Understanding Humanitarian Supply Chain Logistics with System Dynamics Modeling

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Abstract

Purpose – We explore the short-term humanitarian response to a natural disaster that prompts a rapid influx of relief supplies to the area affected by the disaster, aiming to understand the dynamics of systemic processes that apply to humanitarian supply chain logistics.

Design/methodology/approach – We use system dynamics to simulate the disaster relief supply chain elements of humanitarian response. System dynamics is a well-established simulation method for analyzing complex social systems that include feedback. We used it because the timing and coordination of, and feedback loops among, events in humanitarian response incorporate a delay structure that can be modeled effectively using system dynamics.

Findings – Of all the stocks in our model of the Humanitarian Stock Management System, the most important was the Cumulative Food distributed to disaster victims. In all of our simulation runs, victims eventually got all the food they needed, but at varying speeds (fast in the base run, slow in runs where repair of infrastructure was slow). However, the most problematic stock was the amount of Food in the Central Warehouse. In almost all the runs, that stock contained an excess of food (which is very common in such situations), resulting in waste and inefficiency. This problem was worst when the agency panicked at the outset and doubled its estimate of needed food, and when, as is often true, the agency received too many in-kind donations of food. The most interesting finding was that “managing” donations led to the best overall performance--low waste, good relief for victims.

Practical implications – We offer a number of policy recommendations, including the need to avoid early bias, to repair infrastructure as quickly as possible, to develop better methods for keeping track of inventories and supplies on the way, and striking a balance between encouraging and dampening donations.

Originality/value – This study focuses on understanding the short-term dynamics of the logistics of a humanitarian response, using a system dynamics approach. There have been only two other studies applying system dynamics to humanitarian assistance. One was operational and focused on long-term dynamics (often called “development,” as opposed to “response”) and the other was abstract and focused on those same longer-term dynamics. While these studies have produced meaningful insight, our study is unique in that we have applied an operational approach to a short, or “crisis response,” time horizon.

Keywords: Humanitarian Aid, Humanitarian Logistics, Humanitarian Supply Chain, System Dynamics, Modeling, Disaster Response

1. Introduction

1.1 Humanitarian Aid

The international humanitarian community and humanitarian aid groups have increased attention to disaster response in recent years. With the increase in humanitarian response, the need to understand the coordination of aid groups and the quality of response logistics is greater than ever. A recent report, The State of the Humanitarian System (Taylor, et al., 2012), gives insight about the workings of the humanitarian system as a whole. The report comments on everything from financial status and aid effectiveness to aid worker safety and needs assessment methodology. The report notes that aid organizations have increased response to natural disasters in the past decade due in part to the increase in the number of natural disasters. Between 2009 and 2010, aid organizations responded to 103 disasters. This figure marks a 10 per cent increase from the previous two years. Additionally, the number of international aid workers responding worldwide increased four percent between 2009 and 2010 (Taylor, et al., 2012).

There has been overall growth of the humanitarian system and a corresponding increase in humanitarian actors participating in response. Consequently, the systematic coordination and evaluation of operations have proved difficult and have proven to be areas in constant need of improvement. The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) reports nearly 2,000 agencies operating in response to the 2010 earthquake in Haiti (OCHA, 2010). OCHA also notes that the global humanitarian community had pledged in excess of $3.5 billion within one year of the Haiti earthquake.

Despite this tremendous effort to respond to the need in Haiti, leaders at OCHA describe a humanitarian response system in disarray and a response effort that some called just short of a failure (Altay, 2014). Logistical complications associated with the massive influx of relief goods arriving by plane, and the need to divert deliveries of relief agencies, is one noted pitfall during the early stages of the response (Holguin-Veras, 2012). The situation in Haiti demonstrates why having a systemic understanding of humanitarian operations during the early stages of response is critical for a successful response.

1.2 Humanitarian Needs Assessment

OCHA has developed the Multi-Cluster Rapid Needs Assessment (MIRA) method. The MIRA approach is a universal method for needs assessment of disaster/crisis affected areas. The process begins with preparation, initial assessment, and continued assessment until the humanitarian aid actors exit the area. The ongoing process of the needs assessment is a best attempt at coping with uncertain demand in disaster situations. However, delays in timing inevitably lead to oversupply of some goods and under supply of others. There have even been reports of tons of inappropriate goods supplied as part of humanitarian efforts responding to populations in need (Altay, 2008).

In the case of a sudden onset disaster, need is immediate. The MIRA approach attempts initial assessment within 48 hours of the event, but further needs assessment is an iterative process that may continue for years after a disaster. In the initial period, the onslaught of media coverage often sparks an urge for response by the humanitarian and private sectors. Humanitarian actors want to respond accurately and as quickly as possible, to direct the incoming supplies to meet the need of affected populations. In addition to the unpredictable demands of disaster situations, an unexpected supply of unsolicited donations often adds to the chaos of response and makes meeting the accuracy goal very difficult.

1.3 Humanitarian Logistics

The many difficulties of matching the indefinite demand of disaster-affected areas with the cacophony of aid groups and unsolicited supply have led logistics to become a very important topic in humanitarian work. In September 2005, the UN Emergency Response Coordinator introduced a three pillar agenda for reform of the humanitarian system to improve coordination and collaboration (OCHA, 2015). This reform organized the humanitarian system into clusters and cluster leads:

> Clusters are groups of humanitarian organizations (UN and non-UN) working in the main sectors of humanitarian action, e.g. shelter and health. They are created when clear humanitarian needs exist within a sector, when there are numerous actors within sectors and when national authorities need coordination support. Clusters provide a clear point of contact and are accountable for adequate and appropriate humanitarian assistance. Clusters create partnerships between international humanitarian actors, national and local authorities, and civil society. (OCHA, 2015)

The World Food Programme (WFP) is the current cluster lead for the food and logistics clusters. The 2012 WFP response to super typhoon Haiyan in the Philippines demonstrates the immediate need and rapid distribution of goods that calls for accurate understanding of logistics. Within 24 hours of the typhoon, the United Nations Humanitarian Response Depot (UNHRD) had dispatched goods from two hubs on behalf of WFP and other partners. In the two months following the disaster, UNHRD consolidated and dispatched 1,500 metric tons of goods, valued at over US$ 8.2 million, on behalf of 24 partners.

1.4 The Systemic Nature of Humanitarian Logistics

The magnitude of a disaster relief response, and the number of humanitarian actors involved, suggests that the logistics of humanitarian response has a systemic nature and must work with systematic tools to better understand appropriate solutions. The coordination of humanitarian logistics includes a series of timing and delays that create a complex social system that lends itself well to system dynamics modeling. System dynamics is a well-established simulation method for analyzing complex social systems and has been used successfully in modeling humanitarian operations (Goncalves 2008; Besiou and Van Wassenhove, 2011). However, there is no current system dynamics model that captures the short-term humanitarian response from an operational point of view. In this study, we provide this model and aim to construct recommendations from the resulting insights.

1.5 Study Overview

We present the literature review in Section 2, which introduces past research related to humanitarian work in disaster response and system dynamics modeling in humanitarian work. In Section 3, we provide the objective and approach used in this study, including reference modes, a causal loop diagram showing our dynamic hypothesis, and the system dynamics model used in this study. In Section 4, we define and discuss modeling assumptions and inputs. In Section 5, we present the modeling scenarios and simulation results. We discuss our conclusions and recommendations in Section 6.

2. Literature Review

2.1 Humanitarian Logistics

Kovacs and Spens (2007) present a thorough review of the literature available on humanitarian logistics in disaster relief operations. They focus on exploring and describing the unique characteristics of humanitarian logistics in disaster relief and draw parallels between humanitarian logistics and business logistics. The authors identify two main areas of humanitarian logistics: continuous aid work and disaster relief. The authors note that the general phases of disaster relief operations include preparation, immediate response, and reconstruction. During the preparation phase, responding agencies can take critical measures to limit the effects of disasters; however, many donors want their contributions go directly to help victims, which shortchanges *preparation* operations and, as we shall see, overemphasizes *response* operations. Kovacs and Spens's (2007) review of the humanitarian logistics literature concludes that the main problem in the immediate response phase of disaster relief operations is rooted in coordination of supply with the unpredictability of demand and the resultant difficulties of transporting relief items to disaster victims.

2.2 Humanitarian Supply Chain

Cozzolino (2012) provides a detailed review of the current state of knowledge on humanitarian logistics. One chapter focuses on humanitarian logistics and supply chain management. The author notes that, despite some disagreement in the literature, disaster management includes the stages of mitigation, preparation, response and reconstruction. The author mentions that coordination and collaboration among all actors involved in the humanitarian response deserve attention and study. Achieving efficient operations during the first days and weeks after a disaster is critical and understanding the humanitarian supply chain is the key to the needed efficiency. Cozzolino explains that effectiveness in the short term ensures saving time and lives within the disaster affected populations, while efficiency in the long term ensures saving costs and helps in rebuilding more livelihoods. Her call to understand effective supply chain operations in the short term is one focus of the present paper.

2.3 Issues in Humanitarian Logistics

The many complexities involved with humanitarian operations during disaster relief lead to a number of logistical challenges that scholars have identified and defined well in the literature (Altay 2008, Goncalves 2008). A full review of the many logistical challenges faced by managers of humanitarian operations is beyond the scope of this study; however, the most relevant are as follows:

- Disasters yield poor and unpredictable operating conditions. Disabled infrastructure, such as supply ports and roads, slows relief operations.
- Structured logistics processes are often not available because of damaged or inadequate information and communication systems.
- Limited resources and inappropriately assessed needs often drive the relief effort and supply chain.
- Unsolicited donations can overwhelm and bottleneck the supply chain and disrupt the appropriate allocation of resources.

We include all of these challenges in our model.

2.4 System Dynamics in Humanitarian Logistics

Two studies to date have incorporated system dynamics modeling to understand humanitarian operations (Goncalves 2008; Besiou and Van Wassenhove 2011). Goncalves (2008) notes the many challenges faced by humanitarian organizations and suggests that we need tools to help understand the complex systems, in terms of the structures and policies that regulate performance, within which the organizations operate. He goes on to note that system dynamics can be such a tool, and can help managers learn in the complex setting of humanitarian operations. His study uses a system dynamics model to show that overemphasis on short-term relief efforts can hamper capacity building of the organization, which then hampers its longer-term ability to respond to disasters. His view of the longer-term makes his model is somewhat less operational (Richmond, 1993), i.e. too abstract, than a model focused on short-term disaster relief. Nevertheless, Goncalves's (2008) study is a good example of how to use system dynamics to create stylized simulations and help decision makers to understand the long-term effects of policy decisions better, and to explore new strategy.

A study by Besiou and Van Wassenhove (2011) analyzes a well-defined subsystem of humanitarian operations using system dynamics to simulate field-vehicle fleet management. Their study is more operational (it focuses on truck fleets), but still examines long-term decision making, that is, continuous aid work, as opposed to disaster response. However, Besiou and Van Wassenhove (2011) state that beyond their example of vehicle management, additional areas of humanitarian operations would be well suited to research using system dynamics. Besiou and Van Wassenhove (2011) conclude by noting that system dynamics has the ability to represent accurately the complexities of humanitarian operations, and they give their support to the system dynamics approach as an appropriate tool studying humanitarian systems.

By contrast to these two previous works, the present research applies system dynamics to short-term, operational, disaster-response phenomena in humanitarian operations. Thus, we add to the existing literature, which includes no system dynamics models that capture the short-term humanitarian response from an operational point of view. In this study, we provide such a model and aim to construct recommendations from the insights gained.

3. Objective and Approach

3.1 Problem Definition

Section 2.3 listed the many issues that arise during disaster response:

- Disasters yield poor and unpredictable operating conditions. Disabled infrastructure, such as supply ports and roads, slows relief operations.
- Structured logistics processes are often not available because of damaged or inadequate information and communication systems.
- Limited resources and inappropriately assessed needs often drive the relief effort and supply chain.
- Unsolicited donations can overwhelm and bottleneck the supply chain and disrupt the appropriate allocation of resources.

The aim of the present paper is to include these elements in a system dynamics model, to simulate various policies for dealing with them, and to make recommendations based on the results.

3.2 Reference Modes

To help understand the problem, system dynamics typically uses graphs of the behavior over time of relevant variables. Modelers call these "reference modes" because they refer to them as checks on model outputs. The reference modes demonstrate behavior of a model input over time.

We have chosen to focus on food, which is one of the most important supplies needed after a disaster. Aggregating World Food Programme data from three disasters (the Haiti earthquake of 2010, the Philippines typhoon of 2013, and the Afghanistan floods of 2014), Figure 1 shows that the delivery of food rises rapidly in the immediate aftermath of a disaster, but levels off after 150 days or so.

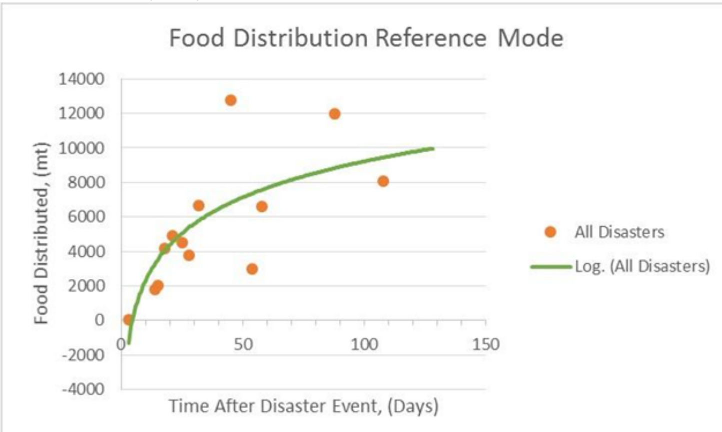

Figure 1. Reference Mode for World Food Programme Food Delivery After Disasters

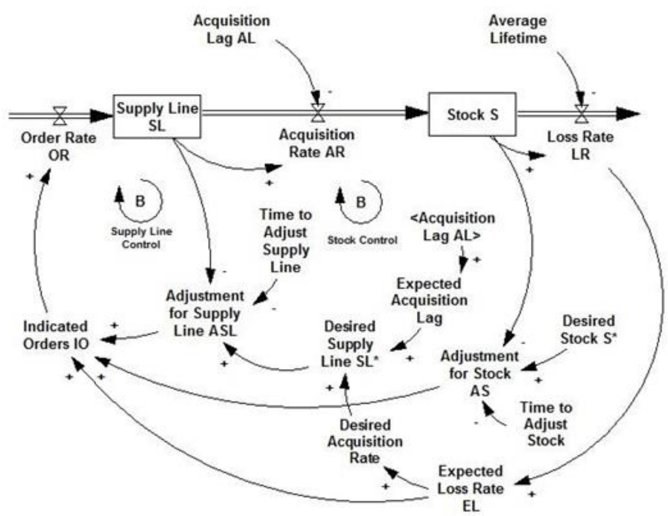

Figure 2. Generic Stock Management Structure

3.3 Dynamic Hypothesis

We assert that the delivery of humanitarian food supplies is a special case of the familiar Stock Management Structure from system dynamics (Sterman, 2000, chapter 17). We show the generic structure in Figure 2.

In the Stock Management Structure, a decision maker needs to maintain the level of a stock S (in our case, food in a central humanitarian warehouse) by replenishing the stocks units as the decision maker delivers them, but at the same time keeping in mind previously ordered units in the pipeline. One key to the Stock Management Structure is its many delays--of physical flows and of perceptions.

We show our dynamic hypothesis in a causal loop diagram in Figure 3. Figure 3 shows five loops, all balancing, along with some specific features of humanitarian response that differ from the generic Stock Management Structure.

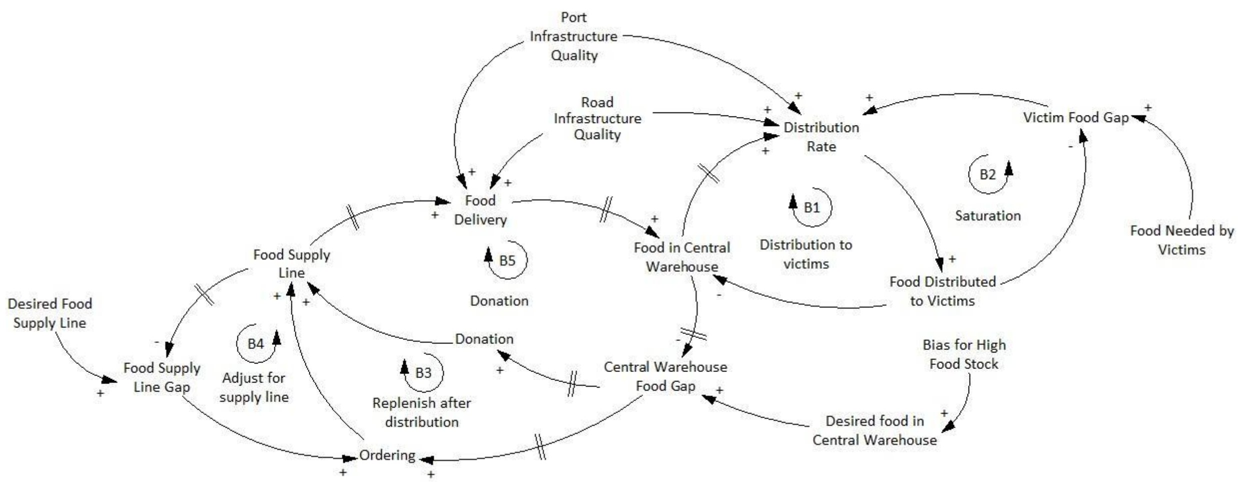

Figure 3. Dynamic Hypothesis

- Loop B1, "Distribution to victims," shows the central activity in humanitarian response--distribution of food aid to disaster victims. Increases in Food in the Central Warehouse increase the Distribution Rate, which increases Food Distributed to Victims, which in turn reduces the amount of Food in the Central Warehouse.
- Loop B2, "Saturation," shows how food distribution slows down as the agency meets the needs of the disaster-stricken population. Increases in Food Distributed to Victims reduce the size of the Victim Food Gap, which reduces the Distribution Rate and, in turn, reduces the Food Distributed to Victims. This loop creates the reference mode—the amount of food the agency distributes levels off and ends as the disaster-stricken population gets all the food it needs.
- Loop B3, "Replenish after distribution," is the first part of the Stock Management System. As food moves out of the Central Warehouse, the agency orders replacement food.
- Loop B4, "Adjust for supply line," modifies the amount of food ordered based on what the agency knows is in the pipeline.
- Loop B5, "Donation," is where donors add food to the pipeline as they react to the need for food. As the Gap in the Central Warehouse Food increases, Donations increase (after a delay). This increases Food in the Supply Line, which increases Food Delivery and Food in the Central Warehouse, closing the Gap.

We do not show it in Figure 3, but a well-known feature of the Stock Management Structure is knowledge of what is in the warehouse and knowledge of what is in the supply line. These relate to Loops B3 and B4; the chaos of the aftermath of disasters often reduces knowledge of existing or ordered food stocks, and makes these two variables relevant to this research. We include them in the full model.

Figure 3 shows three exogenous features peculiar to the humanitarian response version of the Stock Management Structure:

- **Road Infrastructure Quality**. Prior to a disaster, the road infrastructure in an affected country is adequate to ensure both delivery and distribution of food. After a disaster, poor road conditions slow down both of these flows.
- **Port Infrastructure Quality**. Prior to a disaster, the port infrastructure in an affected country is adequate to ensure both delivery and distribution of food. After a disaster, poor port conditions slow down both of these flows.

- **Bias for High Food Stock**. The shock of a disaster may cause responders to overestimate the need for higher levels of food in the system.

3.4 Stock and Flow Model

Figure 4 shows the stock management structure of the full system dynamics model. Its foundation is the generic stock management structure.

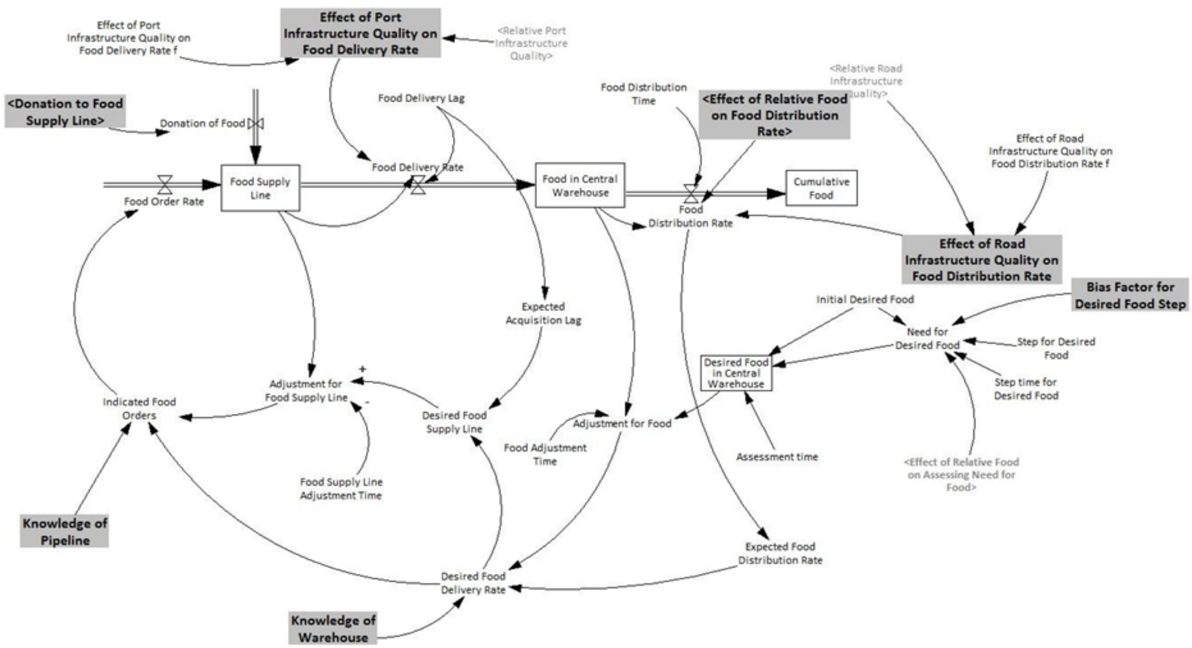

Figure 4. The Full Model of Humanitarian Food Delivery

Boldface items highlighted in gray are the features peculiar to the humanitarian disaster response context:

- Effect of Road Infrastructure Quality (see Figure 5)
- Effect of Port Infrastructure Quality (except for different variable names, the structure is the same as what we show in Figure 5)
- Effect of Relative Food (Figure 6)
- Effect of Donation (Figure 7)
- Effect of Bias for High Food Stock
- Knowledge of Food in Central Warehouse
- Knowledge of Food in Supply Line

We address the first four items using table functions. After a disaster, the ratio of actual infrastructure (either ports or roads) to desired infrastructure drops, so we use an upward-sloping function to reduce the flow of food in the early days, as infrastructure damage is high, while raising the flow as the region repairs its infrastructure. To control the distribution of food as the population gets what it needs, we use a downward-sloping table function that gradually shuts off the flow of food as the ratio of actual to needed approaches one. We formulate the donation sector by using a mildly upward-sloping table function (Figure 8) that reacts to the “Pressure to Donate” created by the ratio of what donors would normally like to see in the Central Warehouse and what is suddenly needed after a disaster. We address bias and logistical knowledge with parameters.

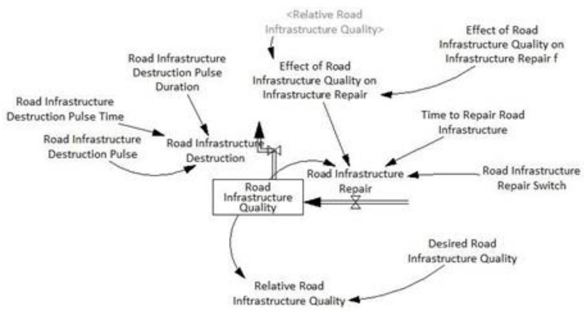

Figure 5. Infrastructure View

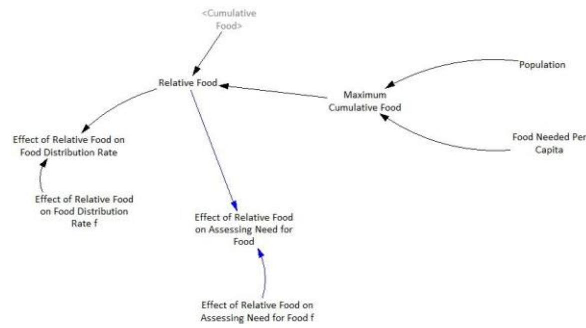

Figure 6. Food View

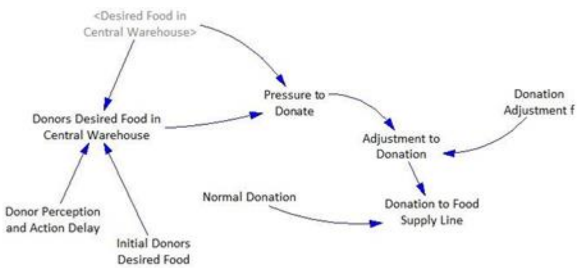

Figure 7. Donation View

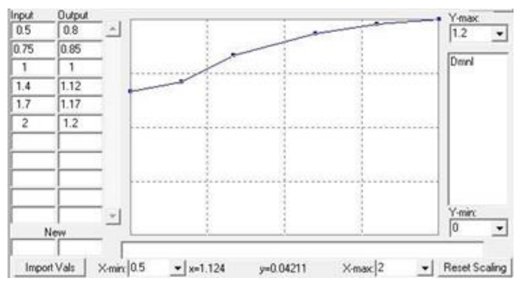

Figure 8. Donation Table Function

Table 1 Parameters Used in Simulation Runs

	Runs								
	1	2	3	4	5	6	7	8	9
	Equil	Base	No repair	No knowl	Dbl bias	Damp donation	Enc Donation	No Donation	Runs 5+7
Initial Desired Food (metric tons)	0	0	0	0	0	0	0	0	0
Step for Desired Food (metric tons)	0	40000	40000	40000	40000	40000	40000	40000	40000
Step time for Desired Food (day)	3	3	3	3	3	3	3	3	3
Bias factor (dmls)	1	1	1	1	2	1	1	1	2
Population (people)	2M	2M	2M	2M	2M	2M	2M	2M	2M
Food Needed Per Capita (metric tons)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Food Adjustment Time (days)	2	2	2	2	2	2	2	2	2
Food Supply Line Adjustment Time (days)	2	2	2	2	2	2	2	2	2
Food Delivery Lag (days)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Food Distribution Time (days)	8	8	8	8	8	8	8	8	8
Knowledge of Pipeline (dmls)	1	1	1	0	1	1	1	0	1
Knowledge of Warehouse (dmls)	1	1	1	0	1	1	1	0	1
Time to Repair Road Infrastructure (days)	60	60	60	60	60	60	60	60	60
Road Infrastructure Repair Switch (dmls)	1	1	0	1	1	1	1	1	1
Desired Road Infrastructure Quality (dmls)	100	100	100	100	100	100	100	100	100
Road Infrastructure Destruction Pulse (dmls/day)	0	75	75	75	75	75	75	75	75
Road Infrastructure Destruction Pulse Time (days)	0	0	0	0	0	0	0	0	0
Road Infrastructure Destruction Pulse Duration (days)	1	1	1	1	1	1	1	1	1
Time to Repair Port Infrastructure (days)	30	30	30	30	30	30	30	30	30
Port Infrastructure Repair Switch (dmls)	1	1	0	1	1	1	1	1	1
Desired Port Infrastructure Quality (dmls)	100	100	100	100	100	100	100	100	100
Port Infrastructure Destruction Pulse (dmls/day)	0	75	75	75	75	75	75	75	75
Port Infrastructure Destruction Pulse Time (days)	0	0	0	0	0	0	0	0	0
Port Infrastructure Destruction Pulse Duration (days)	1	1	1	1	1	1	1	1	1
Initial Donors Desired Food (metric tons)	0	100	100	100	100	100	100	100	100
Normal Donation (metric tons/day)	0	1000	1000	1000	1000	1000	1000	0	1000
Donation Adjustment table (dmls)	Mod up sloping	Mod up sloping	Mod up sloping	Mod up sloping	Mod up sloping	Flat	Steep up sloping	Mod up sloping	Steep up sloping

4. Model Assumptions and Inputs

4.1 Model Parameters

Table 1 shows the parameters (and their units) that we used in the eight simulation runs we discuss in section 5.1. Each run has a 150-day time horizon.

4.2 Model Assumptions

Here are the highlights of the assumptions we made:

- We assume a population of 2 million people in the affected area.
- Each person requires an average of 0.02 metric tons of food, cumulatively, over the 150-day period (approximately 0.25 pounds of food per person per day).
- Each of the adjustments and delivery times in the food stock management system has an associated delay, as we show in Table 1.
- Damage from the disaster happens in a one-day pulse.
- It takes 3 days for the disaster response agencies to assess the level of need for food.
- Port and road infrastructures sustain 75% damage from the disaster.
- It takes 30 days to repair the port infrastructure, and 60 days to repair road infrastructure.
- Once the disaster strikes, donors give 1000 metric tons of food per day to disaster response agencies.

5. Model Results

5.1 Results of Simulation Runs

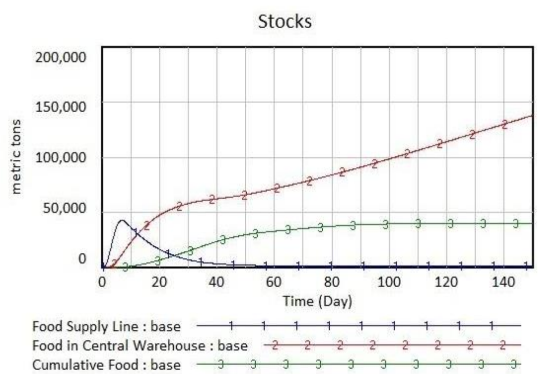

Figure 9. Results of Base Run

Figure 10. No Infrastructure Repair

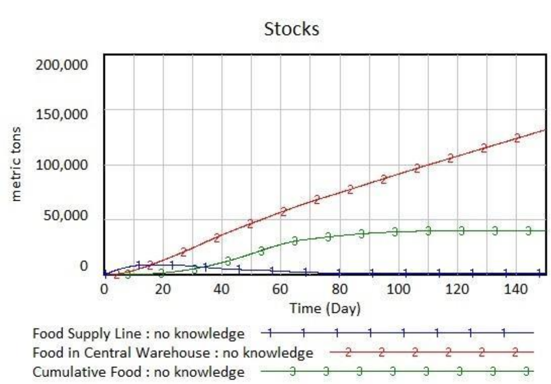

Figure 11. No Knowledge of Pipeline or Warehouse

The equilibrium run shows all outputs flat. We do not show it here because we expect this result, given that in the base scenario there has been no disaster and no donation. By contrast, the "base" run has a disaster and its concomitant need for more food in the central warehouse, road and port infrastructure damage and repair, and donation spurred by the disaster. Figure 9 shows the results for the three major stocks--Food in the Supply Line, Food in the Central Warehouse, and the Cumulative Food Distributed. As one might expect, there is an early spike in the Food Supply Line (curve 1), followed by a reduction as the responders meet the population's food needs. The Cumulative Food delivered to the population (curve 3) levels off as responders meet the required need; this mirrors the reference mode we show in Figure 1. However, Figure 9 shows that donors continue to donate, and the resulting food in the supply line goes to the Central Warehouse, where it piles up (curve 2). This, according to observers like Altay (2008), is a very common scenario following a disaster.

Figure 10 shows the results of a run similar to the base run, but where no repair of any infrastructure occurs, i.e. the roads are only 25% effective for the entire period. As expected, the Supply Line (curve 1) never quite empties out, and the Cumulative Food (curve 3) distributed gets to the population more slowly--and the response agency never quite meets the population's needs (curve 3).

Figure 11 shows the results of a run where the response agency has zero knowledge of what is in its Supply Line or its Central Warehouse. The result is very interesting: the population gets all the food it needs (curve 3), and the Food Supply Line (curve 1) does not spike. However, the Food in the Central Warehouse (curve 2) continues to build, but that is actually the reason that the first two mentioned stocks behave so well--*because* of its ignorance of the situation, the agency never restocks of its *own* accord--it is the *donors* who fill the Supply Line (actually, *overfill* it). We confirmed this with a run (not shown)

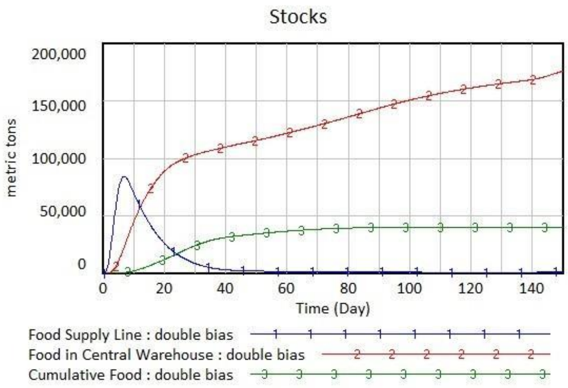

Figure 12. Double Bias

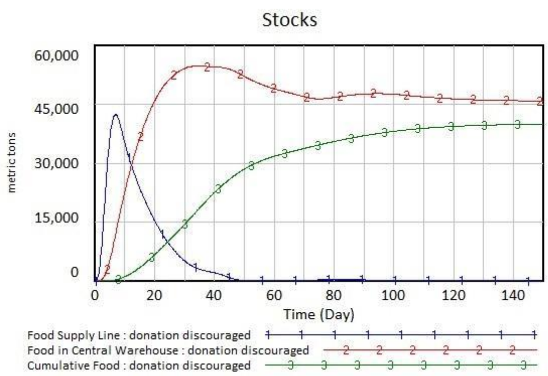

Figure 13. Dampened Donation

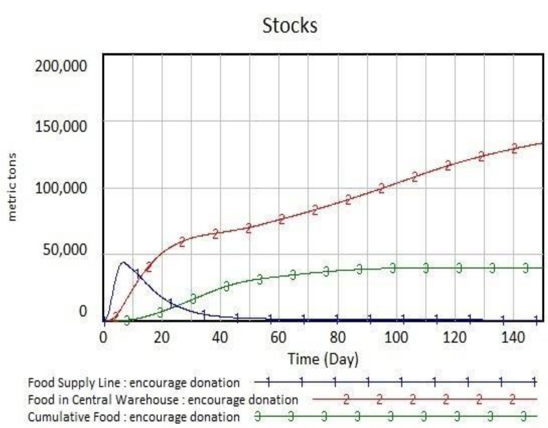

Figure 14. Encourage Donation

where all the parameters were the same as this run, except donations were zero. It was indistinguishable from the equilibrium run, meaning that, in the absence of knowledge of its supply line, a disaster response agency meets the needs of the population by relying on whatever donations show up. (Another run not shown indicated that, with 50 percent knowledge of its pipeline, the agency had a more robust Supply Line and met the needs of the population a bit more quickly, as one would expect.)

In the immediate aftermath of a disaster, damage assessors for the response agency might overestimate the need for food. Figure 12 shows the results of a run with double the bias for the step increase in desired food. As one might expect, the result is that Supply Line (curve 1) spikes a bit early on, and the agency meets the food needs of the population (curve 3) a bit earlier. However, the Food in the Central Warehouse (curve 2) piles up to much higher levels than needed.

We wanted to assess the effects of a dampening of the donors' ardor. Therefore, we altered, in two ways, the table function that controls Donation to the Food Supply Line:

1. When the ratio of Donors Desired Food in the Central Warehouse to the Agency's Desired Food in the Central Warehouse was below one, we eliminated all donation.
2. When that ratio exceeded one, we reduced the Donation Adjustment from 1.2 to 0.75, which is a significant dampening of donation.

Figure 13 shows the results, which are dramatic. There is little change to Food in the Supply Line and Cumulative Food (curves 1 and 3, respectively), but the Food in the Central Warehouse (curve 2) is much lower. In terms of lower costs and less waste, there are clear benefits to the agency to managing the ardor of its donors.

Figure 14 shows the results of a run that did the opposite of the last one--it simulated what would happen if the agency *encouraged* donation. We did this by steepening the table function that controls Donation to the Food Supply Line. Figure 14 shows that the results, compared to the base run, were modest. This is because the Pressure to Donate that feeds into the table function is at its highest in the early days after the disaster. As food comes rolling in, the Pressure to Donate drops, regardless of how steep the table function is.

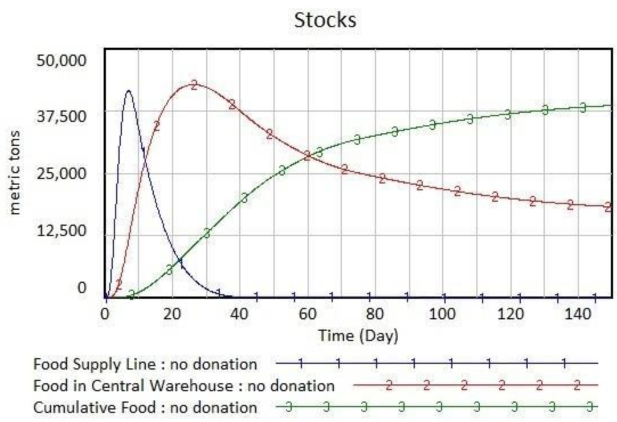

Figure 15. No Donation

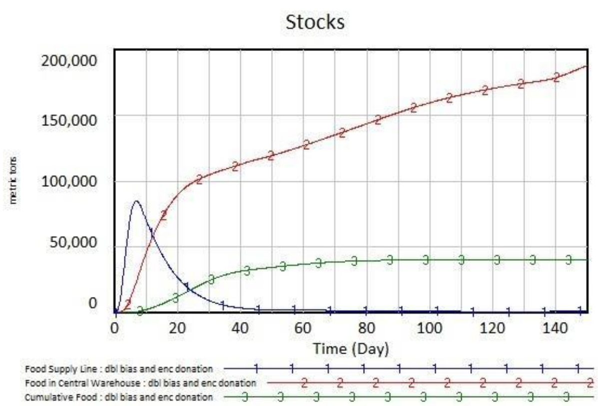

Figure 16. Double Bias and Encouraged Donation

To see what would happen were the agency to cut off donations altogether, we did a run, which we show in Figure 15, where the Normal Donation was zero. The results also were dramatic, with Food in the Central Warehouse (Curve 2) at much more manageable levels. However, one subtle effect was that the population received its needed food much less quickly, and it did not have its entire need met by the end of the simulated period. We conclude that a modest level of donation is desirable.

Lastly, we did a run that combined two previous parameter settings: we doubled the bias and encouraged the donation with a steeper table function. The results, which we show in Figure 16, were subtly different from those we showed in Figure 12. The major difference was a higher cumulative level of Food in the Central Warehouse. This came about because the greater gap at the beginning, caused by the bias, raised donations early, but the delivery of food shut them off later.

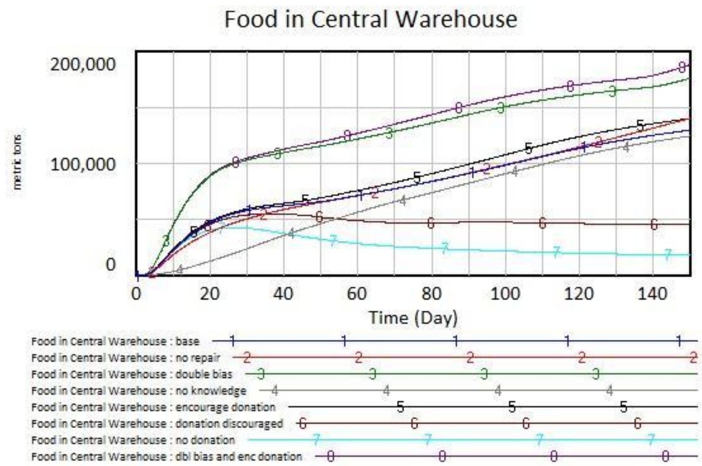

Figure 17. Food in Central Warehouse, Various Runs

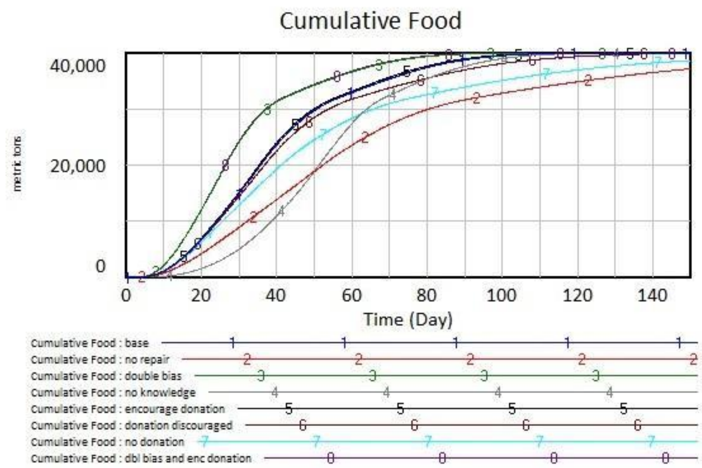

Figure 18. Cumulative Food, Various Runs

6. Discussion and Recommendations

6.1 Discussion

Of all the stocks in our model of the Humanitarian Stock Management System, the most problematic was the amount of Food in the Central Warehouse, and the most important was the Cumulative Food distributed to disaster victims. Figure 17 shows the levels of Food in the Central Warehouse under the various scenarios. Figure 18 shows the results for Cumulative Food for the same scenarios.

Food in the Central Warehouse is too high when the agency panics at the outset and doubles its estimate of needed food (curves 3 and 8 in Figure 17), although the benefit is that the agency reaches its Cumulative Food target more quickly (curves 3 and 8 in Figure 18). It is too low when donations are non-existent (curve 7 in Figure 17), especially when viewed in conjunction with how long it takes response agencies to meet the population's food needs (curve 7 in Figure 18). However, when donation is dampened but not shut off, Food in the Central Warehouse goes to moderate levels (curve 6 in Figure 17) and victims get their food only slightly more slowly than the base run (curves 6 and 1, respectively, in Figure 18).

6.2 Recommendations

From these figures, we may infer the differential desirability of various policies:

1. It is straightforward that disaster response agencies do all they can to avoid bias in the early days. Assessments of the Desired Level of Food in the Central Warehouse should be fact-based and free of panic. The "Double Bias" and "Double Bias and Encouraged Donation" runs clearly showed the problems with not taking this recommendation--large amounts of wasted food with little improvement in relief to victims.
2. It is equally straightforward that disaster response agencies and local authorities do all they can to repair port and road infrastructure as quickly as possible. The "No Repair" run showed less waste but the worst relief performance.
3. Disaster response agencies should develop good methods for keeping track of what is in their Central Warehouses and what is in the Supply Line. Failure to do so results in much slower

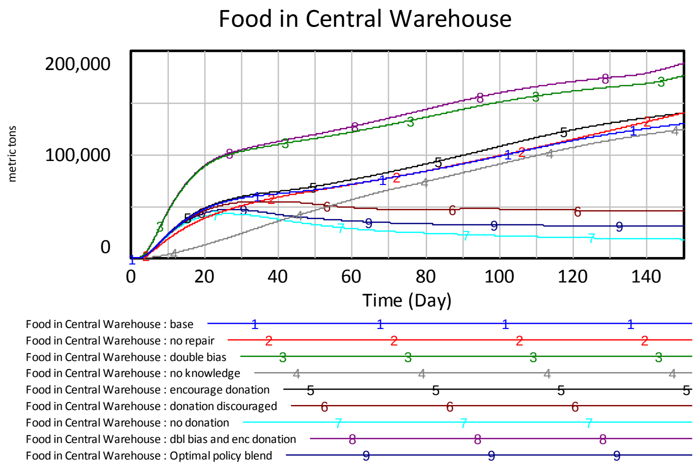

Figure 19. Food in Warehouse, Optimal Run

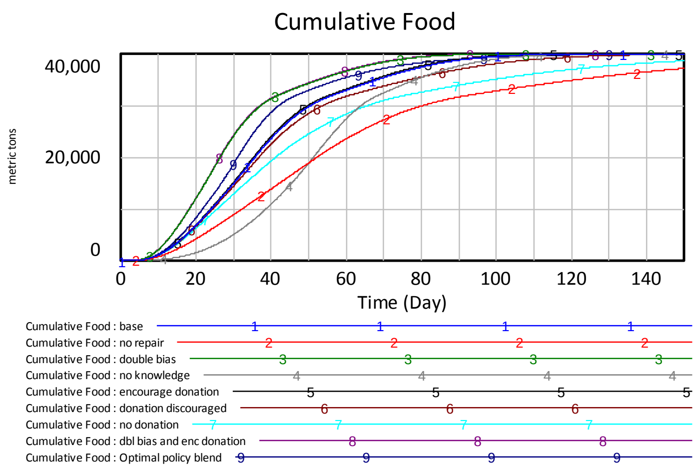

Figure 20. Cumulative Food, Optimal Run

distribution of food to victims. It is interesting that the "No Knowledge" simulation run showed less waste (lack of system knowledge encouraged hyper-conservative ordering), but at the cost of very slow initial response (kept going mostly from uncontrolled donations).

4. Disaster response agencies should strike a balance between encouraging and dampening donations. Having no donations at all would work well enough, *but only* if all other policies worked well. Our simulation runs showed that, in most simulation runs, having too many donations mostly just clogged up the Central Warehouse. However, *managing* donations in a way that started them only after the initial period, and at a dampened level, led to less waste with roughly equivalent relief to victims. Of the three simulation runs dealing with donation--"Encourage Donation," "Discourage Donation," and "No Donation"--only "Discourage Donation" (in the sense of managing, not eliminating, it) had good performance on waste reduction (actually the best on this measure) and relief (second only to the "Double Bias" run).

Figures 19 and 20 show the results from an "optimal policies" run that follows all the recommendations: there is no early bias, authorities repair port and road infrastructures in half their normal time, responders have perfect knowledge of their supply line and central warehouse inventory, and they dampen (but do not eliminate) donations. Food in the Central Warehouse is at its lowest level other than when response agencies cut off donations entirely, and Cumulative Food distributed to victims is highest (and fastest) other than when there are bias and uncontrolled donations.

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