Fostering Community Resilience: Disaster Relief as a Complex Adaptive Supply Network

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Abstract

Adequate response and recovery performance following large-scale and catastrophic disasters has remained elusive despite considerable efforts to coordinate the many government agencies, non-profit organizations, for-profit businesses, and individuals that participate. When these diverse entities interact with each other, they form a large supply chain network and the resultant collective performance emerges, often with unanticipated results. We integrate knowledge from supply chain management and complexity science to discuss how the behaviors of entities, their interactions, and their environmental context determine the level of resilience that communities have following disasters. Based on this framing, we set forth propositions regarding several properties, both of entities and of their interactions, that could give rise to improved community resilience. Finally, we suggest some future work on fostering inter-entity coordination that could give rise to previously unseen levels of community resilience.

Keywords: Disaster Management; Supply Chain Networks; Complex Systems

1 Introduction

Community resilience can be defined as the capacity of a group to successfully conduct *preparation*, *response*, and *recovery* efforts following a disaster. These three phases of emergency management are primarily concerned with coordinating the sourcing, delivery, and application of equipment, goods, and services that are necessary for whatever unique demands are encountered. In large-scale and catastrophic disasters to date, these efforts have relied on considerable interaction between multiple agencies, organizations, businesses, and individuals to help communities save lives, restore economic foundations, and resume “normal” life. Unfortunately, adequate response and recovery performance following large-scale and catastrophic disasters has remained elusive (McEntire, 1999, 2002; Stephenson, 2005; Wise, 2006) in spite of numerous major efforts to coordinate the diverse entities that participate.

Even with continued increases in disaster mitigation efforts over the last 50 years, the rate of large-scale disaster incidents receiving presidential declaration has more than quadrupled (see Figure 1). Several factors have been suggested as contributing to this trend including: growing populations in hazardous areas (such as coast lines, fault zones, high-density metropolises), increased societal brittleness from reliance on technology, growing wealth disparity, weaker community ties, and specialization of local industries (U.S. National Science and Technology Council, 2003). Since none of these suggested contributory factors seem to be reversing their current trends, it is likely that we will continue to see more frequent occurrences of higher-impact disasters regardless of larger investments in mitigation. Therefore, we will need to ensure both our communities and our country become more capable of planning for, responding to, and recovering from disasters.

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As we consider activities taken by individuals, organizations, and agencies reacting within a disaster-affected community, it is logical to apply knowledge from supply chain management (SCM), the business discipline that studies inter-organizational coordination (Van Wassenhove, 2006). SCM traditionally focuses on how to improve the flows of resources, money, and information among firms so as to foster improved performance. Unfortunately, the vast majority of extant academic research in the SCM discipline involves only small sets of firms with few interactions. These simplified models often allow for elegant analytical examinations of simple inter-organizational phenomena, yet the findings they produce may be limited in their generalizability to the real-world.

Recently, some SCM researchers have characterized larger networks of supply chains as complex adaptive systems (Choi et al., 2001; Surana et al., 2005). Moreover, a complex adaptive supply network (CASN) has been defined as a system of entities that occupy a shared environment while interacting with one another through buyer/supplier relationships (Pathak et al., 2007). These entities and their interactions give rise to larger-scale emergent system properties such as supply chain quality, industry performance, or national/global GDP.

In this paper, we assert that an inter-organizational disaster relief effort can be considered a CASN and that community resilience is an emergent system property. Extant knowledge from the fields of supply chain management, complexity science, and disaster management are integrated to illustrate how entities, their interactions, and environmental conditions contribute to the level of resilience communities have following disasters. We examine how this novel perspective provides new insights into what community characteristics give rise to improved community resilience and what kinds of incentives might be used to encourage enhanced disaster response and recovery capacities.

In section 2, we examine some of the current knowledge regarding organizational participation in disaster relief efforts. Section 3 provides a short review of elements that compose a CASN and expands upon this definition to explain emergent system properties. Section 4 relates the concepts of supply chain management and complex adaptive supply networks (CASN) to the inter-organizational context of disaster relief efforts. More specifically, we characterize the flows of resources, money, and information in disaster relief as well as the relevant entities, relational topology, environment, and system performance issues. Section 4 provides propositions regarding several entity and topology properties that may impact community resilience. Finally, Section 5 provides conclusions and suggests future work that might lead to unprecedented improvements in localized community resilience through enhancing distributed coordination.

2 Background Literature

Our examination of previous research was primarily aimed at reviewing the current approaches, theories, and methods of disaster relief in the business operations and management science literature. We found extant literature on organizational issues in disaster relief to be rather fragmented with relatively few consistent references. Nonetheless, when brought together, these diverse sources provide an important perspective on how inter-organizational coordination impacts disaster relief effectiveness.

There are many different approaches to disaster relief, often depending on the perspective of the organization (Kovacs and Spens, 2007; Long, 1997). Perry (2007) discusses that the key natural disaster response requirements are preparedness, activity in vulnerable region, involvement of local people, coordinated needs assessments, collaborative information sharing between parties, and logistical expertise and efficiency. Van Wassenhove (2006) summarizes that disaster logistics operations have to be designed in such a way that they get the right goods to the right place and distribute to the right people at the right time. Smirnov et al (2007) writes that one of the most difficult steps in responding to disasters and emergency situations is providing the right relief supplies for people at the right time. At the same time delivering too many or wrong supplies implies losing time and resources. (Fritz Institute, 2005).

Prevention, planning, and coordination are important in a disaster relief effort and intertwine with supply chain management in the response and recovery phases. A successful relief operation is one that mitigates the urgent needs of a population in the shortest amount of time and with the least amount of resources (Tomasini and VanWassenhove, 2004, Van Wassenhove, 2006). Therefore, prevention is vitally important as it can reduce the risk and potential impact of a disaster and either eliminate or reduce the efforts and time required in response and recovery (Perry 2007; International Federation of Red Cross and Red Crescent Societies, 2002; Newport and Jawahar, 2003; Thomalla and Schmuck, 2004; Benson et al., 2001). Oloruntoba and Gray (2006) suggest that there should be a planned approach in which a longer-term, strategic perspective is adopted that coordinates relief functions.

Effectiveness during the first 72 hours, also known as the response phase of disaster managment, can have a large impact on the overall success or failure of disaster relief efforts. This is a vital time for the relief effort to minimize damages, losses, and other vulnerabilities (Kovacs and Spens, 2007; Beamon, 2004; Long, 1997; Long and Wood, 1995; Ozdamar et al., 2004; Tomasini and van Wassenhove, 2004; Sheu, 2007; Van Wassenhove, 2006). Providing relief quickly is often the most important objectives during the response phase (Kovacs and Spens, 2007; Barbarosoglu et al., 2002).

This quickness depends heavily on logistics operations (Kovacs and Spens, 2007; Thomas, 2003) which establish the goods transport pipelines and service provision processes tailored to fit a particular crisis (Pettit and Beresford, 2005). Van Wassenhove (2006) writes that disaster relief efforts consist of about 80% logistics and that improvement is achieved through efficient, effective logistics operations, or more precisely, supply chain management. Having adequate supply chains following a disaster can mean the difference between a successful or failed operation (van Wassenhove, 2006; Thomas and Mizushima, 2005). Many other authors also state that logistics is a key enabler for successful disaster relief (e.g. Trunick, 2005; Smirnov et al., 2007; Fritz Institute, 2005).

Another key supply chain concern in disaster relief is inventory management. Long and Wood (1995) discusses how inventory management in relief operations is unique in that the time value of the commodities are much greater than the inventory carrying costs. For example, it is much more important to have food available and move it as rapidly as possible to places where it is needed than to hold minimal stock levels. When blockages might intermittently affect a supply pipeline (e.g. physical, political, or security-related impediments), larger stocks must be on hand to move as much as possible when movement is allowed (Long and Wood, 1995). The distribution process can often be problematic since inventory systems may not be in place or appropriate plans for transporting inventories to affected regions may not exist (Hwang, 1999). In a disaster environment, facilities and infrastructure may be damaged and transportation models often have difficulty accounting for this (Larson, 2006). In addition, the infrastructure is usually destabilized (Cassidy, 2003; Murray, 2005) and interdependencies of the infrastructure network may not be fully understood (Wright et al., 2006).

The various disaster management issues identified in previous research are intricately interrelated and give rise to high uncertainty in relief efforts that change quickly over time. Unfortunately, the management strategies that work well in a specific location, time, or context can lead to very poor performance in only slightly different environments. Many other highly-interrelated systems exhibit similar difficulty in replication of certain previously successful strategies. Complexity Science investigates what such systems of interrelated phenomenon have in common in an effort to better understand how collective performance might be influenced. We apply this lens of complexity science to inter-organizational disaster relief efforts in an effort to cast new light on what generates resilience and how it might be fostered in our communities.

3 Supply Chains as Complex Adaptive Supply Networks (CASNs)

For many years, complex adaptive systems research has examined systems of interactive, changing entities (Holland, 1995; Kauffman, 1996; Bar-Yam, 1997). Since supply networks are composed of entities that exhibit adaptivity, maintain myriad interactions, and compose a complex system, it is a natural step to conceptualize a supply chain network as a complex adaptive system. Choi et al. (2001) assert this characterization by providing a detailed mapping of how several common properties of complex adaptive systems apply directly to supply networks. Pathak et al. (2007) extended this research by describing a complex adaptive supply network (CASN), which consists of the following four key elements:

1. Several organizational **entities** exhibiting adaptivity
2. A **topology** of interconnectivity between multiple supply chains
3. An external **environment** that co-evolves with the system
4. Self-organizing and emergent **system** performance

We briefly reflect upon and expand these fundamental elements and their interactions.

3.1 Entities

CASN entities are decision-making organizations that exhibit dynamic learning. In order to learn, they obtain information in the form of feedback from their relationships, observed system performance/behavior and their surrounding environment, incorporating the obtained information into their decision making. Their actions can directly impact the supply network topology, the entire CASN system, and the external environment. To illustrate these potential impacts on other CASN elements consider the following three illustrative examples. First, the decision to serve a competitor's customer introduces a new connection in the supply network topology, altering the previous flow of materials, money, and/or information. Second, an organization's price reduction might induce a price war with competitors, reducing the profitability of multiple supply chains in the CASN system. Third, lobbying with government to alter regulatory policy can significantly alter the environment within which the CASN operates.

3.2 Topology

A CASN topology consists of the connections between organizations. These connections include the resource, financial, and information flow relationships between the entities comprising the system. Over time, decisions made by pairs of entities to create or dissolve relationships result in changes in the CASN topology. The CASN topology configuration helps determine how the activities of one entity impact other entities and vice-versa. Influencing other entities' connections is possible, but autonomous entity objectives are often conflicting and may change. Thus, organizations can only manage their extended supply networks to a certain extent since network change is likely to be simultaneously impacted by supplier, customer, and competitor influence as well.

3.3 Environment

The environment of a CASN provides a logical stage on which the entities, their interactions, and the overall system perform. The environment may include external conditions that do not originate within the system itself but have some impact on its behavior or performance. It is important to note that the system itself can impact changes in these environmental components, creating co-evolution, or mutually impacted change over time. For example, regulatory policies, market demand, or economic cycles might be modeled within the environment and each of these could be allowed to change over time as some function of system properties. In turn, their new states might induce changes in decisions at entities, leading to new topological structure and/or system behavior that eventually cycles back to impact the environment yet again.

3.4 System

The system behavior in a CASN emerges not only from the interactions between and among the entities, but also from the impact of its surrounding environment. As entity behavior and environmental components evolve, the corresponding changes in system behavior tend to be non-linear in nature. Thus, there may be very small entity activities or environmental changes which have a dramatic effect on the system, or conversely, there may be large changes which have relatively little effect.

3.5 Properties of CASN Elements

Each of these fundamental elements within a CASN can maintain several properties. Element properties can be used to describe the state of a CASN at a moment in time and the changes in these states over finite time-spans. Some of these properties may already be well-accepted measurements or metrics within the supply chain management discipline, such as an organization's inventory holding costs. Other properties, such as supply chain agility, may not yet have a universally agreed upon definition and it is highly likely there are many more properties that have yet to be conceptualized or observed.

A careful identification and definition of a long list of potential properties associated with each fundamental CASN element is beyond the scope of this paper. However, we suggest a few potential properties for each element in Figure 2. Of particular interest to us is how we might impact system resilience by influencing changes in various entity and topology properties.

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4 Characterizing the Disaster Relief CASN

Humanitarian aid and disaster relief efforts have been directly characterized as supply chains. For example, Van Wassenhove (2006, p. 477) suggests that the overall objective of disaster relief and humanitarian efforts is to "get the right goods to the right place and distribute to the right people at the right time." A similar phrase often appears as the definition of a supply chain management in business textbooks (e.g. Simchi-Levi et al., 2007). Nonetheless, research has pointed out that disaster logistics is quite different from traditional business logistics (Sheu, 2007). Nevertheless, researchers stress the importance of effectively managing the flows of resources, money, and information during disaster relief efforts (Kovacs and Spens, 2007). We first examine the similarities and differences between how each of these flows behave in disaster relief as opposed to traditional supply chain contexts. Next, we describe how each of the CASN elements in Section 3 is embodied by disaster relief efforts.

4.1 Examination of Disaster Relief Supply Chain Flows

In traditional supply chains, the downstream flow of resources often provides the organizing structure between suppliers and buyers while the flows of money, which are typically upstream, distribute compensation for value-creating transformations. Flows of information, both upstream and downstream, provide important inputs for performing these transformations in a response and efficient manner. Disaster relief supply chain flows operate in much the same way, yet exhibit some interesting, and perhaps important, differences too.

4.1.1 Resource Flow

The primary flow of interest in many supply networks is that of resources and disaster relief is no exception. Other flows are only useful insomuch as they can be leveraged to more responsively or efficiently provide the goods and services required to save lives, reduce suffering, and restore a community's economic and social foundations. Ultimately, disaster relief resources flow downstream to satisfy the needs and wants of the relief clients, i.e. end consumers, as they would in traditional industry supply networks.

Figure 3 provides a very general depiction of how resources, including a large portion of monetary flows, move downstream through a disaster relief supply chain network. Each box depicts a specific type of supply network entity while each arrow shows the flow of resources between entities. The conversion of raw materials (e.g. volunteer time, donations, profits, taxes) into goods and services that pass through entity transactions creates the downstream flow of resources that eventually alleviates relief client demand. These resources flow downstream to eventually satisfy relief client demand. There may be several transactions within the manufacturer and distribution stages that are necessary before resources are eventually provided to those that need them.

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4.1.2 Monetary Flow

Monetary flows provide for some interesting differences between supply networks of traditional industries and those found in disaster relief. In traditional industry supply networks, money is typically provided in compensation for the provision of goods or services. Therefore, the flow of money primarily moves upstream from the end customer to raw material suppliers, diminishing in value at each stage in accordance with the value produced there. In disaster relief supply networks however, a large portion of monetary flows originate somewhere upstream and filter out to the relief clients (Long and Wood, 1995; Perry, 2007), either diminishing in value at each stage in accordance with the administrative overhead costs held back at each stage or being held back due to a lack of demand within a jurisdiction. These downstream monetary flows are often found moving between government agencies, non-profit organizations, and individuals. Instead of providing compensation for value creation, they function more like a raw material resource flow in the sense that money becomes an input that gets transformed into goods and services.

4.1.3 Information Flow

Every participant in the disaster relief supply chain network has some piece of information that may be important to other participants and to the overall effort. Relief clients have information about their needs; relief provision organizations and agencies have information about the services they can provide and their throughput capacities; manufacturers have information about their inventories or service capabilities; and individuals have information about their intent and ability to contribute through donations of either time or money. Fostering the proper flow for these pieces of information is important if competent decisions are to be made throughout the supply network.

Unfortunately, inter-organizational information flows during disaster relief efforts face challenges that may be more intense than those faced in traditional industries. Based on a multi-organization case study, Day et al. (2009) identified eight specific impediments to the flow of information in disaster relief supply networks, including: inaccessibility, inconsistent information and data formats, inadequate flow of information, low information priority, source identification difficulty, storage media-activity misalignment, unreliability, and unwillingness. Each one of these impediments arose from the environmental context and reduced the ability of organizations to perform the data collection, information processing, and information sharing activities that promote information flow. Although these same impediments may also impact traditional industry supply networks, their intensity is heightened to what may seem an unmanageable extreme in the highly uncertain and dynamic disaster relief context.

4.2 Disaster Relief CASN Elements

Maintaining this understanding of the various supply chain flows, we now describe how disaster relief efforts are embodied within the various CASN elements. Here, we use existing research to explore how the different elements of the disaster relief CASN have already been characterized.

4.2.1 Characterization of the Disaster Relief Environment

The environment inherent to relief efforts following major disasters has been characterized along many different dimensions. This section discusses three categories of external factors that act on a disaster relief effort: inherent, physical, and sociopolitical. Various combinations of these factors can be present in a post-disaster environment. This environment, although it is external to the relief effort, changes with the effort and influences both behavior and decision making at relief providing entities.

Inherent elements of a disaster relief environment have a tremendous effect on the relief effort. In fact, these elements make disaster logistics significantly more difficult to manage than conventional business logistics, which is more stable and predictable. Disasters occur with little or no warning (Pettit and Beresford, 2005), have a low frequency of occurrence, and are high-consequence, low-probability events (Larson, 2006) in which there may be large quantities of wounded or casualties (Gong and Batta, 2007; Yi and Ozdamar, 2007). The environment has been characterized as complex (Van Wassenhove, 2006), dynamic (Perry 2006; Pettit and Beresford, 2005), chaotic (Perry 2006; Pettit and Beresford, 2005), unpredictable (Kovacs and Spens, 2007; Larson, 2006; Sheu, 2007), and politically volatile (Long and Wood, 1995). Both relief clients and relief providers typically face conditions of extreme uncertainty and incomplete information (Kovacs and Spens, 2007; Perry, 2007).

The physical environment of a disaster is often difficult to traverse and usually damaged or deteriorating at unpredictable rates. Some regions are more vulnerable than others to particular types of disasters (Kovacs and Spens, 2007). Geographic features, such as mountain barriers, remoteness areas, or severe climatic conditions can drastically impact relief efforts (Pettit and Beresford, 2005; Perry, 2007; Thomas and Kopczak, 2005). A region's wide geographical dispersion may also affect the distribution of goods and provision of services (Oloruntoba and Gray, 2006; Tzeng et al., 2007). The destruction of or damage to various infrastructures can lead to unanticipated cascading effects because of interdependency between infrastructures (Cassidy, 2003; Pettit and Beresford, 2005; Moore and Anthill, 2000; Long and Wood, 1995; Min et al., 2007; Perry, 2007; Thomas and Kopczak, 2005; Thomas 2003; van Wassenhove, 2006; Sheu, 2007).

Other factors external to the system such as social and political elements of the environment must also be accounted for. Since disasters rarely respect geographical or cultural boundaries, there are often language barriers which relief providers must overcome (Long and Wood, 1995; Kovacs and Spens, 2007). Although aid agencies often operate under neutrality, they typically maintain widely varying political agendas, ideologies, religious backgrounds, and beliefs (van Wassenhove, 2006). A variety of social, political, cultural, and economic factors disproportionately cause poorer communities to be more vulnerable than others (Benson et al. 2001; Perry, 2007). Unequal attention is given to more popular disasters and as a result, the level of support provided to relief clients depends on the popularity of the disaster (Long and Wood, 1995).

4.2.2 Disaster Relief System Performance Measures

System performance in inter-organizational relief efforts following large-scale and catastrophic disasters can be measured in several ways. The common aim of any disaster effort is to provide appropriate and timely relief to the final beneficiaries (Smirnov et al., 2007; van Wassenhove, 2006; Sheu, 2007; Pettit and Beresford, 2005; Kovacs and Spens, 2007; Thomas and Kopczak, 2005). Ultimately, the overall disaster relief system performance is concerned with bringing relief to survivors, minimizing lives lost, and reducing damage (Tzeng et al., 2007). The achievement of each of these can be considered with respect to measurements of speed, efficiency, and responsiveness. Furthermore, in disaster relief efforts, which of these measurements is considered the most important often changes over time.

During a relief effort's response phase, roughly the first 72 hours, the speed (i.e. throughput) of provision activities is by far the most essential measurement. Often, the speed of provision is highly dependent on the supply chain activities including procurement, transport, and distribution (Kovacs and Spens, 2007). Speed in the response phase can provide strong leverage for success or failure of the entire disaster relief effort (Sheu, 2007). During this time, increased speed often conserves human life and can help prevent cascading failures in the infrastructure which might otherwise lead to increased cost or duration of further relief efforts; therefore, the utilization of the fastest option is extremely important in spite of the additional expense required (Tomasini and van Wassenhove, 2004; Perry, 2007).

After the initial response period, the measurement focus shifts towards efficiency. The recovery phase of the first 90 to 100 days begins concentrating on keeping costs reasonable while balancing that efficiency with effectiveness (Van Wassenhove, 2006). For example, Long and Wood (1995) discuss how distributing food to centralized facilities is cost efficient yet the inability of some victims to travel to the food site must be strongly considered along with the benefits.

Responsiveness, the ability to quickly provide appropriate resources with dynamically shifting needs, remains critical throughout the relief effort (Sheu, 2007; Oloruntoba and Gray, 2006; Perry, 2007; Thomalla and Schmuck, 2004; Newport and Jawahar, 2003; Benson et al., 2001). Relief efforts which allow for sufficient adaptability to external influence and unforeseen problems can improve overall relief effort performance (Pettit and Beresford, 2005; Long and Wood, 1995).

4.2.3 Participating Disaster Relief Entities: Motivations & Incentives

There are many types of entities that participate in relief efforts and they exhibit different behaviors even though the collective goal is to provide relief to final beneficiaries (Kovacs and Spens, 2007). The types of entities involved include for-profit businesses, non-profit organizations, government agencies (including military), and individuals such as donors, volunteers, and relief clients (Kovacs and Spens, 2007). Many of these entities are capable of providing various relief services such as medical attention, clearing away rubble and debris, providing transport access, or basic survival requirements such as clean water, water purification kits, cooking utensils and food, safe areas, relocation, shelter and general living, and psychological support (Perry, 2007).

Participating entities range in breadth of focus from international to local communities and they have diverse ideologies, political agendas, and religious beliefs (Oloruntuba and Gray, 2006). The largest agencies are global actors, but there are also many small regional and country-specific aid agencies (Thomas and Kopczak, 2005; Kovacs and Spens, 2007). Many international organizations are mobile and have a short term focus, moving from one disaster to the next sometimes overnight (van Wassenhove, 2006). These entities are created primarily to provide emergency aid and have little or no linkages to long-term community recovery (Oloruntoba and Gray, 2006; McEntire, 1999; Denning and Hayes-Roth, 2006). The role of local entities are undeniable and very important (Perry, 2007). Their knowledge of local preferences, languages, and culture often prove important, if not essential, in provision of certain relief services. In fact, when adequate provision is perceived as unavailable, ad hoc local entities, such as new aid organizations (Oloruntoba and Gray, 2006), emergency shelters (Yi and Ozdamar, 2007), or loose associations of community individuals may mobilize to fill the underserved gap.

The entities involved often have different operating and organizational structures (Long and Wood, 1995; Kovacs and Spens, 2007). They range from being highly structured to highly decentralized (Oloruntoba and Gray, 2006). Some entities grow to become dominant and their actions may exceed their actual authority (Oloruntoba and Gray, 2006). Byman et al. (2000) write that some groups falsely perceive that they have a leadership role and act accordingly. Kovacs and Spens (2007) point out that non-profit organizations and governmental entities are most likely to be dominant. Host governments control significant assets such as warehouses or fuel depots (Kovacs and Spens, 2007) while non-profit organizations often create service niches that increase system performance through improved efficiency and/or more effective provision (Long and Wood, 1995). However, successful niches foster competition between entities that desire dominant control of that particular niche (Perry, 2007; IFRC, 2005).

Although most entities are likely to desire an overall outcome that is beneficial to those affected, ultimately, entities are motivated by their own self interests. Individually, each entity can have very different reasons for providing relief (Long and Wood, 1995). Many organizations have their own political motives in providing relief (Long and Wood, 1995; Kovacs and Spens, 2007). Perry (2007) describes some entities as manipulating their power for self-interest.

Donors play an important role for non-profit organizations during relief efforts since they are a primary source of funding (Oloruntoba and Gray, 2006). The expectations of these donors can greatly influence the behavior of relief providing organizations (Oloruntoba and Gray, 2006), especially as they compete with each other for donations (Oloruntoba and Gray, 2006; Munslow and Brown, 1999; Bookstein, 2003). As a result of the focus on raising funds, organizations have a high concern for public visibility (Oloruntoba and Gray, 2006; Byman et al., 2000).The competition for donor investments can drive organizations' behaviors as they vie for media attention (van Wassenhove, 2006). Large donations are often politicized, require greater transparency of organizational uses, and may be ear-marked for specific purposes, ultimately leading to an unstable supply chain (Ebersole, 1995; Oloruntoba and Gray, 2006; Bennett and Daniel, 2002; van Wassenhove, 2006).

The media often plays a significant role as well (van Wassenhove, 2006). Due to the nature of organizations' dependence on donors and government responsibility to taxpayers, the visibility and popularity of a disaster plays a significant role in overall relief efforts. For instance, low visibility disasters are typically underfunded and become forgotten (van Wassenhove, 2006; Long and Wood, 1995). In such relief efforts, some organizations may focus on fundraising rather than relief efforts and agencies have little incentive to improve on past performance (Van Wassenhove and Samii, 2003).

For-profit businesses significantly contribute to the relief effort by providing donations, business expertise in logistics, or individual manpower (Garry, 2005; Leonard, 2005; Rowell, 2005; Kovacs and Spens, 2007). For-profit involvement in a relief effort is primarily motivated by profits and positive publicity (van Wassenhove, 2006). These businesses become relief resource suppliers that often form partnerships and alliances with the government agencies and non-profit organizations that provide those resources to relief clients (Kovacs and Spens, 2007; Murray, 2005).

4.2.4 Disaster Relief Supply Network Topology

It is difficult to manage the rapid integration of entities into an inter-organizational disaster relief effort for many reasons (Denning and Hayes-Roth 2006). Disaster relief efforts are usually dispersed geographically (Oloruntoba and Gray, 2006) with numerous entities involved (Byman et al., 2000). Entities are individually distinguishable but their interconnections between each other are often not well known or understood (Kovacs and Spens, 2007) and there is rarely a clear division of labor (Byman et al., 2000). However, the presence of numerous and diverse entities – there can be as many as several hundred humanitarian organizations at the scene of a disaster at one time – can significantly hamper coordination (Perry, 2007; Van Wassenhove, 2006).

Since each disaster is unique there is no typical humanitarian supply chain (Oloruntoba and Gray, 2006). However, the typical humanitarian supply chain sequence consists of the following order from the highest to the lowest level: government, donor, international agency, international (nongovernmental organizations) NGOs, local NGOs, in-aid recipient countries, community based organizations, also known as local partners, and finally consumers or aid recipients (Oloruntoba and Gray, 2006). Some disasters draw several governments and independent NGOs together and force them to interact (Beresford and Rugamba, 1996). And although some organizations have strong informal networks (Oloruntoba and Gray, 2006), success requires the mutual cooperation between all levels from state to local to business entities (Kovacs and Spens, 2007).

Unfortunately, the interactions between entities within the disaster relief CASN often experience considerable problems. Interactions between international and local governments can be quite problematic (Perry, 2007). Inter-organizational coordination is also very difficult (Long and Wood, 1995) since each organization generally works independently from others (Sommers, 2000; Perry 2007). The physical paths between entities matter as well since relief resources generally flow via multiple modes of transport including air, land, and sea (Beresford and Rugamba, 1996; Oloruntoba and Gray, 2006). Weak communication is not only present between different entities, but also occurs within entities between the field personnel and managers in the office (Oloruntoba and Gray, 2006).

5 CASN-Related Contributions to Community Resilience

Within the context of a disaster relief CASN, characterized in the previous section, community resilience can be regarded as an emergent system property. That is, resilience to an environmental disruption, such as a natural disaster or terrorist attack, arises from the entities involved, their behaviors, and the topology of their relationships. As a system property, therefore, community resilience changes as the properties of that system's entities and topology evolve. Therefore, community resilience can be influenced by understanding what kinds of entity properties and what topology properties should be cultivated. We present several propositions that posit how entity behavior and relationship topology can impact the system-wide property of community resilience.

5.1 Entity Contributions to Community Resilience

Much of the impact that participating entities have on community resilience is fairly evident from past experience and has informed traditional approaches to disaster management. This list is not intended to be exhaustive, but rather representative; and although there may be many more issues that could be discussed, we present general issues that are thought to be common across a wide set of contexts.

5.1.1 Entity Self-Resilience

First and foremost, **entities themselves must be resilient** to disaster if they are to effectively contribute to community resilience. This is certainly the case for relief clients since, if a significant portion of a community is destroyed, that community may no longer exist. Yet it is also the case for local government agencies, non-profits, and for-profits. These local entities often maintain unique knowledge of specialized community requirements and they usually constitute 'the last mile' of relief provision following a disaster. Furthermore, without the people, agencies, organizations, and businesses that exist in a community, the community itself does not continue to exist.

Proposition E1: Enhancing the sustainability of the entities that comprise a community can improve the resilience of the overall community.

5.1.2 Relief Demand and Supply Capacity

The number of **relief client and relief provider entities**, and their potential levels of demand and supply capacity, impact resilience as well. Communities with a large number of high-demand entities in prone areas are likely to experience high demand levels when a disaster occurs. For example, if largely indigent populations hold residence in lowlands that become flooded, the demand requirements are likely to be greater than if more self-resilient professionals occupied that same area. If both the type and capacity of those needs is unlikely to be matched by the available relief provision entities, the community will require external resources for a successful relief effort.

Proposition E2: Reducing potential entity relief demands and increasing the available supply of resources can contribute to the level of community resilience.

5.1.3 Regional Entity Diversity and Flexibility

The **diversity and flexibility of entities** within a region can also contribute to community resilience. Following a disaster, there is often a very diverse set of needs that emerge. If a community's entities are highly specialized and the community must import critical resources, fewer types of the necessary goods and services are likely to be immediately available following a disaster and its resilience will be dependent on external sources. If a disaster cuts off a highly-specialized community's access to imports, when experiencing critical infrastructure damage or quarantine for example, the lack of access to critical external resources is more likely to threaten survival.

Proposition E3: Encouraging diverse and flexible entity capabilities can reduce reliance on external resources and will enhance community resilience.

5.1.4 Scalability of Throughput Capacity

The **scalability of throughput capacity for relief provision** can have an impact on community resilience. Plans for rapid expansion of production and quick-training programs can enable entities to rapidly foster an ability to serve more relief clients in a shorter amount of time. Given the common 'lean' level of inventories sought across many industries today, plans for rapid temporary expansion of local throughput capacity may be considered a lower-cost alternative than maintaining surplus service capacity or storing stockpiles of goods. However, it is important to ensure that the flow of any required input resources can be quickly increased to match needed throughput capacity levels following disasters. If entire supply networks focus on increasing local throughput to provide for affected entities' needs, as the community provides for its own survival it enhances its ability to restore economic foundations as well.

Proposition E4: Community resilience will benefit from entities that are able to quickly scale-up their throughput capacity in response to a disaster.

5.1.5 Entity Decision-Making Capabilities

Entities' decision-making abilities can also impact overall community resilience. Following a disaster, many entities are forced to speed-up decision making by forming localized assumptions from insufficient, and sometimes invalid, information. This is especially true for control entities, but certainly effects relief clients and providers as well. Knowing they lack sufficient or valid information, entities are often compelled to take actions that may be inappropriate for the circumstances that actually exist (Smith and Dowell, 2000). When relief clients, relief providers, and control entities are provided with appropriate information they can make better decisions that improve relief efforts. However, it is important to only provide the information that is useful to an entity since there are bounds on the amount of information an entity can effectively process during its decision-making.

Proposition E5: As entities are provided efficient access to accurate information and are enabled to more quickly make decisions, community resilience can improve.

5.2 Topology Contributions to Community Resilience

Again, it is not only the entities themselves, but also the structure and qualities of their relationships that help to determine the level of community resilience. While several of the entity properties identified are commonly addressed in traditional approaches to disaster management, consideration of the following topology properties have received little attention. It is the application of a complexityoriented perspective that brings these issues to light. Each of the following properties provides an understanding of how entity relationships contribute to resilience.

5.2.1 Network Structure

Network structure characteristics, such as path length, clustering, and connectivity, have been shown to contribute to resilience. Complex networks with few highly-connected hubs (i.e. scale-free networks) are more tolerant of a few random errors (Albert et al., 2000; Thadakamala et al., 2004). However, these same hubs also increase a network's vulnerability to targeted attacks. In this sense, communities with highly centralized structures may experience a trade-off between their resilience to targeted disasters, such as terrorist attacks, and their resilience to more regional-spread natural disasters, such as earthquakes or hurricanes.

Proposition T1: The network structure created by entity relationships can impact community resilience. This impact can be beneficial or detrimental and can experience tradeoffs for different types of disasters.

5.2.2 Path Redundancy

The level of **redundancy in paths between entities** impacts community resilience as well. For example, the number of different routes that goods can travel through various intermediate entities to get to an affected client population can be very important to resilience. If there are very few possible routes for goods, information, or money to be exchanged between entities, they may be likely to become overloaded by swelling throughput demands. Even worse, they may be rendered inoperable by the disaster, leaving no routes at all for essential relief inputs.

Proposition T2: Higher levels of path redundancy between entities can enhance community resilience.

5.2.3 Topology Dynamics (Supply-Base Flexibility)

A capability for managing **dynamic connections in the relief provider network**, e.g. flexible sourcing and sales strategies, can have an impact on resilience as well. When a supply network is capable of coping with many changes between multiple suppliers and customers, it is better able to alter its operations in response to change or disruption. In the response phase of disaster relief, it is common to simultaneously encounter an altered workforce, supplier stockouts, and new customers. Groups of entities that regularly respond to dynamic operational and inter-organizational environments are more likely to maintain operations despite the shifting topology that marshals the flows of resources, information, and money.

Proposition T3: Communities of entities that can effectively manage a shifting network of relationships will experience higher levels of resilience.

5.2.4 Inter-Entity Trust

Trust between entities is often a prerequisite for transactions in normal operations. Procurement and sales decisions are often driven by experiences of previous interaction or referrals from trusted sources. When entities without established trust interact in one-time transactions in an urgently responsive post-disaster environment, we often see excessive selfish or even malicious behavior. The Government Accountability Office's report on the inappropriate distribution and use of FEMA's Post-Katrina individual assistance checks and debit cards provides a good example of this behavior (GAO, 2006). These resources could have been used more appropriately for the response and recovery efforts.

Proposition T4: Fostering greater trust among relief-participating entities can increase community resilience.

6 Conclusions and Recommendations

Our characterization of an inter-organizational disaster relief effort as a CASN provides several insights into how appropriate management action can influence community resilience. The flows of resources, money, and information are generated by the interactions between the many entities participating in disaster relief supply chain. These entities and their interactions give rise to the emergence of system properties observed in the collective performance. Community resilience is one such emergent system property.

Changes in CASN system properties result from entity decisions to alter their behaviors or relationships. Therefore, community resilience can be impacted by judiciously influencing both the behaviors of and the relationships between entities. At the entity level, we provide propositions that self-resilience, demand and supply capacity, diversity and flexibility, scalability of throughput capacity, and decision-making capabilities each contribute to resilience. Within the topology of relationships between entities, contributions to resilience come from sources including network structure, path redundancy, topology dynamics, and inter-entity trust. By influencing changes in these entity and topology properties, it is possible to impact system performance with respect to community resilience. However, it is important to note that influencing such changes is likely to impact other emergent system properties as well. And although influence is possible, full control of system performance in a dynamic system with multiple entities that hold conflicting objectives is notoriously difficult and can be very counter-productive.

We recommend that distributed coordination mechanisms for effective disaster management be investigated. Various species of ants, bees, and other biological organisms that maintain social collectives of a large number of entities employ distributed efforts from several specialized capabilities without any centralized control. These complex systems, which exhibit incredibly high levels of resilience to disasters, may provide guidance on how individuals, non-profit organizations, for-profit businesses, and government agencies can integrate their efforts to achieve greater speed, responsiveness, and efficiency in integrated disaster relief efforts.

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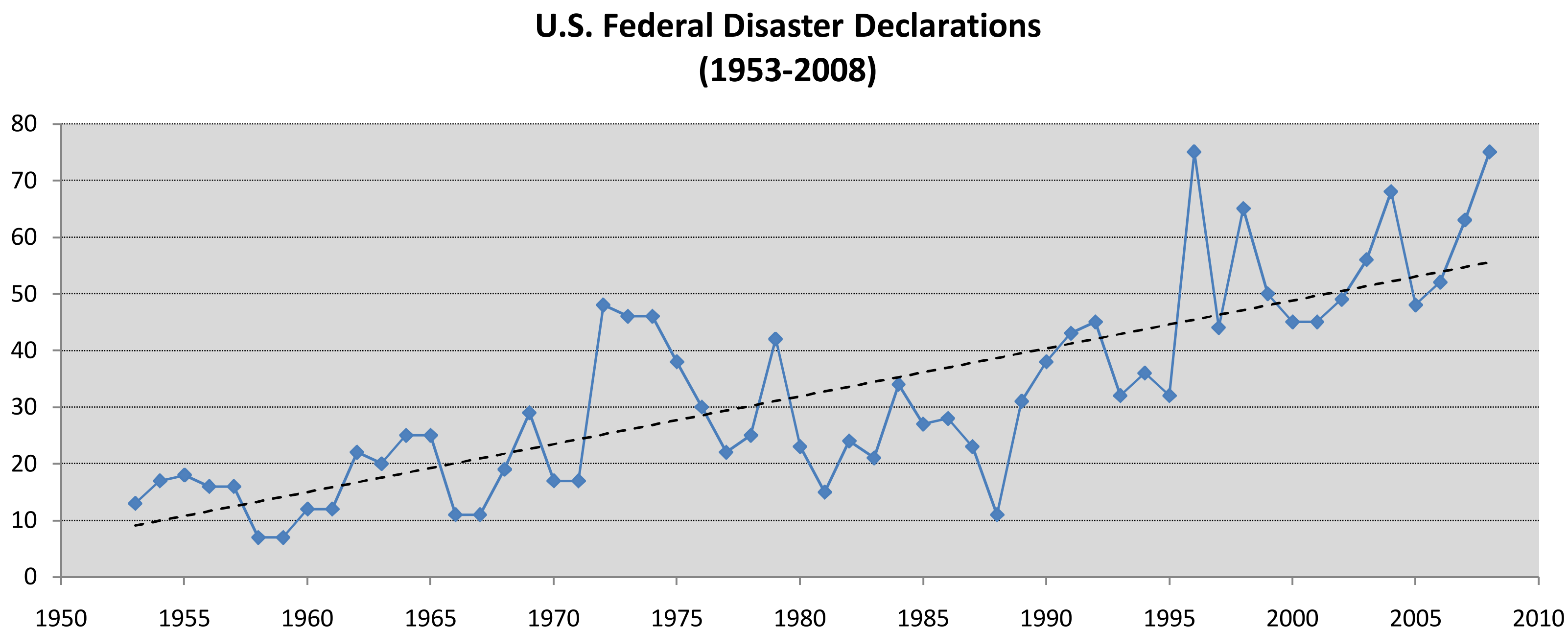

Figure 1: U.S. Federal Disaster Declarations, 1953 – 2008 with trend line (Source Data: FEMA)

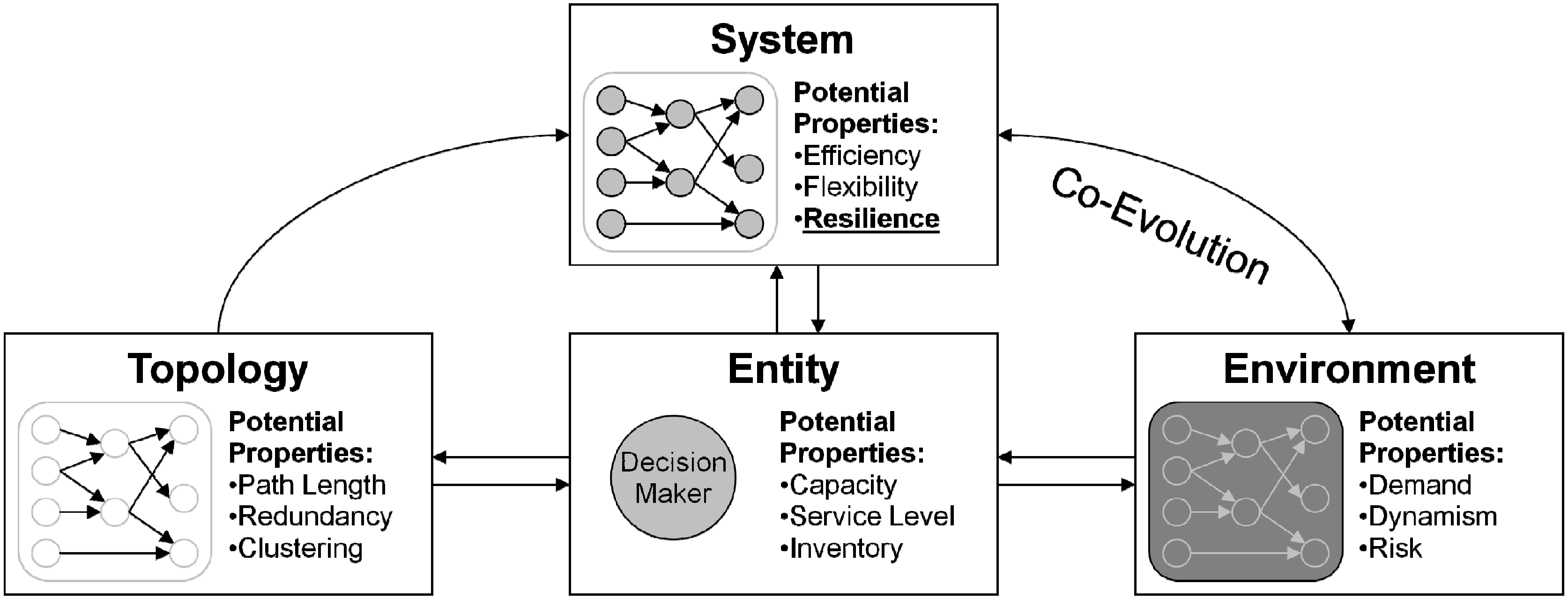

Figure 2: Key elements, interactions, and some potential properties of a Complex Adaptive Supply Network, based on Pathak et al., (2007)

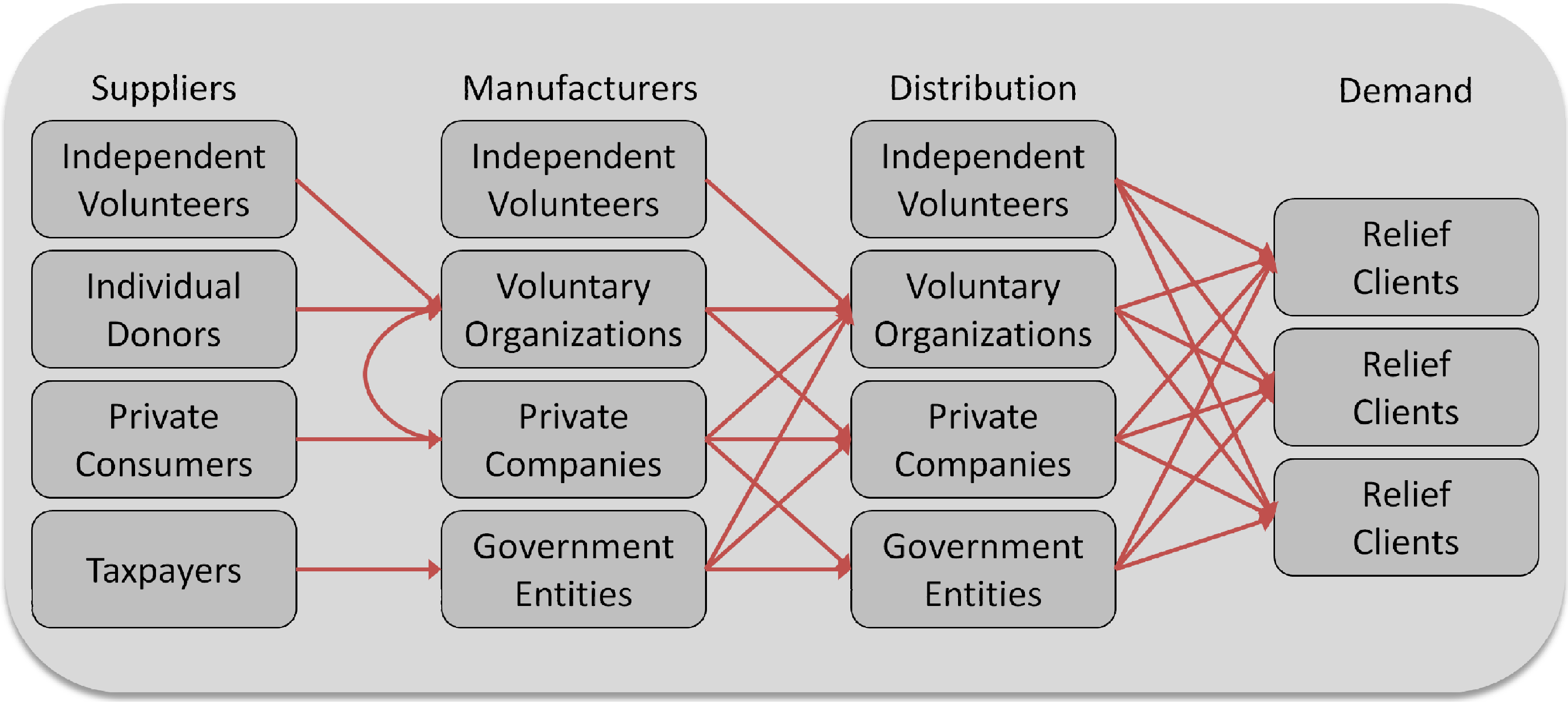

Figure 3: Typical resource flows in a generalized disaster relief supply network