A Capital Model for Disaster Resilience

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ABSTRACT

This paper proposes a capital model for disaster resilience. A central notion to this effect is viewing an organization as a capital conversion and capital creation system (Mandviwalla et al. 2014). Systems resilience was originally defined as the measure of a system's persistence and ability to absorb disturbances (Holling 1973). Our approach corresponds to "resilience-1; Resilience as rebound from trauma and return to equilibrium as," which according to Woods (2015) is one of the four main categories of disaster resilience.

We develop a system dynamics model expressing the main features observed in selected municipalities affected by the Great East Japan Earthquake. We show that the model is able to describe qualitatively the processes of capital destruction by the earthquake with the associated tsunami and the subsequent capital recreation. We discuss how the system dynamics model can be used to further increase our understanding of capital conversion processes in disaster resilience.

Keywords

Resilience, capital conversion, Great East Japan Earthquake, system dynamics, simulation.

REALITY OF UNEXPECTED CALAMITIES

Following an unexpected disaster, many organizational routines and processes are severely impaired or even suspended. In the preparedness phase, organizations draw up a disaster management plan intending to mitigate damage from a devastating disaster situation by making people, facilities, and organizations robust. The plan defines the chain of command and the tasks to be performed (Gebbie et al. 2002). However, plans are often effective only in anticipated situations, in other words, for expected events. Plans fail to deal with departures from predictable outcomes. In reality, unexpected calamities require an adaptable capability that recognizes new opportunities in any given situation (Dynes et al. 1976; Mintzberg et al. 1985).

The Great East Japan Earthquake disaster in 2011, one of the greatest earthquakes faced by mankind, illustrates the reality of the unexpected. All business operations, including those of public organizations, were suspended and remained so for some time in areas directly affected by the earthquake and tsunami. In some areas, power supply and connectivity were completely lost at the most critical lifesaving phase immediately after the earthquake. In those areas, people were instantly confronted with a situation they had never experienced and which had never been anticipated in any disaster management plan. This earthquake makes it clear that a key point is planning for returning to business as usual as speedily as possible.

This paper contributes to understanding how an organization regains an adaptive capability after the occurrence of a disaster. We incorporate a broader interpretation of the notion of capital and propose a capital model for disaster resilience. We analyze empirical data from the Great East Japan Earthquake using a system dynamics model and visualize the model results as a simulation.

The paper is structured as the following: (1) introduction of the model, (2) case description, (3) result of analysis by a system dynamics model and (4) conclusion.

TOWARD DISASTER RESILIENCE

The discussion surrounding resilience originally started with the examination of ecological systems (Bhamra et al. 2011). Though the literature reflects different views of resilience, we take the path of providing adaptive capacity and allow for ongoing, proactive development; i.e., dynamic, adaptive interplay between sustaining and evolving processes in response to change (Anderies et al. 2004; Berkes et al. 2003; Folke 2006; Gunderson 2001; Woods 2015; Zolli et al. 2013).

To understand the process of reconstructing, we introduce the notion of capital beyond the common association with financial resources. In this sense, we assert that resilience is the ability to reconstruct capital effectively and efficiently, relative to the magnitude of the disaster. The capital model consists of five dimensions of capital (Mandviwalla et al. 2014): economic (financial, physical or manufactured resources), social (individual or organization empowered by social connections), symbolic (the amount of honor or prestige possessed within a given social structure), human (skills, knowledge and abilities that individuals use to generate income or other useful outputs), and organizational (institutionalized knowledge stored in databases, routines, patents, manuals and structures to support an organization's goal). One form of capital can modulate changes in another form through a capital conversion and creation system. For instance, spending economic capital on education increases human capital. Social capital affects the economic performance of companies (Nahapiet et al. 1998). The purpose of this paper is to demonstrate that capital conversion can play a critical role in enhancing the resilience of systems. Once a form of capital is destroyed, communities will attempt to compensate by deploying other dimensions of capital.

The five dimensions of capital can play different roles through their particular conversion and creation systems. As the literature points out (Wildavsky 1988), interdependence is recognized as one of important factors in building resilience to disasters. When we consider the reality of unexpected events happening, the capital resilience framework reaches well beyond the predetermined plan. Thus, our research leads us to consider how organizational resilience is expressed through capital conversion and capital creation.

CASE OF OTSUCHI TOWN

Based on the notion of capital, this paper analyzes the result of interviews with officials from the municipal government of Otsuchi, which experienced huge damage from the earthquake. The interviews aimed at clarifying how a municipality handled disaster relief operations. In the discussion below we label in brackets each dimension of capital to make it clear which dimension was destroyed, how it was recovered and so on.

Based on the definition showed in the previous section, we label each dimension of capital as following: economic capital is labeled for office building, servers and residential related data, human capital is labeled for employees of municipal governments and Mayor, social capital is labeled for social connections with outside organization, symbolic capital is labeled for town's representatives (Mayor) and entrance permission to the towns, and organizational capital is labeled for information systems which requires to resume disaster relief operations. Social capital can be raised within the organization (Leana et al. 1999), however, this paper focuses on the relationship between organizations since we want to look at how outside organizations could support the recovery process. Information systems are regarded as organizational capital, as it comprises tools to integrate a range of operations that enable disaster relief operations.

The town lost its Mayor (*human and symbolic capital*) in the tsunami and his deputy's term was nearing its end on June 20, 2011. As many decisions in an emergency situation require high level authority, absence of a legitimate leader hindered relief operations. This forced the town to concentrate its efforts on implementing a mayoral election. Thus priority was placed on restoring the Basic Resident Registration Network System (*organizational capital).* This paper considers the ICT environment as organizational capital, as it comprises tools to integrate a range of operations that enable the town to generate a voter list.

The task was not easy. Otsuchi Town lost one-third of its employees (*human capital*) when its three-story town office building (*economic capital*) was completely engulfed by the tsunami. The server room located on the first floor was submerged in muddy water, which disabled all the machines in the room (*economic capital*). All residential data including backup (*economic capital*) was lost. As it was apparent that the old system could not be repaired, the decision was made to recreate the ICT environment (*organizational capital*) from scratch in a temporary town office (*economic capital*) located in the community center.

The assumption had never been made that servers, robustly designed to withstand severe earthquakes, could actually be lost. Lack of preparation further complicated recovery. Most importantly, a security system to protect sensitive data on the servers blocked efforts to extract data from them. This problem was solved by salvaging residential data from a flooded server's hard disk. Before salvage was complete, the town was able to use a back-up database (*economic capital*) that was fortuitously maintained by the town's system vendor (*social capital*). The back-up data (*economic capital*) were then fed into a temporary system (*organizational capital*) that the town had prepared in the community center by March 29. The system vendor (*social capital*) lent out the server (*economic capital*) for system development.

On April 13, restored residential records salvaged from the server hard disk were fed into a second temporary system (*organizational capital*) also prepared in the community center. It enabled Otsuchi to resume resident services including the issuance of residential certificates. The tax system and the residential record network system were also restored at this time. Naturally, the data were not current, but were rather the state of the database on March 11, when the tsunami hit. On April 25, officials moved to temporary government office buildings that were set up in the grounds of Otsuchi elementary school (*economic capital*).

Recovery of the Basic Resident Registration Network System, necessary to provide synchronized service in multiple locations, required the reconstruction of physical landline cables as well as of communication servers and firewalls (*organizational capital*). The temporary government building was too small to house these, so they were also placed at the community center. Server room construction and network connection were completed on June 15. Firewalls were installed on June 29. Preceding that, fiber optic cable had been laid between the temporary town government building and the community center building on May 20. A communications server was brought in on July 6 and went into operation after preparatory works on July 15. The town was finally ready to update its voter list by receiving data from other towns reporting people who had moved out of town following the earthquake (*organizational capital*).

The mayoral election was carried out five months after the earthquake and two months after the deputy's term had expired, on August 28, 2011. Thus the town had been lacking a legitimate leader when leadership was critically needed. The new mayor (*economic and symbolic capital*) asked other municipalities (*social capital*) to send relief staff to the town.

On September 20 temporary servers were replaced with permanent servers.

A CAPITAL MODEL FOR DISASTER RESILIENCE

Using the data obtained in the interviews, we develop a simulation model known as concept model in system dynamics for visualizing conversion of resilience capital. Concept models have traditionally been used to provide a platform for further exploration of a problem by displaying the relationships over time of key factors according to current understanding. Concept system dynamics models – which are simplified and, thus, preliminary – serve as stepping stones towards a more complete understanding of the problem in question by illuminating the causal structure that is responsible for the simulated behavior and paving the way to elicit missing factors and causal relations (Andersen et al. 1997; Richardson 2013; Richardson et al. 1992; Richardson et al. 1995).

In accordance with best modeling practice we have created our simulation model as simple as possible, but not simpler than absolutely necessary – this is the Occam's Razor version for simulation model design. For example, one may criticize our assumption that the capital forms recover to their values before the disaster as too simplistic. Such objection would crash against one of the Golden Rules of model design (Occam's Razor again) since one would have to add to the model the complexity of lessons learned from the disaster which would be the drivers for enhancement of capital forms. Apart from adding complexity prematurely, before a simpler model has had the chance to show its ability to render the observed behavior of capital forms over time, it is doubtful that within the time horizon considered – 36 weeks – the processes of lessons learned would have proceeded far enough to contemplate goals significantly higher than before the disaster. It is even more doubtful that within that short period of time there would be resources available and enough of drivers to contemplate and achieve significantly higher capital values.

Figure 1 shows the "sketch" version of the system dynamics model as constructed with the simulation software Vensim DSS[1]. Vensim models consist of a diagram (called "sketch" view) and the model equations (which can be viewed by changing to the "text" view). The sketch view depicts the variables and the parameters of the model along with arrows expressing inputs for the definition of equations (single lines) and "flows" that add or subtract from stock variables (shown by variable names in boxes). The model building process proceeds by sketching the model diagram. Afterwards, one adds equations that must be consistent with the topology of the sketch. The equation for how flow variables (such as '*creation of human from social capital*' and '*disaster destruction of human capital*') affect the stock are created by Vensim directly from the diagram. In this case:

'Human Capital'= INTEG ('creation of human from social capital'-'disaster destruction of human capital', 'initial human capital')

which expresses that '*Human Capital*' is computed by integrating the sum of the flows over time, where *'initial human capital'* is the value of human capital before the disaster strikes.

The capital dimensions human, economic, etc in the model are represented by values on the scale [0…1], with the two extremes representing lack of capital and maximum achievable capital given the town resources. Admittedly, one needs to develop better metrics for the capital dimensions.

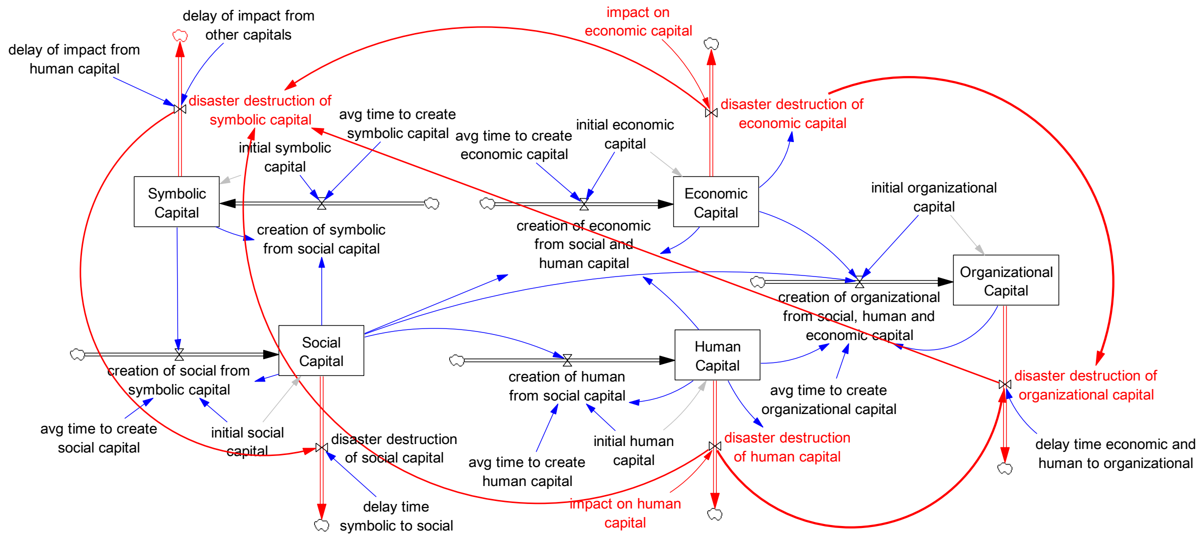

Figure 1. Concept Capital Model for Disaster Resilience

Taking the variable '*creation of human from social capital*' as example, from the single line arrows pointing to it Vensim enforces that the equation defining '*creation of human from social capital*' must use '*Social Capital*', '*avg time to create human capital*', '*Initial human capital*' and '*Human capital*'.

Here the modeler must use an equation that makes sense, either by expressing some known fact in mathematical form or by hypothesizing a plausible relation. In our model we hypothesize that the (re-)creation of any capital dimension following the disaster is a process attempting to close the gap between the value of the capital before the disaster strikes (the "initial" value of the capital) and the current value of the capital, such that the value of the flow variable is proportional to the gap. Staying with the example for human capital, the gap is *'initial human capital'-'Human Capital'*. Further we assume that the value of the flow variable is inversely proportional to a time constant. According to such process, the time constant is the average time to close the gap according to an exponential averaging process (Sterman 2000). Further, in accordance with the empirical findings described previously, we assume that the creation of a capital dimension is modulated by one or more of the other capital dimensions. Again for the case of the human capital, the empirical findings indicate that social capital modulates the creation of human capital. Thus, the model uses the following equation

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[1] Vensim is probably the most used system dynamics software tool in the academic world. Nearly all work published in the leading journal in the field, the *System Dynamics Review*, use Vensim for modeling and simulation.

'creation of human from social capital' = 'Social Capital'('initial human capital'-'Human Capital')/'avg time to create human capital'*

In accordance with the empirical findings the disaster causes a direct destruction of economic and human capital. We model the direct impact of the disaster using the Vensim function *PULSE*. For example, for human capital, we assume:

'disaster destruction of human capital' = ('impact on human capital''Human Capital'/'TIME STEP')*PULSE(2, 'TIME STEP')*

which states that a pulse of height *('impact on human capital'*'Human Capital'/'TIME STEP')* and width *'TIME STEP'* occurs at intervals of two weeks. We chose the disaster to strike at week 2 of the simulation so as to depict horizontal lines for the capital types expressing steady state before the disaster. We use *'TIME STEP',* which corresponds to *dt* in the integration process, as the width of the pulse it should be interpreted as describing a instantaneous process. Obviously, the simulation cannot occur in terms of an infinitely small *dt*, but rather the numerical approximation uses a very small, but finite value for the time step. The choice of the time step determines the accuracy of the simulation. The usual practice is to choose the value of the time step as to achieve visual accuracy (the resulting simulation graphs do not change perceptively if the time step is further decreased). For the simulation (Figure 2), the value of the time step that achieves visual accuracy is:

'TIME STEP'= $1/2^5=1/32=0.03125$ *Weeks*

Empirical data from the Otsuchi case indicate that the organizational and symbolic capital dimensions were indirectly affected by the disaster destruction of human and economic capital. We model the indirect impact using delay functions available in Vensim. For the symbolic capital we assume – as suggested by empirical observations – that the destruction of human capital had the fastest and strongest impact on the symbolic capital.

One cannot exclude that the destruction of symbolic capital in turn would affect the social capital. Therefore, the diagram shown on Figure 1 includes a link to this effect. However, for Otsuchi no such effect was observed. Therefore, the model has been calibrated so that there is zero impact from symbolic to social capital for the Otsuchi case.

Figure 2 shows the results of simulating the model. The model parameters were chosen so that the resulting patterns of behavior over time are in qualitative agreement with the empirical data for Otsuchi.

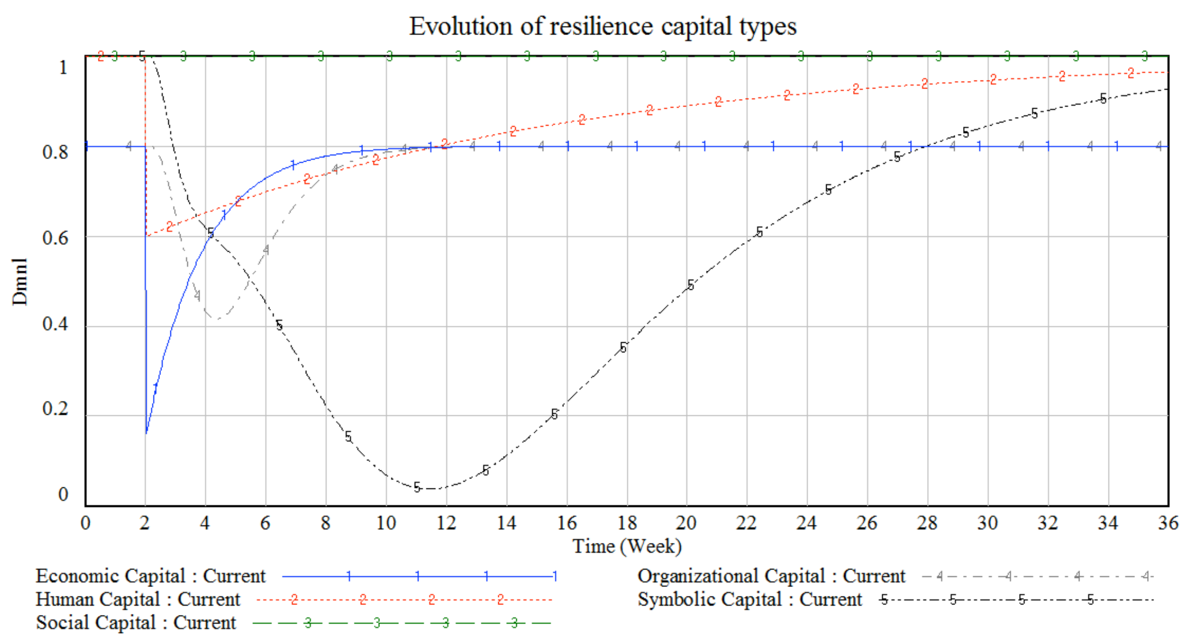

Figure 2. The Result of Simulating the Concept Model

USEFULNESS OF THE MODEL

Our concept model contains features well entrenched in the data collected for the towns affected by the Great East Japan Earthquake, such as the main structure of capital conversion processes as well as the impact the disaster destruction and the overall duration of the capital recreation. The model has been supplemented with a number of assumptions and hypothesis that are documented in the Vensim model file.

One of the advantages of expressing qualitative models as equations that can be simulated is the ability to analyze the consequences of the model. This is what a simulation is: the expression of what the model implies. By taking this step, one recognizes the limitations of one's knowledge and how to proceed so as to extend one's knowledge.

It is beyond the scope of this paper to document the numerous issues that need more research. We will proceed to do so in an extended paper which includes simulations for two other towns affected by the Great East Japan Earthquake.

In the meantime, we invite readers of the published version of this paper to request the fully documented the Vensim model so as to inspect the model's equations and the documentation of the extent to which the parameters and the equations relate to empirical observations or assumptions as well as to proceed to experiment and to simulate the model. Note that there is a version of the Vensim software that can be freely downloaded and used for academic purposes[2].

CONCLUSION

For developing a future disaster-tolerant government or community, the capacity to mobilize responses in the field is important. When we think about how to accomplish this goal, we tend to focus on the restoration of buildings, personnel, and community (Aldunce et al. 2014). Categories of social, economic, institutional, infrastructure and community are also discussed as a resilience indicator which proposes the way of measure resilience (Cutter et al. 2010). The model we propose in this paper deals with all aspects of entities which discussed in the research. In addition, the model analyzes resilience with one key notion, capital, which enables us to see interactions between entities. This paper advances the capital model for disaster resilience to reveal capital conversion and recreation process. Examining this process enables us to analyze and develop the notion of resilience more systematically. The model describes interdependencies both in how capital destruction indirectly affects other capital forms and how capital forms are created. As a further step, in future publications we will provide an analysis of factors that need further consideration. In addition to this, we will apply the same analysis for other municipalities which also affected by the earthquake.

This paper contributes not only to the disaster recovery literature but to business practice in the sense of which kind of resources an organization should strengthen or prepare as part of disaster readiness. The resulting capital resilience framework is proposed as a tool for all organizations to employ in future disaster situations.

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[2] The free version of the software, Vensim PLE, can be downloaded from http://vensim.com

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