conclusion that there needs to be more research on the relationship between a creative response and self-organization.

Self-organization has characteristics such as adaptive and scalable interactions between the entities. It also is localized and has no central coordination (Prehofer et al. 2005). To enable each creative response to be scalable and adaptive, the notion of unison is essential. In addition, as municipalities return to normal operations, a creative response needs to share information with IS that are used for standard operational tasks. Unison means information sharing between temporary systems and standard operational systems. Even as municipalities returned to normal operations, operations such as providing relief programs to disaster victims continued. In some cases, they lasted several years. In Tagajo, for example, disaster relief programs were still being delivered to its residents as of July 2014. The city no longer use the temporary system developed during the crisis and returned to the conventional system. Ironically, this led to the loss of data compatibility among systems of the various departments involved in the relief effort. The lack of compatibility cannot, for example, prevent fraudulent multiple relief claims.

As municipalities' disaster relief operations are quite distinct from normal day-to-day tasks, the requirements for information systems become different as well. It should recover quickly and support a creative response in the field. It is thus natural to return to the conventional systems designed for normal use. However, the experiences of the earthquake indicates the importance of (1) a seamless transfer of the recording of each resident's situation with unison from temporary systems to the normal use systems, as well as (2) data compatibility among systems for normal operations.

In this stage, the characteristic of resilience becomes different. It focuses on the degree *of smoothly returning to fully stable operations*. This means that we should measure the degree of data compatibility among temporary systems and normal ones.

In Advance Stage

While this paper emphasizes the role and importance of a creative response to deal with unexpected events, it does not assert that preparation is meaningless. Rather, we emphasize the importance of adopting open and standard technologies for our peacetime systems so that data from the system can be extracted and used by creatively developed systems in the field.

In the in advance stage, preparation of ubiquitous networks and unison databases is essential. These days, we can assume network connectivity everywhere. We can also assume that most people own universal devices, such as smartphones, which are able to connect to the network easily. Databases should include static characteristics, such as residents' medical information and household membership details. In a previous example, the static characteristics of Mr. Kato would be gender, date of birth, address, phone numbers, medical prescriptions, and family situation (whether he needs special help in the disaster or not). These data should be linked in the database that would be used in the initial response stage. This helps in maintaining unison and uniqueness of information when data from multiple systems are merged in later stages of disaster recovery.

During the Great East Japan Earthquake, each evacuation center created separate and unstandardized evacuation lists that were not based on the official residential database. This made the job of later stages of data integration very difficult. This data fragmentation problem informs us of the importance and the challenge of maintaining data unison in a disaster setting. We believe that this is a critical element if we want to see multiple creative responses self-organize to become mutually reinforcing parts of a large collaborative effort. It will make the transition from initial response to longer-term recovery smoother.

To support the in advance stage, applications should be designed to run in environments and on devices that can support the four u-constructs (e.g., an app running of a smartphone with access to a database). Some common applications, such as MS Access and Excel have properties that support universality and unison. For example, many other applications can read an Excel file (universality) and both Access and

Excel can interface to a database (unison). However, they do not satisfy other u-constructs because of copyright issues. Although the software was available in many places, licensing requirements became a major barrier in actually using them as emergency backup systems. In addition to this, they do not employ a function for identifying people or entities.

We need to make sure such applications become operational and widely used before they are needed and then made available as quickly as possible after disasters. With regard to preparedness at a practical level, FEMA (The Federal Emergency Management Agency) is adopting a five category exercise model, i.e., orientation, drill, tabletop, functional, and full-scale (Watkins 2000). Normally a fire drill is conducted once a year in each municipality, but it focuses on how to escape to an evacuee center and does not emphasis how to support officials and residents with using ICT. We should recognize the importance of running a fire drill based on an information systems failure. This means that we turn the power off for the information systems and start from the initial response stage assumption.

Future Research Plan

We plan to build a prototype application using smartphones that employs the design principles we discussed earlier. The test will be conducted in October 2014 in Tome City, one of the municipalities damaged in the earthquake. Because smartphones realize the four information drives of a frugal system, they are the foundation of the prototype. A smartphone is a universal device, has a ubiquitous network connection, has a phone number to provide uniqueness, and has a connection to a database, which enables information unison.

We place an emphasis on ensuring data compatibility. This is accomplished partly by an "in advance" agreement to use a standardized ID to identify individuals. This ID will be used in the application to register required assistance with municipalities' disaster relief. Thus, we need in advance to prepare ubiquitous network connection bases, a unison database, and hand powered chargers for smartphones. Then, people need to be trained to make sure this application can be used following a disaster. Retraining should occur as new versions of the app are distributed and during annual disaster preparation days on which a fire drill is conducted.

According to a 2011[4] survey by the Japanese Ministry of Internal Affairs and Communications, the diffusion of mobile phones for Japanese households is 95 percent, of which smartphones are 29 percent. The percentage of households with smartphones is rapidly increasing. It was 10 percent in 2010 and became almost three times as much in one year. Mobile-cellular penetration rates stood at 96 percent globally, 128 percent in the developed world, and 89 percent in the developing world in 2013.[5] Smartphones are rapidly becoming a standard platform for people's everyday lives, and thus a suitable foundation for disaster recovery in Japan and many other countries.

The initial test will be with the operation of evacuation centers, which will test the use of smartphones for supporting disaster relief. It involves the use of three key functions; (1) identification and registration of people at evacuation centers by phone number or SIM ID, (2) recording people's arrivals and departures and, (3) creating an evacuee database. Using a smartphone's number, the application can transmit information to people who need specific information, such as medicine or milk for infants.

Since this research is based on the interviews from the Great East Japan Earthquake, the external validity of the findings is limited. In order to increase generalizability, we plan to apply the resilience framework to the analyses of other types of disasters in Japan as well as in other countries that frequently suffer from catastrophes.

---

[4] Last accessed Sep. 3rd 2014, at http://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h24/html/nc122310.html

[5] Last accessed Sep. 3rd 2014, at http://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2013-e.pdf

Conclusion

Following the Great East Japan Earthquake, there has been a lot of discussion in Japan about building a disaster proof society. Our conclusions are

- ✧ It is impossible to build systems that never fail and thus a disaster proof society. We should thus aim at preparing resilient information systems that can quickly regain critical capabilities following a disaster.
- ✧ The design of a resilient information system should allow for autonomous creative responses in the disaster region.
- ✧ The notion of frugal IS supports a creative response.
- ✧ The smartphone, as a universal device, provides the foundation for building a resilient system.

The earthquake was perhaps the harshest possible challenge to an information society. It made Japanese leaders and citizens acutely aware of how much daily life depends heavily on ICT infrastructure. Disaster recovery operations to help people in stressed times must rely on ICT. However, most importantly, we should start with the recognition that it is not possible to build systems that are unbreakable in all circumstances. The study of the earthquake's effects indicates the importance of having a staged recovery process model for designing systems. We should instead build in flexibility so that creative responses to divergent situations are possible and advance the saving of lives. Such systems should also enable self-organizing creative efforts.

Acknowledgements

This work was supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Number 26.7013.

References

Anderies, J. M., Janssen, M. A., and Ostrom, E., 2004. "A framework to analyze the robustness of social-ecological systems from an institutional perspective," *Ecology and Society* (9:1), 18 [online] URL http://www.ecologyandsociety.org/vol9/iss1/art18/.

Ashenhurst, R. L. 1972. "Curriculum Recommendations for Graduate Professional Programs in Information Systems," *Communications of the ACM* (15:5), pp. 363-398.

Bijker, W. E, Hughes, T. P., and Pinch, T. 1987. *The Social Construction of Technological Systems*, Cambridge, MA, MIT Press.

Bhamra, R., Dani, S., and Burnard, K. 2011. "Resilience: the concept, a literature review and future directions," *International Journal of Production Research* (49:18), pp.5375–5393.

Butler, B. S., & Gray, P. H. 2006. "Reliability, Mindfulness, and Information Systems," *MIS Quarterly* (30:2), pp.211-224.

Cerullo, V., & Cerullo, M. J. 2004. "Business Continuity Planning: a Comprehensive Approach," *Information Systems Management* (21:3), pp.70-78.

Comfort, L. K. 1994. "Self-Organization in Complex Systems," *Journal of Public Administration Research and Theory: J-PART* (4:3), pp.393-410.

Comfort, L. K., Ko, K., and Zagorecki, A. 2004. "Coordination in Rapidly Evolving Disaster Response Systems: The Role of Information," *American Behavioral Scientist* (48:3), pp.295-313.

Comfort, L. K., Sungu, Y., Johnson, D., and Dunn, M. 2001. "Complex Systems in Crisis: Anticipation and Resilience in Dynamic Environments," *Journal of Contingencies & Crisis Management* (9:3), pp.144-158.

Gilbert, C., Eyring, M. and Foster, R. N. 2012. "Two Routes to Resilience," *Harvard Business Review* (90:12), pp.65-73.

Holling, C. S. 1973. "Resilience and stability of ecological systems," *Annual Review of Ecology and Systematics* (4), pp.1–23.

Hollnagel, E., Woods, D. D. and Leveson, N. 2006. *Resilience Engineering: Concepts And Precepts*, Burlington, VT, USA, Ashgate Pub Co.

Horne, J. F. and Orr, J. E. 1998. "Assessing behaviors that create resilient organizations," *Employment Relations Today* (24:4), pp.29–39.

International Telecommunication Union. 2013. “The World in 2013: ICT Facts and figures,” Geneva, Switzerland.

Juergens, H. F. 1977. "Attributes of Information System Development," *MIS Quarterly* (1:2), pp. 31-41.

Junglas, I., and Ives, B. 2007. "Recovering it in a Disaster: Lessons from Hurricane Katrina," *MIS Quarterly Executive* (6:1), pp.39-51.

Junglas, I. A., and Watson, R. T. 2006. "The U-Constructs: Four Information Drives," *Communications of the Association for Information Systems*, 17, pp.2-43.

Kauffman, S. A. 1993. "*The Origins of Order: Self-Organization and Selection in Evolution*," Oxford University Press, U.S.A.

Kunreuther, H. and Miller, L. 1985."Insurance versus Disaster Relief: An Analysis of Interactive Modelling for Disaster Policy Planning," *Public Administration Review* (45), pp. 147-154.

Lee, H. L. 2004. "The Triple-A Supply Chain," *Harvard Business Review* (82:10), pp.102-112.

McLoughlin, D. 1985. "A Framework for Integrated Emergency Management," *Public Administration Review* 45(Special), pp.165-172.

Ministry of Internal Affairs and Communications Japan. 2012. "White Paper 2012," Tokyo, Japan.

Prehofer, C., and Bettstetter, C. 2005. "Self-organization in communication networks: principles and design paradigms," *IEEE Communications Magazine* (43:7), pp.78-85.

Ponomarov, S.Y. and Holcomb, M.C. 2009. "Understanding the concept of supply chain resilience," *International Journal of Logistics Management* (20:1), pp.124–143.

Sakurai, M. and Kokuryo, J. 2012. "Municipal Government ICT in 3.11 Crisis: Lessons from the Great East Japan Earthquake and Tsunami Crisis," *Berkman Center Research Publication No. 2012-14*, http://cyber.law.harvard.edu/publications/2012/Municipal_Government_ICT_in_3_11_Crisis, Berkman Center for Internet & Society, Cambridge, MA.

Sakurai, M. and Kokuryo, J. 2013. "Preparing for Creative Responses to Beyond Assumed Level Disasters: Lessons from the ICT Management in the 2011 Great East Japan Earthquake Crisis," *Corporate Ownership & Control* (10:2), pp.195-206.

Sakurai, M., Watson, R. T., Abraham, C. and Kokuryo, J. 2014. "Sustaining Life during the Early Stages of Disaster Relief with a Frugal Information System: Learning from the Great East Japan Earthquake," *IEEE Communications Magazine* (52: 1), pp.176-185.

Settle, A. K. 1985. "Financing Disaster Mitigation, Preparedness, Response and Recovery," *Public Administration Review* (45), pp.101-106.

Seville, E., et al., 2006. "Building organisational resilience: a summary of key research findings," *Resilient organisations research programme*, 6 August, New Zealand.

Shklovski, I., Palen, L., and Sutton, J. 2008. "Finding community through information and communication technology in disaster response," *In Proceedings of the 2008 ACM conference on Computer supported cooperative work*, pp. 127-136.

Shoaf, K., I. and Rottman, S. J. 2000. "The Role of Public Health in Disaster Preparedness, Mitigation, Response, and Recovery," *Journal of Prehospital and Disaster Medicine* (15:4), pp.18-20.

Starbird, K., and Palen, L. 2011. "Voluntweeters: Self-organizing by digital volunteers in times of crisis," *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM. pp.1071-1080.

Watkins, S. 2000. "Developing Statewide Emergency and Disaster Preparedness Expertise," *Journal of the American Institute for Conservation* (39:1), pp.165-172.

Watson, R. T., Kunene, K. N. and Islam, M. S. 2013. "Frugal IS," *Information Technology for Development* (19:2), pp.176-187.

Zolli, A. and Healy, A. M. 2012. *Resilience: Why Things Bounce Back*, City of New York, NY, USA, Free Press.