MIT Sloan School of Management

MIT Sloan School Working Paper 4704-08
6/2/2008

System Dynamics Modeling of Humanitarian Relief Operations

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Abstract

Against the backdrop of over two hundred thousand people dead or missing and millions of people homeless after China's massive earthquake and Myanmar devastating cyclone, forecasts estimate that natural and man-made disasters are likely to increase five-fold both in number and impact over the next 50 years. Hence, the need for disaster relief provided by humanitarian organizations during disasters should continue to increase. At the same time, humanitarian organizations face increased challenges scaling capacity, improving operational efficiency, reducing staff turnover, improving institutional learning, satisfying increasingly demanding donors, and operating in increasingly challenging environments, with poor or inexistent infrastructure, high demand uncertainty and little time to prepare and respond. To address such challenges, managers in humanitarian organizations must understand the complexity that characterizes humanitarian relief efforts to learn how to design and manage complex relief operations. Yet, learning in such complex and ever changing environments is difficult precisely because managers seldom confront many of the consequences of their most important decisions. Effective learning in such environments requires methods and tools that allow managers to capture important feedback processes, accumulations, delays, and nonlinear relationships, visualizing complex systems in terms of the structures and policies that create dynamics and regulate performance. The system dynamics approach provides managers with a set of tools that can help them learn in complex environments. These tools include causal mapping, which enables managers to think systemically and to represent the dynamic complexity in a system of interest, and simulation modeling, which permits managers to assess the consequences of interactions among variables, experience the long-term side effects of decisions, systematically explore new strategies, and develop understanding of complex systems.

Keywords: Humanitarian relief operations; complex systems; dynamics complexity; system dynamics; causal loop diagrams; simulation modeling.

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Introduction

On May 2 2008 cyclone Nargis hit Myanmar leaving at least 78,000 people dead, 56,000 missing and about 2.4 million victims (NRP 2008a). Shortly after, on May 12, a massive 7.9-magnitude earthquake shook China's Sichuan province leaving more than 68,500 dead, another 20,000 missing, 300,000 hurt and 5 million people homeless (NRP 2008b). While on average 500 large scale disasters kill about 75,000 people and affect a population of 200 million people every year (Wassenhove 2006), these numbers pale in comparison to future expectations. Forecasts estimate that over the next 50 years natural and man-made disasters will increase five-fold both in number and impact (Thomas and Kopczak 2005). A characteristic of disasters, disruptions that physically affect a system as a whole threatening its priorities and goals (Wassenhove 2006), taking place today is that they disproportionately affect populations in nations that are still developing economically (McEntire, 1997, p. 226). Contributing to the increase in the impact of disasters in developing nations are a combination of factors, such as: strenuous environmental degradation caused by rapid unplanned urbanization, indiscriminate farming and industrial practices; competition for and depletion of essential resources (such as water, forests, etc.) in densely populated areas; and climate change, amplifying the environmental impact through droughts, floods, desertification, deforestation, etc. (Colitt and Bilefsky 1999, McEntire 1999). As a consequence of the rise in the number and impact of natural or man-made disasters, the need for disaster relief, humanitarian aid provided during disasters, is expected to continue to increase. The inability of international humanitarian relief organizations to properly scale capacity in the face of ever-increasing needs, however, has led to a generalized scarcity of resources and intense pressure to improve operational efficiency of disaster relief efforts (Thomas and Kopczak 2005). Many humanitarian relief organizations today have resources thinly stretched among simultaneous operations in different theaters around the world. In addition, increasingly demanding donors pressing for better results and data demonstrating impact of aid to those in need have subjected relief organizations to greater scrutiny, leading to further pressure toward operational transparency and results orientation (Thomas and Kopczak 2005).

While both academics and practitioners recognize that more effective and efficient logistics operations have the potential to improve the results of disaster relief efforts, while providing additional operational transparency, until recently logistics was not perceived as central to relief operations. The pressure to improve operational efficiency, transparency and results has generated a recent outcry for improved logistics in relief operations, especially in the aftermath of the magnitude of the humanitarian mobilization efforts required by the Indian Ocean Tsunami (Wassenhove 2006). The widespread adoption of supply chain management tools in the commercial sector illustrates the opportunities for improving logistics efficiency in the humanitarian sector. At the same time, humanitarian relief operations are characterized by a number of complex challenges not faced by commercial operations (see table 1). Such complex challenges play an important role in determining operating conditions in the field and the ability to apply traditional supply chain management tools to humanitarian relief efforts.

Table 1 –Challenging Factors in Humanitarian Relief Efforts

- Because of the disaster, operating conditions are frequently poor and unpredictable. Relief effort must operate with inadequate infrastructure as roads, railroads, airports, may not be available.
- Conditions may not allow adequate implementation of information systems and structured logistics processes.
- Political unrest and turmoil in affected countries may limit or severely delay the ability of agencies to provide relief.
- Demand for relief is highly uncertain, requiring short-term on site assessment and little time for preparedness.
- Scarce resources and priority to relief, means assessment is done quickly, and frequently not updated, inappropriately assessed needs often drive the relief effort.
- Supply conditions must be evaluated on site, requiring the whole supply chain to be often designed and implemented in short periods of time.
- Humanitarian relief operations experience extreme time pressure to perform, with failure in humanitarian aid measured in loss of lives.
- Pressure to resolve current short-term crisis often precludes attention to long-term capability building.
- Humanitarian staff often lacks adequate training and skills, and field stress leads to high turnover.
- Donors often fund specific relief efforts but not long-term infrastructure building in relief organizations.
- Relief agencies must often manage multiple stakeholders with different and sometimes conflicting goals.
- Unsolicited donations can create unpredictable bottlenecks in different parts of the supply chain and strain usage of limited resources.

The list in table 1 is sobering. Humanitarian relief efforts face hostile or at best poor operating conditions, often lacking basic infrastructure; highly uncertain demand both in terms of numbers and needs; little time to prepare, respond and structure processes, resulting in quick design and implementation; high stakes lead to extremely high pressure; high field staff turnover limits learning by headquarter staff, limiting institutional learning from past disasters; and attention to short-term needs in detriment of long-term capability. And, while humanitarian relief efforts face a number of complex challenges, Tomasini and Wassenhove (2004) caution that things could actually be worse. "Disasters evolve into crises as their complexity increases and they interact with other vulnerability factors demanding a response that challenges the traditional response mechanisms and capabilities." For instance, China's Sichuan earthquake caused landslides to form a new lake above the city of Beichuan. Fears that the Tangjianshan quake lake could burst its banks required the evacuation of 150,000 people, in addition to operations directly addressing earthquake victims (NPR 2008b).

Characteristics of Complex Systems

To address the existing challenges, understand potential interaction among vulnerability factors, and possibly prescribe ways to improve efficiency, it is important to understand and characterize the complexity that typically exists in humanitarian relief efforts. However, we must first clarify the difference between two types of complexity: detail complexity and dynamic complexity (Senge 1990, Sterman 2000). Detail, or combinatorial, complexity arises when decision makers must consider a large number of components or possible combinations in a system before making a decision. In contrast, dynamic complexity arises from the subtle and delayed cause-and-effect interactions of system agents over time. In dynamically complex settings, decision makers must account for the nuanced and delayed system interactions that are not closely connected causally or temporally. While detail complexity is frequently part of humanitarian relief operations, dynamic complexity poses a far bigger challenge, in particular because decision makers "tend to make decisions using mental models that are static, narrow, and reductionist" (Sterman 2001) instead of dynamic, broad, and encompassing.

Table 2 provides an initial characterization of the different factors responsible for generating the dynamic complexity observed in humanitarian relief systems (Wassenhove 2006). The dynamic de to unclear and incremental cause-and-effect relationships that when small are invisible and unpredictable, but due to interactions can accelerate escalating their impacts. Adapting the work of Richardson (1994) on disaster management, the characterization highlights the challenges associated with anticipating the behavior of complex systems. The characterization allows an initial understanding of the different factors responsible for generating the dynamic complexity and is an important step in management of complex crisis. However, it does not provide a framework that allows decision makers to infer emerging behavior from individual factors.

Table 2 – Characteristics of Dynamic Complexity (Adapted from Wassenhove 2006)

Characteristic	Comments
Incremental change	Focus on most severe aspects of a crisis often leave other factors unchecked, allowing them to interact, grow over time and lead to further consequences.
Highly interactive	Interaction among factors accelerates rate at which disasters might escalate.
Highly ambiguous	Cause and effect relationships are not clear and dispersed over time.
Challenges from new phenomena	Challenges due to unknown effects and impact.
Invisibility/Unpredictability	Inability to understand or anticipate which factors are important and may dominate the dynamics.

According to Tomasini and Wassenhove (2004), "complex crises demand the intervention of multiple specialized agencies that will be addressing the different factors… [requiring] non-traditional responses tailored to the needs, and a comprehensive long-term plan … that aims to coordinate the response activities." To design their innovative, non-traditional, comprehensive, and long-term responses, however, agencies must not only understand the different factors, but also have dramatic insight into how they interact and generate the unanticipated and ambiguous behavior. It is easy to understand that this is no small task.

A similar characterization of complexity in dynamic systems shown in table 3 is found in the system dynamics literature (Forrester 1961, Richardson and Pugh 1984, Sterman 2000). Incremental change arises in dynamically complex systems because changes in variables (important states in the system) take place over time, changing constantly through processes of accumulation. Because such systems are tightly coupled, variables in one part of the system feedback and interact with variables in other parts the behavior of these systems is highly ambiguous and often unpredictable. Because causes and their effects are not necessarily close together in time or space relationships go unnoticed while they are small and become evident only when it might be too late. Nonlinearity among interactions exacerbates the lack of predictability. Because complex systems are self-organizing and adaptive they resist changes and adapt to policies.

Table 3 – Characteristics of Dynamic Complexity (Adapted from Sterman 2001)

Characteristic	Comments
Constantly changing/Past-dependent	Changes in variables over time characterize the current state of the system. The past history influences the available futures.
Tightly coupled/Governed by feedback	Variables in the system interact strongly with one another, until they feedback to influence themselves.
Self-organizing	The dynamic behavior of the system arises from the structural interactions in the system.
Adaptive/emergent behavior	Systems are often resistant to changes and adaptive to policies.
Nonlinear	Effect is not proportional to cause. Local effects do not apply globally.

An initial appreciation for behavior in complex systems can come from the challenging behavior associated with individual elements, such as: feedback, delays, stocks and flows, and nonlinearity.

Feedback

Most people have a tendency to hold an event oriented perspective of the world. Because we learn from early on that for every action there is a reaction, when we observe an event (reaction) we tend to search for its cause (action). The search for the cause is frequently informed from people's experiences with simple systems, where "the cause of a trouble is close in both time and space to symptoms of the trouble. If one touches a hot stove, the burn occurs here and now; the cause is obvious" (Forrester 1971). Experience with simple systems also suggests that the cause is often outside the control of, or exogenous to, the people impacted by the effect, e.g., the hot stove is a condition of the environment. The problem is that complex systems do not behave like people's open loop view of the world, systems are characterized by feedback and actions often lead to new, and unanticipated, reactions. Because of feedback in complex systems, cause and effect might be far removed from each other in both time and space. Forrester (1971) explains the role of feedback:

> "True causes may lie far back in time and arise from an entirely different part of the system from when and where the symptoms occur. However, the complex system can mislead in devious ways by presenting an apparent cause that meets the expectations derived from simple systems… the apparent causes are usually coincident to occurrences that, like the trouble itself, are being produced by the feedback-loop dynamics of a larger system."

For instance, if available resources for relief in a region affected by disaster are below required resources, humanitarian organizations will attempt to close the resource gap by increasing resources allocated to the disaster region. The allocation of resources allows the organization to close the resource gap originally identified and solves the original problem. Because resources are typically constrained, however, the additional resources are usually sourced from another disaster region where the organization operates, limiting the organization's ability to provide relief in that other region. That is, to solve a resource gap in one disaster region, the organization creates a resource gap in another. As an example, to provide relief to people affected by the Indian Tsunami, many organizations cannibalized resources originally allocated to Darfur, sending them to Sri Lanka and creating resource shortages in Darfur. In fact, a survey conducted by the Fritz Institute (2005), in collaboration with experts from KPMG and MIT found that 88% of the 18 organizations interviewed had to mobilize experienced logisticians to Tsunami relief from other previously affected areas.

Delays

People's experiences with simple systems reinforce the connectedness of cause-and-effect in time. However, delays present in complex systems separate causes from its effects, preventing people from realizing the possible connection between them. Delays are a critical source of dynamics and dramatically increase the behavioral complexity of a system. In some contexts, delays can cause or amplify instability and oscillation. In other ones, they can filter out and attenuate unwanted variability, by separating important signals from noise.

It is well understood that delays in responding to disasters can lead to significant loss of life. Hence, agencies strive to be able to respond to emergencies that may take place in any part of the globe in a matter of days. At the same time, quickly committing to a course of action may limit valuable alternative options as further understanding of the needs of the disaster are clarified. Committing to supplying goods by ship can be ineffective and block access to scarce supplies if the port infrastructure is inoperative. Short decision making delays can both help or hurt a relief effort, it is important to understand when they are more likely to operate for or against it.

Stocks and Flows

Stocks, or accumulations, describe the state of the system at any point in time. In addition, stocks provide the source of information for decisions, give systems inertia and memory, and generate disequilibrium dynamics as they accumulate the difference between inflows and outflows (Sterman

2000). People's poor ability to predict how differences between inflows and outflows accumulate over time (equivalent to an intuitive integration exercise) often makes the behavior of systems highly counterintuitive.

Important accumulations in a humanitarian relief effort include, but are not limited to: the number of people requiring relief, the number of people receiving relief, and the amount of available resources such as funds, medications, tents, water bottles, blankets, personnel, etc. Considering one of such stocks, e.g., the number of people requiring relief, we see that it changes over time. The number of people requiring relief increases with the flow of people that are recently affected by a disaster. A drought may cause famine to spread over time reaching a wider population over time; it decreases with the removal of people that receive relief and also with deaths.

Nonlinearity

"Effect is rarely proportional to cause, and what happens locally … often does not apply in distant regions" (Sterman 2000). Growth processes often display exponential behavior, but because quantities cannot grow forever they encounter barriers that limit them. Rapid and unplanned urbanization can take place while there is physical space to grow. Rivers, lakes create nonlinear barriers to urban sprawl. At the same time, population growth may face limits from environmental degradation.

When feedback, delays, stocks and flows, and nonlinearity are taken together, they provide clues regarding behavior in complex systems including unanticipated side-effects, tradeoffs between subsystems and the broader system, short-term versus long-term tradeoffs, and insensitivity to interventions, ultimately highlighting the counter intuitive behavior and policy resistance nature of complex systems (Forrester 1971, Sterman 2000, Sterman 2001). The 1995 Kobe earthquake in Japan injured some 30,000 people and damaged the majority of Kobe's hospitals. To provide aid to the injured, the Japanese government established free health clinics. However, because the free clinics remained in operation for too long, it had the unanticipated consequence of delaying the recovery of the damaged private hospitals, nearly driving them into bankruptcy. In addition, "a conflict exists between the goals of a subsystem and welfare of the broader system" (Forrester 1971). Acting to optimize the subsystem, leads to a sub-optimal outcome for the broader system. Emergency relief creates recipient dependency, often preventing or limiting local economies ability to develop sustainably. For instance, CARE has recently decided to turn down US$45 million in funds from Food aid, because it recognized that by selling large quantities of subsidized farm products in African nations it may drive local farmers out of business (Dugger 2007).

Also, “social systems exhibit a conflict between short-term and long-term consequences of a policy change. A policy that produces improvement in the short run is usually one that degrades a system in the long run” (Forrester 1971). Humanitarian relief addressing the needs of affected people in the short-term makes local communities more susceptible to the longer-term threat and impact of disasters. After the Ethiopian Red Cross Society guaranteed food relief for Ethiopians that were completely destitute, people denied assistance on the grounds that were not too poor promised to sell their meager possessions in order to qualify. Then there is a bias in the international humanitarian system toward responding to “loud” emergencies, while neglecting “silent” ones that receive neither attention nor funding, but often afflict larger populations for longer periods of time. Finally, “social systems seem to have a few sensitive influence points through which behavior can be changed. These high-influence points are not where most people expect” (Forrester 1971). Few hard to find leverage policies lead to what is commonly known in social systems as *policy resistance*.

Sterman (2001) exemplifies the problem of policy resistance through an interesting citation from Sir Thomas More’s *Utopia* (1516): "And it will fall out as in a complication of diseases, that by applying a remedy to one sore, you will provoke another; and that which removes the one ill symptom produces others."

System Dynamics Tools

Clearly, managers in humanitarian relief organizations must learn how to design and manage complex relief operations with multiple feedback effects, long time delays, accumulations of diverse and important factors, and nonlinear responses to their decisions. Yet, learning in such complex and ever changing environments is difficult precisely because managers never confront many of the consequences of their most important decisions. Effective learning in such environments requires methods and tools that allow managers to capture important feedback processes, accumulations, delays, and nonlinear relationships, visualizing complex systems in terms of the structures and policies that create dynamics and regulate performance. The tools must also help managers “to evaluate the consequences of new policies and new structures” (Sterman 2001). The system dynamics approach provides managers with a set of tools that can help them learn in complex environments. These tools include causal mapping, which enables managers to think systemically and to represent the dynamic complexity in a system of interest, and simulation modeling, which permits managers to assess the consequences of interactions among variables, experience the long-term side effects of decisions, systematically explore new strategies, and develop understanding of complex systems.

System dynamics modeling starts with generating a clear and precise problem statement. A model is only useful if it can address a clear purpose. For instance, consider an organization dealing constantly with the pressure to resolve short-term crises. A new disaster requiring immediate attention pulls resources away from existing operations in other affected areas; assessment teams are assembled quickly and deployed to the affected region. The immediate crisis mobilizes the organization shifting its attention to the existing need. While this is the nature of humanitarian relief operations, managers in this organization also recognize that their past efforts and successes also precluded them from developing long-term capability both in terms of human resources and structured processes. Currently, managers feel vulnerable due to their reliance on limited human resources and inadequate IT infrastructure and ineffective processes.

The next step would be to capture the important stocks that describe the state of the system. For the problem described above, we could aggregate human resources and infrastructure into one stock that captures the overall "organizational capability." Alternatively human resources and infrastructure could be captured separately allowing managers to understand specific gaps in different areas of the organization. Stocks change over time. Organizational capability increases with investments in capability and decreases due to deteriorating capabilities. The stock of people increases with hiring; and, it decreases with attrition and firing.

Next, we would try to represent the feedback processes (and other elements such as delays and nonlinearity) that determine the dynamics of a system. Interestingly, there are only two types of feedback processes that describe all sorts of dynamics. The first feedback process is called positive, or self-reinforcing, and it tends to amplify the current state of the system. As an example, pressure to resolve the current crisis erode efforts to build capability, by diverting human resources from training to affected areas and by shifting investments in capability to the disaster relief . Limited investments in capability reduce the growth in the organizational capability; and, with the same outflow from deteriorating capabilities, overall organizational capability decreases limiting its ability to perform effectively when another disaster takes place. Ineffective performance during a disaster creates even more pressure to resolve the current crisis. This reinforcing process amplifies the initial pressure to resolve the disaster when it strikes the next time. When the new disaster strikes the organization will need to respond with even lower organizational capability than before. In contrast, the second feedback is called negative, or self-correcting, and it tends to counteract the current state of the system. Through the self-correcting feedback loop, pressure to resolve the current crisis leads to more effort to relief effort, eventually reducing them and decreasing the initial pressure due to the crisis. While it may appear that the self-reinforcing process might exactly balance the self-correcting one that is rarely the case. Whether the self-reinforcing processes or the self-correcting ones dominate, really depend on the specific strength of each one, which depend among other on the value of the important stocks. All dynamics arise from the interaction of these two types (self-positive and self-corrective) feedback loops.

Having captured the main stock-and-flow structures and the feedback processes that characterize the system of interest, the following step would be to translate the diagrams into a mathematical simulation model. In this translation process, it is critical to only incorporate variables in the model that have a real counterpart. Also, the representation of decision processes must capture how managers make decisions in the real system given the actual constraints faced and information cues available. The model should be a fair representation of the system of interest, responding in a way similar to what the original one would, given the specific conditions faced. Once the model captures the behaviors observed in the system for the right reasons, it is possible for managers to approach the model to assess the consequences of interactions among variables, experience the long-term side effects of decisions, and systematically explore new strategies. In the next section, we develop a causal loop diagram for the example of the organization dealing with a disaster that requires immediate attention. The causal map presented here draws directly from Repenning and Sterman (2001).

Causal Lop Diagrams

We capture the interaction of feedback loops in a causal loop diagram and we start from the representation of the measure of performance for humanitarian organizations: the number of *People*

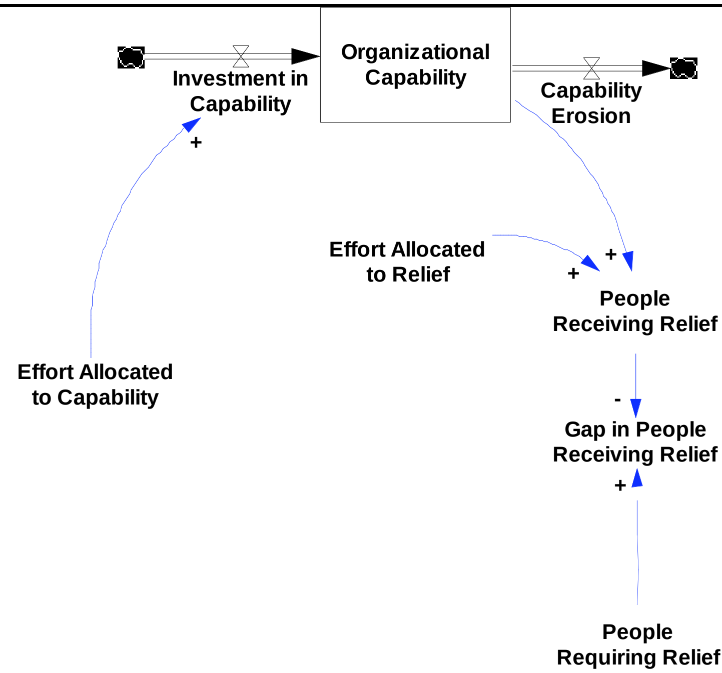
Receiving Relief. Typically, humanitarian organizations compare their actual performance (*People Receiving Relief*) with a desired performance level (*People Requiring Relief*) and explore whether there is a gap between desired and actual performances. If a gap in performance exists, it leads to managerial action to close it. A simple decision that managers, working at the headquarters level for relief organizations, can do to correct poor performance observed in the field is to allocate more resources (e.g., people, money, supplies, etc.) to relief. Two factors influence the people receiving relief (actual performance) in the theater: the *Effort Allocated to Relief* and the *Organizational Capability* (Figure 1). By allocating more effort to relief, say through additional people, trucks, and other resources the organization can provide more relief to the disaster affected region. Everything else equal, more resources will lead to an improvement in actual performance in the field. However, these efforts can only be sustained while the additional resources are available.

In contrast, the *Organizational Capability* provides more enduring effects. By developing the logistics capability of its field people (and retaining them), or building its IT infrastructure, the organization can be more effective assessing needs in the field, understanding potential bottlenecks, and quickly adapting to challenging conditions, while providing more relief with fewer people. Lack of appropriate IT infrastructure can lead to a number of problems. As Lars Gustavsson (2003), director of emergency response and disaster mitigation for World Vision International, puts it "[NGOs'] systems and approaches are often antiquated… [which] means increasing the time required to handle information and process a shipment… reduced inefficiencies, duplication of functions, increased inaccuracies in reporting and increased costs." At the same time, humanitarian organizations could use better trained staff. Gustavsson (2003) recognizes the need for capability training:

> "Logisticians in the field are often not trained professionals but have developed their skills on the job. Competency-based capacity-building initiatives and mechanisms need to be developed and supported so that humanitarian logisticians' skills and know-how are raised to more professional levels…"

The stock of organizational capability accumulates the difference between the inflow of "*Investment in Capability*" and the outflow of "*Capability Erosion*." The "*Effort Allocated to Capability*" increases the investment in capability. Managers at headquarters must always decide what fraction of resources will be allocated for relief (in the field) and what fraction will be allocated to capability building. While managers will not allocate more effort to capability building if a disaster has just occurred, they may not shift all their resources to relief effort. Also, since disasters cause lasting impacts in the affected regions, humanitarian organizations continue to provide relief long after the disaster has occurred just as they devote some of its resources to capability building. Figure 1 provides a causal loop representation of the mechanisms that influence people receiving relief in the field.

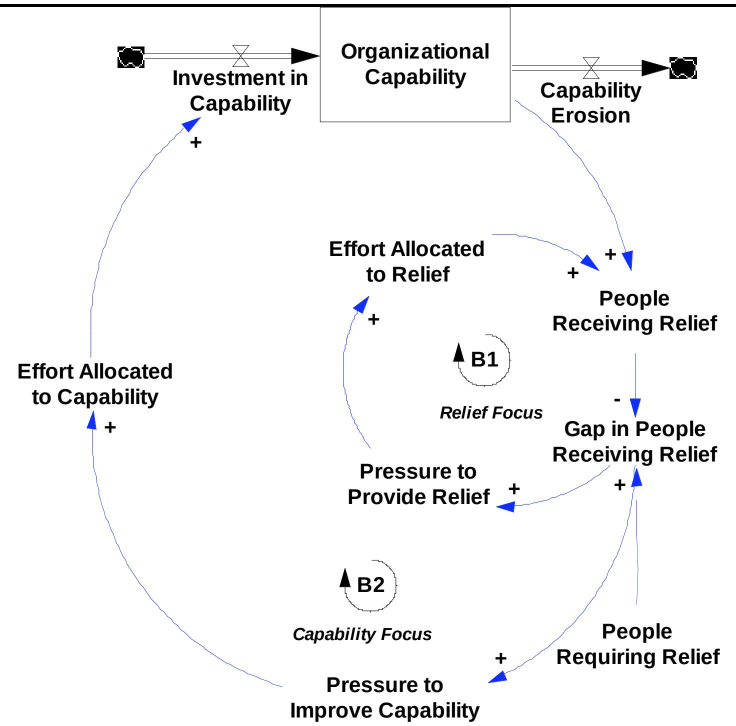
Figure 1 – The Basics of Humanitarian Relief Efforts



Note: The positive (+) signs indicate that the effect is positively related to the cause. More *Effort Allocated to Relief* causes an increase in the number of *People Receiving Relief.*

Figure 2 details the managerial decision making process at the headquarter level. Note that a gap in performance leads to increased *Pressure to Provide Relief* and increased *Pressure to Improve Capability.* Both measures close the original gap in performance. Once more effort to relief is made available, it closes a self-correcting, or balancing, feedback loop - the *Relief* loop (B1). Because deploying more people to the field is fairly quick, this loop operates quickly as the gap is identified. Headquarter managers can also allocate more effort to improve capability. The action of allocating more effort to capability improvement accumulates in the stock of organizational capability. However, due to the inherent delays associated with building capability, this loop operates with a longer time delay. More Effort to Capability closes another balancing *Capability* loop (B2).

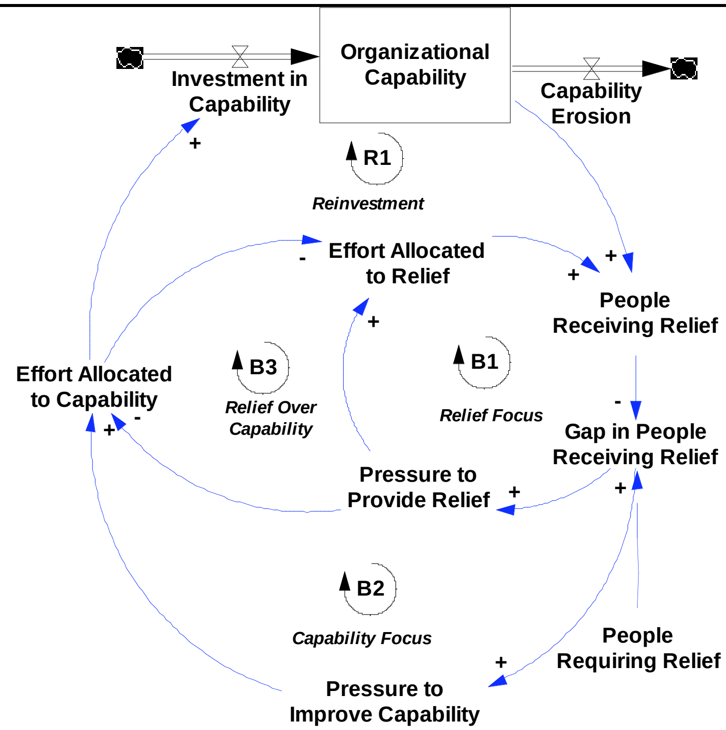
Figure 2 – Managerial Action: Pressure to Improve Capability and to do More Relief.



Because available resources are limited, however, more effort allocated to relief results in less effort allocated to capability improvement (Figure 3). At the individual level, personnel deployed to a disaster theater will forego opportunities for training and personal improvement. At the organizational level, resources allocated toward relief take away from resources that could have been used to develop new processes and institutionalize lessons learned. For instance, field people in humanitarian organizations hold the specific knowledge about operations, needs and constraints in a specific theater. Such knowledge is tacit, fragmented, and frequently lost when people leave the organization. Unfortunately, high turnover among field people significantly limits institutional learning from past disasters. Hence, the organization must allocate resources to develop processes (e.g., post-mortems, debriefs, gather lessons learned, develop cases, etc.) to capture, accumulate, make sense, and disseminate the learning from past disasters. Because the *Relief* loop (B1) generates immediate results, whereas the *Capability* loop (B2) takes time before it has an impact, managers often prefer allocating more effort to relief. The results accruing from the *Relief* loop are fast, lead to tangible results and are unambiguous, i.e., more resources lead to more people getting relief. In resource constrained environments, however, effort to relief consumes the availability of effort that can be allocated to capability improvement.

Once we include the links capturing the limited resources relationships, we close two additional feedback loops. The first one, the *Reinvestment* loop (R1), differs from the previous ones, as it is a self-reinforcing loop that amplifies the initial trajectory of the system. On the one hand, if the humanitarian organization has been allocating effort toward relief to the detriment of effort in capability improvement, the reinvestment loop will reinforce those vicious dynamics. Without adequate investment in capability, *Organizational Capability* will erode over time, reducing the effectiveness of its relief efforts. Gustavsson (2003) recognizes the cost of these vicious dynamics: "Millions of dollars could be saved each year by simply being able to work more 'smartly' – more efficiently" through investment in technology and communication. On the other hand, if the humanitarian organization continues to allocate effort to capability improvement, despite the pressure to allocate more resources to relief, then, the reinvestment loop will reinforce those virtuous dynamics. Adequate investment in capability improves capability allowing the organization to be more effective with existing resources.

Figure 3 – Counterintuitive Behavior from Relief and Capability Tradeoff.

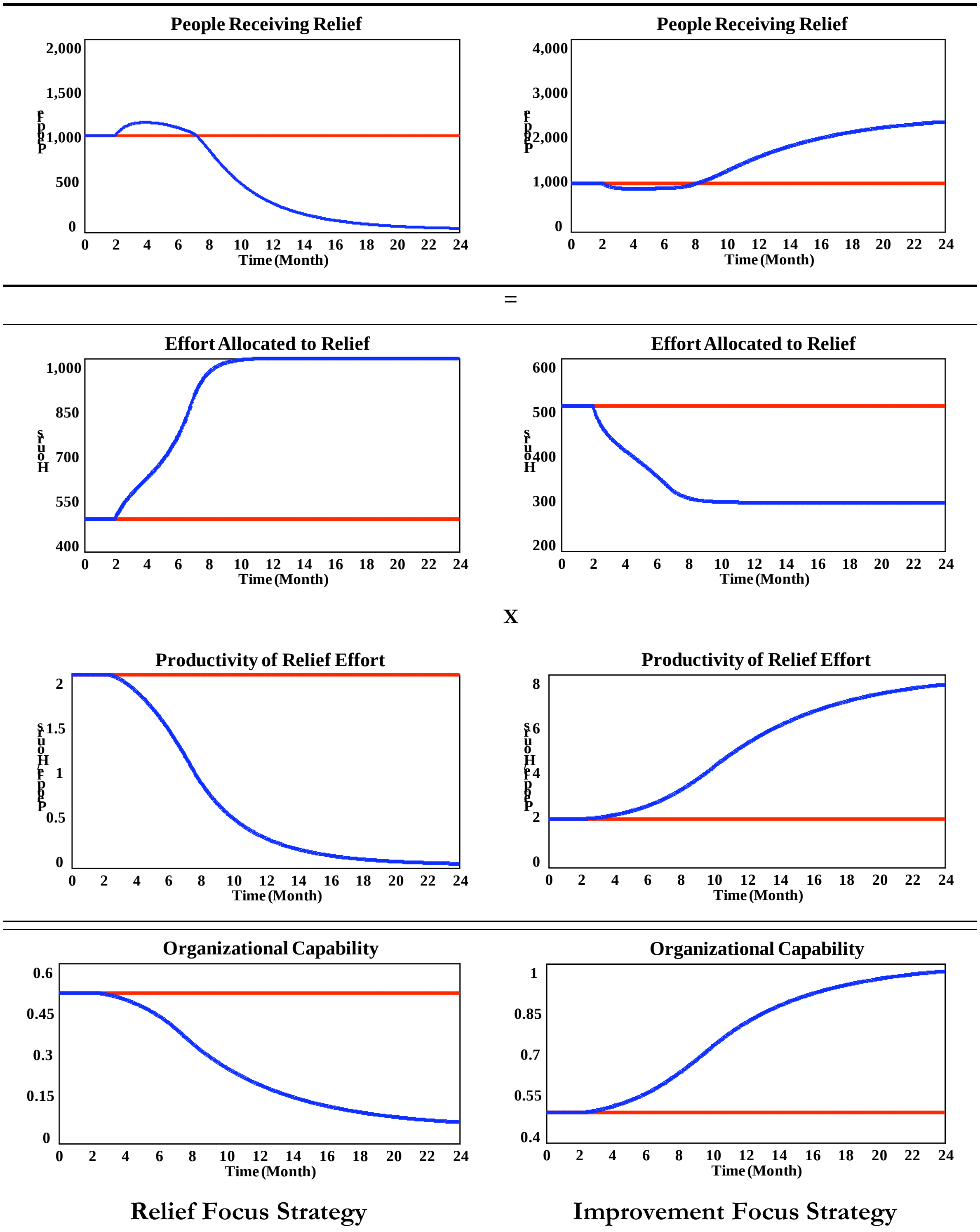


Model behavior

To illustrate the dynamics described above, we implemented the model in a simulation software environment (Vensim) that allows us to construct these complex nonlinear systems with multiple feedback effects, delays, stocks and flows. The model follows closely the causal loop description provided in the previous section, but is not presented here. We start the model in dynamic equilibrium and allow it to run for 24 simulated months. In two simulations of the model, we explore how actual system performance evolves in two different humanitarian organizations: one that emphasizes relief efforts and another that emphasizes improvement efforts. The first simulation (on the left column) shows system performance for an organization that increases emphasis on relief (perhaps due to a disaster that strains resources of the organization) on the second month of the simulation. As more effort is allocated to relief, the number of people receiving relief immediately rises. Because the amount of resources is fixed, however, the organization allocates less effort to capability, decreasing the inflow of investment in capability. Because the stock of capability has inertia, it decreases only mildly in the first two months. With time, however, organizational capability decreases faster. As the capability or the organization erodes, it decreases the productivity of relief efforts.

The product of effort allocated relief (measured in hours) and productivity of relief (measured in people/hours) determines the number of people that receive relief. Immediately after the increase in relief effort performance improves. Because of the inertia in organizational capability the increase in relief effort allows more people to receive relief. However, the benefit associated with emphasis on relief does not last long. As capability erodes with time, it limits the effectiveness of the operation. While more people are providing relief and they may be working harder, they are not as effective as before due the limited infrastructure and training. Hence, the strategy emphasizing relief shows a better-before-worse behavior.

Figure 4 – Simulating the Relief Focus and Capability Focus Strategies.



In contrast, the second simulation (on the right) shows the behavior of the system for an increased emphasis on organizational capability (perhaps due to earmarked donor funding toward capability improvement). As more effort is allocated to capability improvement (and less to relief), the number of people receiving relief immediately falls.

Because the amount of resources is fixed, however, the organization allocates less effort to capability, decreasing the inflow of investment in capability. Because the stock of capability has inertia, it decreases only mildly in the first two months. With time, however, organizational capability decreases faster. As the capability or the organization erodes, it decreases the productivity of relief efforts.

More effort to capability improvement leads to a higher inflow of investment in capability. Due to its inertia, the stock of organizational capability grows but slowly at first. Hence, the productivity of relief effort increases but only mildly. Because the amount of resources is fixed, there are fewer resources available for actual relief effort. Thus, the shift toward improved organizational capability leads to performance erosion, that is, fewer people receive relief. However, the eroded performance imposed by the emphasis on organizational capability is short lived. With time organizational capability improves and raises the productivity of relief effort and the overall effectiveness of the relief operations. While fewer people are allocated to the relief effort, due to the additional organizational structure and individual training they work smarter and more effectively. Performance rises even as fewer people are allocated to the relief effort. Hence, the strategy emphasizing capability improvement shows a worse-before-better behavior.

Conclusions

The aim of the paper was to provide an illustration of how managers in humanitarian relief organizations can use system dynamics modeling to learn how to model and understand the behavior of complex systems with multiple feedback effects, long time delays, accumulations of diverse and important factors, and nonlinear responses to decisions. The methodology briefly described here represents an opportunity to model different phenomena in humanitarian relief and to help managers design more effective policy interventions in the long run. Even the most basic tools of causal mapping can enable managers to think more systemically about the theaters where they operate and the dynamic complexity to which they are subjected. Simulation modeling with system dynamics can have a significant impact on the way managers in humanitarian organizations assess the interactions among variables, experience the long-term side effects of their decisions, and systematically explore new strategies, to develop a more robust understanding of complex systems and more effective strategies.

While the example provided is stylized, aggregated and generic, it could be easily disaggregated and tailored to map a particular application. Disaggregating the model to capture people, resources, IT infrastructure separately would provide managers with a clearer understanding of the gaps in different areas and their impact in overall productivity. Mapping the model closely to a particular resource allocation challenge would allow managers to see the consequences of their decisions and alternative policies in a familiar problem. To draw specific conclusions and validate the relationships used in this (or any) model, quantitative and qualitative data is required. For example, qualitative data regarding the allocation of resources would be gathered through interviews of decision makers we could understand the decision process for resource allocation under different conditions; quantitative data regarding resource allocation would look at the time series of allocation to relief or capability improvement. The combination of both the quantitative and qualitative data would allow us to understand the process and check if the simulated dynamics correlate to the historical behavior.

Modeling the organizational dynamics in specific situations would allow better understanding of the behaviors that develop and the potential policies that might be used to improve performance. From the modeling process, managers could develop their systems thinking skills allowing them to better grasp the dynamic complexity in humanitarian relief systems. Furthermore, having the models at hand, managers gain an appreciation for the consequences of interactions among variables, experience first-hand the long-term side effects of current decisions, and can explore what-if-scenarios that would be possible under different strategies, all of which should help them further their understanding of humanitarian relief systems.

References

Fritz Institute. 2005. "Logistics and the Effective Delivery of Humanitarian Relief." Fritz Institute.

Baum, D. 2005. "Mission to Sumatra: the marines of Expeditionary Strike Group Five take on the tsunami." *The New Yorker, 36*.

Colitt, R. and Bilefsky, D. 1999. "Cold comfort for the flood's survivors," *Financial Times*, 22 December. 11-13.

Dugger, C. 2007. "CARE Turns Down Federal Funds for Food Aid." *The New York Times*. August 16.

Dynes, R. & Tierney, K. (Eds.) 1994. *Disasters, collective behavior, and social organization*. Newark, DE: University of Delaware Press and Associated University Presses.

Easterly, W. 2006. "White Man's Burden: Why the West's Efforts to Aid the Rest Have Done So Much Ill and So Little Good." New York, NY.: The Penguin Press.

Forrester, J.W. 1961. *Industrial Dynamics*. Cambridge, MA: Productivity Press.

Forrester, J.W. 1968. "Market Growth as Influenced by Capital Investment*." Industrial Management Review*. **9**(2), 83-105.

Forrester, J.W. 1971. "Counterintuitive Behavior of Social Systems*." Technology Review*. **1**.

Gustavsson, L. 2003. "Humanitarian Logistics: Context and challenges." *Forced Migration Review* **18**, 6–8.

Kaatrud, D., Samii, R., & Van Wassenhove, L. (2003). "UN Joint Logistics Centre: a coordinated response to common humanitarian logistics concerns." *Forced Migration Review,* **18**, 11-14.

McEntire, D. 1997. "Reflecting on the weaknesses of the international community during the IDNDR: Some implications for research and its application," *Disaster Prevention and Management*, **6**(4), 221-33.

McEntire, D.A. 1999. "Issues in disaster relief: Progress, perpetual problems and prospective solutions," *Disaster Prevention and Management*, **8**(5), 351-61.

McEntire, D. 2002. "Coordinating multi-organisational responses to disaster: lessons from the March 28, 2000, Forth Worth Tornado." *Disaster Prevention and Management,* **11**(5), 369.

McLaughlin, A. 2004. "How Ethiopia's cooking-oil industry got burned by US aid." *Christian Science Monitor*. January 6.

NPR. 2008a. "Aid Coordinator Says Situation Is Dire in Myanmar." National Public Radio. All Things Considered, May 20, 2008. http://www.npr.org/templates/story/story.php?storyId=90645060

NPR. 2008b. "Powerful Quake Kills Thousands in China." National Public Radio. 2008. http://www.npr.org/templates/story/story.php?storyId=90430135

NPR. 2008c. "Chinese Troops Work to Prevent Flooding." National Public Radio. Morning Edition, May 29, 2008. http://www.npr.org/templates/story/story.php?storyId=90931426

Repenning, N. and J. Sterman. 2001. "Nobody Ever Gets Credit for Fixing Problems that Never Happened: Creating and Sustaining Process Improvement." *California Management Review*. **43,** 44–63.

Repenning, N. and J. Sterman. 2002. "Capability Traps and Self-Confirming Attribution Errors in the Dynamics of Process Improvement." *Administrative Science Quarterly*. **47,** 265 - 295.

Richardson, B. 1994. "Crisis management and management strategy—time to 'loop the loop'?" *Disaster Prevention Management* **3**(3), 59–80.

Richardson, G. and A. Pugh. 1980. *Introduction to System Dynamics Modeling with Dynamo*. Productivity Press, Portland, Oregon.

Sterman, J.D. 1989. "System Dynamics Modeling: Tools for Learning in a Complex World." *California Management Review*. **43**(4) 8-24.

Sterman, J.D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill, New York.

Thomas, A. 2003. "Humanitarian Logistics: Enabling Disaster Response." Fritz Institute.

Thomas, A. and L. Kopczak. 2005. "From logistics to supply chain management: the path forward in the humanitarian sector." Fritz Institute.

Tomasini, R.M. and L.V. Wassenhove. 2004. "A framework to unravel, prioritize and coordinate vulnerability and complexity factors affecting a humanitarian response operation." Working Paper. INSEAD, Fontainebleau, France.

Wassenhove, L. 2006. "Blackett Memorial Lecture: Humanitarian Aid Logistics: Supply Chain Management in High Gear." *Journal of the Operations Research Society*. **57**, 475-489.