Toward resilient humanitarian cooperation: examining the performance of horizontal cooperation among humanitarian organizations using an agent-based modeling (ABM) approach

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ABSTRACT

This article proposes a multi-agent simulation model to examine how different operational environments and incentive mechanisms affect the collective performance of complex humanitarian response systems. Using the UN Humanitarian Response Depot (UNHRD) system as an example, a stylized model of one service provider, two member organizations and multiple humanitarian crises is developed to illustrate the changing uses of four alternative relief goods sourcing options, namely: i) own storage for own items ii) UN storage for own items iii) stock-swaps and iv) white stock uses. Under the plausible assumption that the past success of sourcing options influences member organizations' future resource allocation, the model indicates that the additional buffer stock capacity offered by horizontal cooperation induces undesirable system dependency: while it gives member organizations more flexibility to meet highly stochastic demands under uncertainty, it also encourages them to store less of their own relief goods as a result. This tendency was particularly notable under a flexible budgeting regime, highlighting the further need to understand and evaluate the details of the decision-making heuristics of individual member organizations.

Keywords: Horizontal Cooperation, Humanitarian Organization, Agent-Based Modeling

1. Introduction

Learning and improvement are seen as the key to successful humanitarian coordination where ever-changing and complex operational environments demand proactive strategies for the successful delivery of emergency assistance (UN 2013; Christopher and Tatham, 2014). Responding to the rising demand for global humanitarian assistance observed in recent years, the total official humanitarian assistance by bilateral and multi-lateral donors has nearly tripled from approximately $6.5 billion in 2001 to 16.4 billion in 2013 (Global Humanitarian Assistance 2009; Global Humanitarian Assistance 2014). As the frequency and complexity of natural and man-made disasters have risen in recent years (Thomas and Kopczak, 2005), increasing efforts have been exerted globally to build more effective and efficient coordination mechanisms among humanitarian organizations.

Horizontal cooperation among humanitarian organizations is increasingly seen as an efficient and effective way to coordinate humanitarian preparedness, response, and recovery processes under complex and changing environments (Thomas and Kopczak 2005, Van Wassenhove 2006, Schulz 2009). Unlike vertical cooperation in which organizations at different stages of the humanitarian response chain collaborate, horizontal cooperation encourages pooling of skills and resources among organizations that are operating at similar levels (Schulz and Blecken 2010). The formation of horizontal cooperation mechanisms globally is rapidly changing the ways capacity building, warehouse management and emergency delivery are carried out collectively by humanitarian organizations.

One example of horizontal cooperation that has grown in recent years is the UN Humanitarian Response Depot (UNHRD) established in 2001. As of February 2015, the UNHRD has grown to a truly global system of six warehouses—strategically located across the globe in Accra (Ghana), Brindisi (Italy), Dubai (UAE), Subang (Malaysia), Panama City, (Panama) and Las Palmas (Spain) offering a range of humanitarian logistics services to 65 member organizations (UNHRD, 2015). Member organizations adhere to a standard set of operational procedures that enables effective pooling of resources and substantial cost savings in terms of storage, procurement and transportation. For example, it is estimated that transporting relief items via air to N'Djamen, Chad cost between 25%-45% less from the regional depot in Accra, Ghana than the headquarters in Brindisi, Italy. By utilizing such regional hubs with free storage, many organizations may reduce their humanitarian logistics operation costs (UNHRD 2015).

However, the growth of such distributed humanitarian logistics internationally has also given rise to new challenges. The truly voluntary nature of collaboration and membership means that their success is predicated on member organizations' good will and trust in the collective management system. The shared logistic arrangement globally requires continued willingness of organizations to collaborate, while the rapid expansion of operations seen in recent years will likely add further complexity in coordination. There is also a need to acquire continued funding support of donor agencies.

As previously identified by Schultz and Blecken (2010), horizontal cooperation for humanitarian logistics coordination may be hampered by a number of institutional and operational factors such as: i) the desire of humanitarian organizations to maintain logistics as core competency of the organization (therefore, its unwillingness to delegate core tasks under collective management); ii) the differences in organizational culture and mistrust towards each other and collective systems; iii) limited transparency regarding the benefits of cooperation and iv) a potential lack of resources especially during a period of high demand. It therefore remains to be seen how a global coordination mechanism founded on the humanitarianism of good will and mutual support may thrive in the face of growing demands likely to materialize in the age of climate change and ensuing regional conflicts (Leiras et al. 2014).

Given our need to understand the effectiveness and robustness of horizontal cooperation among humanitarian organizations under changing environments, this article proposes a multi-agent simulation model that examines how different operational environments and incentive mechanisms affect the collective performance of the complex humanitarian response system. In particular, the article uses the UNHRD system as an example and proposes a model that simulates the emerging system behaviors of individual members responding to simultaneously occurring humanitarian crises. Prior to model development, a number of semi-structured interviews with the UNHRD and its member organizations were conducted (see Appendix 1 for a list of interviews) to understand the current status of network operations and challenges. These on-the-ground insights provided important inputs to the design of the present agent-based simulation model. While the development of a full-fledged model is an ongoing process, this article describes the main features and algorithms of the proposed stylized model and presents the results based on an illustrative case application.

The use of a stylized agent-based model of one service provider, two member organizations and multiple humanitarian crises illustrates the difficulty in coordinating a purely voluntary system of collective inventory management under highly uncertain demand. Under the plausible assumption that the past success of sourcing options influences member organizations' future resource allocation, 5-yearsimulation runs found that the additional buffer stock capacity offered by horizontal cooperation induces undesirable system dependency. This was particularly the case under the flexible budget system where additional donor funding allows a more flexible use of such buffer stocks.

Factors such as whether, and to what extent, budgets remain binding in the case of a catastrophic event and whether and to what extent each organization uses different types of heuristics for pre-positioning decisions (e.g. according to past success, cost minimization or mixture of both) seem to influence how effective incentive mechanisms (such as rising and reducing the prices of buffer stocks) affect individual decisions and system performance. While the present model adopts a highly simplistic set of assumptions, further sophistication of model assumptions will certainly improve our understanding of horizontal cooperation among humanitarian organizations.

The remainder of this article is organized as follows. First, Section 2 provides a brief overview of the literature regarding humanitarian logistics and demonstrates how this article makes a major contribution by applying agent based modeling analysis to the field of humanitarian horizontal cooperation. Section 3 presents detailed descriptions of the modeling structure and algorithms, describing the individual decision rules that collectively make up the complex system of humanitarian coordination. This is followed by Section 4, which executes the proposed multi-agent model using an illustrative example. Section 5 draws major insights gained and describes the next steps for model development and further empirical application. Finally, Section 6 provides the conclusion of this article.

2. Modeling Humanitarian Logistics Operation

Quantitative modeling has long served as an important analytical tool in commercial supply chain management (Tayur et al., 1999; Cachon and Terwiesch, 2012; Christou, 2011). Modeling approaches such as deterministic and stochastic optimization as well as various simulation techniques have examined how different decision variables such as the level of inventory, timing of production and buyer-supplier relationships affect supply chain performance such as the overall cost of operation, customer satisfaction and speediness of product delivery (Beamon 1998; Caunhye et al., 2012). As opposed to commercial supply chain logistics, which has long been assessed quantitatively in the field of operations research: quantitative studies on humanitarian logistics are relatively new with increasing attention placed on topics such as strategic prepositioning of relief supply (Balcik and Beamon, 2008; Duran et al., 2011); optimal inventory control under uncertainty (Beamon and Kotleba, 2006) and the relationship between operation costs and fund-raising (Wakolbinger et al., 2011; Toyasaki and Wakolbinger, 2014) and others (see for example Caunhye et al., 2012; Rafael et al., 2013; Ortuño et al., 2013 Gösling and Geldermann, 2014 for recent reviews on this topic).

In order to understand the complex interactions that underlie the dynamics of global horizontal cooperation among humanitarian organizations, analytical tools should be sufficiently flexible to examine its multifaceted nature. This gives flexible modeling environments such as multi-agent modeling a natural advantage over other techniques for quantitative analysis, in which collective system performance can be modeled and evaluated based on individual decisions of software agents. The utility of agent-based modeling has been demonstrated in a number of recent studies on commercial logistics (Fu et al., 2000; Jiao et al., 2006; Lai and Kao, 2009), while its application to the humanitarian logistics domain remains limited even today.

2.1. Commercial versus Humanitarian Logistics

The existing literature indicates that humanitarian logistics are characteristically different from their commercial counterparts (Van Wassenhove 2006; Kovács and Spens 2007; Pujawan et al., 2009; Apte, 2010, Gatignon et al., 2010). Quantitative analysis of humanitarian supply chains therefore requires a sound understanding of the differences in operational objectives, management approaches and workings of the two supply chain operations. Beamon and Balcick (2008) for example summarize three major areas of divergence between commercial versus humanitarian logistics, namely i) strategic goals ii) demand characteristics and iii) customer characteristics.

Firstly, Beamon and Balcick (2008) assert that the humanitarian supply chain differs fundamentally from its commercial counterpart since the former embraces strategic goals such as reduction in human causality and suffering while the latter operates to maximize share-holder values, minimize costs and improve customer satisfaction. The difference in strategic objectives is closely linked to the contrasting ways in which the two entities raise funds—while humanitarian organizations remain largely dependent on donor funding (Wakolbinger et al., 2011; Toyasaki and Wakolbinger, 2014), business logistics must ultimately be accountable to the shareholders. These differences fundamentally shape the ways in which resources are allocated to various strategic, tactical and operational objectives thereby ultimately determining the characteristics of the two logistics systems. As illustrated in Section 3, firstly, the proposed model incorporates a set of operational goals that are identified as important by humanitarian organizations participating in the UNHRD system by literature and interviews such as reduction in lead-time and overall logistic costs.

Secondly, humanitarian logistics must face demands that are highly unpredictable. Natural disasters (and to a lesser extent regional conflicts), occur stochastically with limited ability for organizations to predict timing, locations, magnitudes and types of events (e.g. hazards) in advance. The specific relief items required also depend largely on the nature of crises and the characteristics of the population affected. Such unpredictability of demand contrasts sharply with that of the commercial logistics system, which serves relatively predictable demands in terms of their locations and seasonality. Therefore, the proposed model incorporates the stochasticity of crisis situations in terms of timing, magnitudes and locations of demand occurrence.

Thirdly, humanitarian logistics serves a different customer base, where recipients of support have no consumer choice. There are neither explicit price mechanisms that can regulate demand and supply nor many alternative service providers to choose from. This fundamentally departs from the commercial supply chain where an individual consumer has the liberty to choose from a variety of potential suppliers and exercises an option to buy items if the market meets its expectation for quality, price and overall service. Governing self-organizing humanitarian supply chains therefore requires a unique set of principles that is uncommon to the commercially oriented logistics systems. Instead of market prices, the concept of 'fair' and 'equitable' access to relief items, for example, becomes an important topic of humanitarian logistics studies. We build an agent-based model that can explore these supply chain governance issues (such as prioritization of demand) in this study.

2.2 Vertical versus Horizontal Cooperation—Example of the UNHRD System

Commercial and non-profit logistics cooperation may be categorized as either being vertical or horizontal in nature. Vertical cooperation may be defined as a form of cooperation whereby there are "different actors along the value chain of one industry, such as suppliers, manufacturers, distribution centers and customers" (Schultz and Blecken 2010 p. 638) while that of horizontal cooperation may be defined as those "tak[ing] place between entities operating at the same level in the market" (ibid) such as international relief organizations that share similar humanitarian operations. Horizontal cooperation is being increasingly adopted in both commercial industries such as maritime shipment, commercial aviation and others (Cruijssen et al., 2007) and also non-profit operations such as fundraising (e.g. the Humanitarian Coalition Canada[1]), procurement (e.g. the Humanitarian Procurement Center of ECHO[2]), and relief inventory management (e.g. the UNHRD).

An example of horizontal cooperation explored in this article is the UNHRD established in 2001. Through strategic prepositioning of relief items, the UNHRD aims to achieve speedy delivery of relief goods globally within 24/48 hours to emergency locations (Table 1). The scope of UNHRD service and membership has been steadily growing. In 2013 for example, the UNHRD served a total of 32 organizations, arranging 951 shipments (7278 MT of goods) to 90 countries with a total value of $49 million. The system also facilitated the use of 30 stock swaps between partners, or an exchange of 400 MT in relief goods (UNHRD 2013). Our interviews indicate that the UNHRD system is yet to achieve financial sustainability—approximately 50% of the total operation costs are covered through donor funding, and 25% are recovered from paid services. The system currently has a 25% shortfall in operational funding.

1 Further information is available at: http://humanitariancoalition.ca/
2 Further information is available at: http://dgecho-partners-helpdesk.eu/actions_implementation/procurement_in_humanitarian_aid/hpc

Table 1: UNHRD Global Pre-Positioning Network

Location	Total storage (m^2)	Dispatched in 2013	Users
Brindisi, Italy	6,600 (covered) 3,500 (open)	130 consignments to 23 countries with the total value of $ 9.5 million.	FAO, WHO, WFP, Italian Cooperation and International Medical Corps
Dubai, UAE	21,500(covered) 5,000 (open)	715 consignments to 91 countries with the total value of $30 million.	Irish Aid, World Vision, CARE, FAO, Catholic Relief Services, ECHO, Action Contre La Faim, Johanniter, Mercy Corps, UNDP, International Rescue Committee, Norwegian Church Aid, Qatar Charity, OCHA, JICA, Handicap International, Korea International Cooperation Agency, ShelterBox, Lutheran World Relief, WHO, Italian MOFA, WFP, Islamic Relief Worldwide, Concern Worldwide, Solidarites International, UNRWA, Save the Children, UNHCR, and ACTED.
Subang, Malaysia	8,250 (covered) 1,000 (open)	40 consignments to 14 countries with the total value of $4.4 million.	ASEAN/AHA, AustralianAID, Care, Irish Aid, JICA, Mercy Corps, Mercy Malaysia, NCA, Swiss Red Cross, UNFPA, WFP, WHO and World Vision International.
Accra, Ghana	3,500 (covered) 5,000(open)	47 consignments to 17 countries with the total value $4.6 million.	UNICEF, Shelter Box, UNFPA, UNHCR, JICA, Irish Aid, WHO, ACF, IFRC, Swiss Red Cross, World Vision International, WFP, and Global Mercy Mission Project.
Panama city, Panama	3,605 (covered)	17 consignments to 11 countries with rhe total value of $1 million.	Accion Contra El Hambre, Agencia Espanola de Cooperacion Internacional Para El Desarrollo, Comisión Cascos Blancos, Intermon Oxfam, Irish Aid, Korea International Cooperation Agency, Mercy Corps, Shelterbox, Swiss Red Cross, UNICEF Supply Division, UNICEF TACRO, WFP, Panamerican Health Organization (PAHO), and World Vision International.
Las Palmas, Spain	1,700 (covered) 4,400 (open)	To be operational in 2014	To be operational in 2014

Source: UNHRD (2015)

Confirming an observation in the existing literature, our interviews also indicate that a variety of motivations encourage or discourage humanitarian organizations to join or exit horizontal cooperation (Schulz and Blecken 2010). Many organizations interviewed stated that they have joined horizontal cooperation to achieve cost reduction through free-of-charge storage, consolidated procurement and transportation, etc. Organizations also joined the UNHRD to gain additional security and flexibility in operation made possible by an option to exchange relief stocks in the case of shortages. Others have joined horizontal cooperation to create a collegial brand image and to appeal for further donor support.

At the same time, a number of factors may also hamper their continued membership. As Schultz and Blecken (2010) indicate, when an organization has different operational philosophies, or if members feel that benefits are allocated unfairly, or the system under-performs when demands for goods are high, a member may be less willing to continue their collaboration. Our interviews indicate that some organizations are concerned with the transparency and traceability of stock management and shipment and that continued under-performance of the UNHRD (long lead-time) has already affected their willingness to continue using the system. Given the diverse strategic, tactical and operational goals of humanitarian organizations, it is important to evaluate how horizontal cooperation performs under different operational environments and how their experience will affect a member's willingness to continue such cooperation. The proposed agent-based model evaluates these individual incentives and disincentives for horizontal cooperation.

The form of horizontal inventory management adopted by the UNHRD system may be described as a 'service provider approach' in which one organization serves as logistics services provider for all members (Schultz and Blecken 2010). The World Food Program (WFP) acts as a service provider for the UNHRD system by offering free-of-charge services such as warehousing, stock management, white stocks and transportation of member relief items. In addition, other services such as procurement insurance and stock disposal may be obtained on the basis of full cost recovery plus a management recovery fee of 7%.

Voluntary coordination is an important aspect of the UNHRD arrangement. There are neither explicit top-down mechanisms by which the WFP influences member behaviors nor ways to ensure the optimal performance of a system. The service provider approach thus departs significantly from the commercial supply chain management in which explicit incentives and penalties are used to influence supply chain behaviors (e.g., Cachon and Zipkin, 1999, Cachon, 2001, Lee and Whang, 1999, and Chen, 2001). The proposed model evaluates the emerging behavior of voluntary horizontal cooperation in the absence of such central management.

3. Model Description

3.1. Autonomous Agents and Their Major Roles

This article proposes a stylized multi-agent model of horizontal cooperation based on the core functions of the UNHRD system. The model represents horizontal rather than vertical cooperation and has member organizations cooperate in the same level of operations including procurement, warehousing and shipping. The model is written and implemented using the agent-based modeling language NetLogo 5.1.0 (Wilensky 1999).

The software agents included in the model are: i) a humanitarian crisis agent that creates and communicates stochastic demands for relief items ii) a member organization agent that responds to stochastic relief demands with a specific set of operational goals and constraints; iii) a UNHRD warehouse agent that facilitates the use of free storage, stock-swap, white stocks and iv) a virtual observer agent, which ensures that the same random

Table 2: Agents and their roles in horizontal cooperation

Agents	Major roles
Humanitarian Crisis	Occurs at random geographic locations and creates stochastic demands for relief items. Stores and communicates information such as when the original demand occurs, when each relief shipment is received, what are the levels of remaining demands and whether demands are met within specified lead-time targets.
Member Organization	Participates in horizontal organization and collectively seeks to fulfill stochastic demands created by humanitarian crisis. Stores and communicates information such as the level of budget constraints, the availability of stocks at each sourcing options, and their willingness to swap stocks with other member organizations. Learns from system experience and forecasts and make ex-ante sourcing decisions based on the past success of each sourcing options.
UNHRD	Provides storage capacity and offers additional buffer stocks (known as 'white stocks') in case member organizations run out of their own relief items during the period of extremely high demand.
Virtual Observer	A virtual agent who pre-seeds random values and ensures that same stochastic scenarios can be repeated.

experiments can be performed for reproducibility (Table 2).

A member organization may choose from the following relief good sourcing options: i) own relief items stored at a member's own storage ii) own relief items stored at the UNHRD storage, iii) relief items swapped with other UNHRD members and iv) 'white-stocks' (unbranded supplier's stocks stored at the UNHRD system) (Fig. 1). The model simulates the occurrence of multiple humanitarian crises in which member organizations collectively aim to deliver sufficient relief items within a specified window of lead-time. Based on the perceived success of UNHRD system operation, budget constraints, and forecasted demands, a member organization decides to decrease or increase relief items stored at the UNHRD and

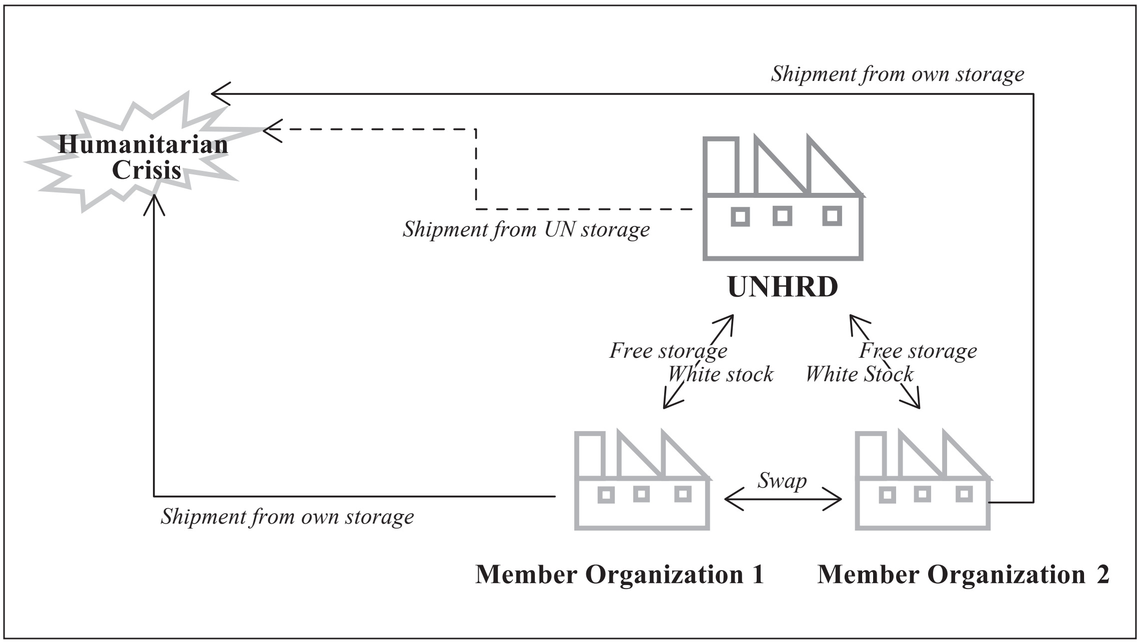

Figure 1: Overview of the Proposed Model (Source: authors)

own facilities.

3.2. Behavioral Assumptions of Horizontal Cooperation.

Using the agent-based modeling framework, the UNHRD operation may be represented as a series of information exchanges between software agents. Unlike the existing multi-agent based modeling of commercial logistics that incorporates explicit bidding processes of negotiations, shipment orders in the proposal model are handled on a first-come first-served basis. Member organizations handle simultaneously occurring demands that are highly unpredictable in location, size and magnitude. Figure 2 shows an illustrative sequence diagram that shows the message flows between autonomous agents.[3]

Firstly, a humanitarian crisis agent is modeled as an autonomous agent, who specifies stochastic demands for a relief item with a given probability. It is assumed that a crisis agent determines its demand at the beginning of its formation and exists in the simulation environment until its demand is fully satisfied. In this article, all crises are assumed to be rapid-onset events (in which members must meet acute demands within their lead-time target).

3 A sequence diagram is a common way to show objects and message exchanges in the software development literature. For those readers unfamiliar with the concept

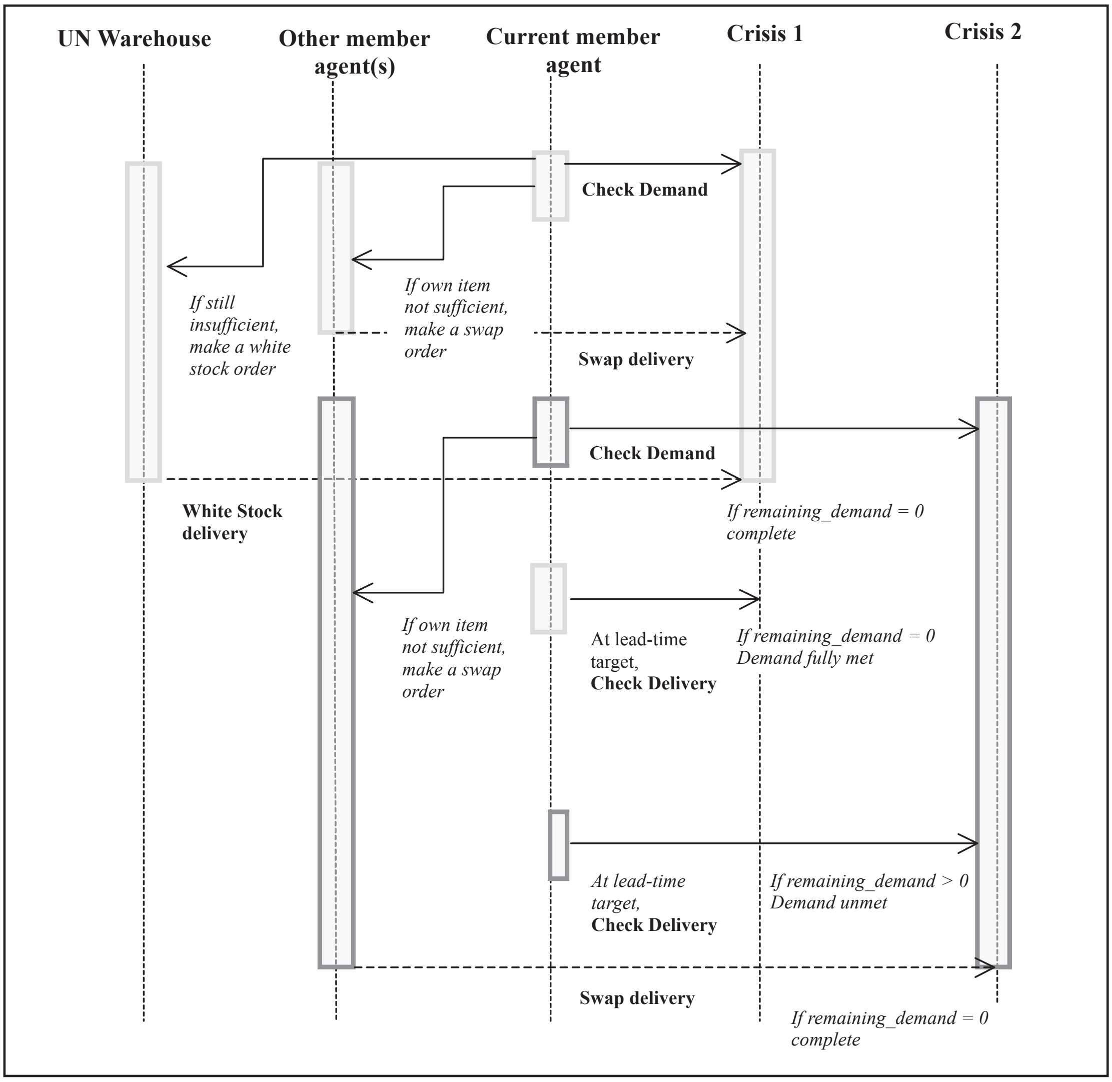

Figure 2: A sequence diagram illustrating the interactions of agents (Source: authors)

Note: At the beginning of the sequence diagram, the current member agent checks if any demands are created for the crisis agent and makes a relief shipment arrangement. In the case that its own stock level is insufficient, the current member agent sends a message to other member agent(s) requesting the use of stock swap (to be delivered at a later time). If demands are still unmet, the current member agent sends a message to the UN warehouse, requesting the use of white stock (to be delivered at a later time). At a particular lead-time target, the current member agent sends a message to the crisis agent again, and checks if and to what extent demands have been met. These sequences are repeated for each member agent, as and when new crisis demands are created. Please note that all member agents jointly aim to fulfill humanitarian demands, therefore the model does not capture cases of conflict cooperation.

of a sequence diagram, see for example (B'Far, 2004).

Secondly, a member organization agent is modeled as an autonomous agent, who interacts with other members and the UNHRD warehouse agent to meet the demand for a given crisis. In the base assumption a member forecasts relief demands based on the experience of past crises events. At the beginning of each time step (i.e. a day), a member organization agent communicates with crisis agents to determine whether a new demand has been generated. When a new demand is detected, a member agent evaluates whether its own facility and the UNHRD warehouse are closer to the newly created crisis location and places an order to ship items from the nearest facility. The quantity of demand, destination and time of the delivery are then stored as a tuple to signal a shipment order. In such a case, if the available stock level is insufficient to meet the demand, a member organization solicits stock-swaps and use of white stocks at the UNHRD facility. Appendix 2 provides a pseudo-code developed for these operational steps.

3.2.1. Forecasting and ex-ante purchasing decisions of a member agent

In this stylized example, each member has a unique set of initial variables that characterize its initial endowment and operational constraints including: budget constraint, demand target (a percentage of disaster demand), lead-time target, and willingness to swap stocks. At every replenishment interval (T), a member evaluates its experience of the UNHRD system recording whether and to what extent relief demands have been met during the window of its lead-time target (T*). A member organization is assumed to forecast a demand based on a weighted average of past demands and deliveries.

Forecasting decisions are modeled in two parts. First, for every monthly replenishment period, daily demand is forecasted as a weighted average of past demands.

$$FTD_{j,T} = \sum_{t=1}^{T} \omega_t (\sum_{i=1}^{I} ID_{j,t,i}) \ldots (1)$$

$$\omega_t = \frac{t}{\sum_{t=1}^{T} t} \ldots (2)$$

$FTD_{j,T}$: A forecasted total demand (FTD) for the next 30 day period determined at the time of replenishment (T; T=30) for member organization (j).
$ID_{j,t,i}$: An initial demand for humanitarian crisis (i) for member organization (j) recorded at time (t).
ω_t : a weighting factor

The weighting factor ω_t in this model can be interpreted as a member organization having a 'fading memory' (Norling et al., 2001) of past disaster demands. Rather than simply dividing the sum of past demands by the number of days, Eq. (1) calculates a weighted average whereby recent demands are emphasized over earlier demands.

Secondly, an ex-ante sourcing (i.e. prepositioning) decision is also determined based on how well each sourcing option performed in the past. Performance is measured in terms of the proportion of items delivered within a lead-time target (T*) from specific sourcing options.

For each of the four options, a ratio of past delivery success is calculated at the time of replenishment as follows. The model again assumes that a member organization has a fading memory.

$$DS_{j,k,T} = \sum_{t=1}^{T} \omega_t (\sum_{i=1}^{I} \frac{DD_{kit:(T'<T*)}}{TD_{it:(T'<T*)}}) \ldots (3)$$

Where

$DS_{j,k,T}$: The extent of successful delivery from sourcing option (k) at a time of replenishment (T) for member organization (j).
$DD_{kit:(T'<T*)}$: Demands delivered from source option (k) for humanitarian crisis (i) that had delivery time (T') below the target lead-time (T*).
$TD_{it:(T'<T*)}$: Total demands delivered from all sources for humanitarian crisis (i) that had delivery time (T') below the target lead-time (T*).
ω_t : a weighting factor

In addition, it is further assumed that a humanitarian organization has two modes of budgeting behavior, namely: i) budget constrained and ii) budget unconstrained. In the budget constrained mode, each member organization makes purchase decisions based on its past experience as described above, while also considering the level of its monthly budget constraint. In the case that a purchase decision made based on Eqs. (1) & (3) is above its budget constraint, a member agent will adjust its purchasing decisions by cancelling the order for the most expensive category and searching for the next feasible alternative and repeating this algorithm until the budget constraint is met. In the case that a purchase decision made based on Eqs. (1) & (3) is below its monthly constraint, then the remaining portion of the budget is carried over to the following month.

In the budget unconstrained mode, ex-ante decisions are made in the same manner as the budget contained mode, except that when a catastrophic humanitarian crisis overwhelms its capacity, an organization is allowed to access swap items and white stocks beyond its original budget constraint. This budgeting mode may be plausible when additional donor funding can be expected in the case of a catastrophic event, thereby an organization faces non-binding budgets under high relief demands.

Also, the UNHRD warehouse is modeled as an autonomous agent, which interacts with member organizations to fulfill relief demands created by crisis agents. In the following illustrative case, this article assumes that only one central UNHRD warehouse exists within the software environment, though this assumption can also be relaxed by modifying the inventory scheduling system. Finally, there is also a virtual observer agent that ensures the reproducibility of stochastic scenarios in the proposed model.

4. An Illustrative Example

To demonstrate the utility of this modeling approach, this section implements an illustrative case of one service provider, two member organizations and multiple humanitarian crisis situations. While some variables used in this illustrative example are selected based on empirical observations (e.g. crises demands for example closely resemble empirical demands for relief goods reported in news releases from 2006-2014 as retrieved from the JICA website (2006-2014)[4]), most data values are chosen for purely an illustrative purpose, and therefore should be interpreted as such. Under the assumptions described in Table 3, we evaluate how the system behaves under two alternative budgeting regimes, namely: i) flexible budget regime (C1) and ii) budget constrained regime (C2).

4 Available in Japanese at: http://www.jica.go.jp/information/jdrt/2014/index.html

Table 3: List of baseline assumptions

Humanitarian Crisis		
Demand	Stochastic demand with a gamma distribution (α = 4, λ =0.16)	
Member Organizations		
	Member 1	Member 2
Demand targets	Attempts to satisfy 20% of stochastic demand for each disasters	Attempts to satisfy 80 % of stochastic demand for each disasters
Target lead-time	5 days	5 days
Initial level of own storage	5 units	50 units
Initial level of own item at UN storage	10 units	20 units
Budget constrains	\$30/month	\$200/month
Willingness to swap stock	100% of own items stored at the UN storage	100% of own items stored at the UN storage
Cost for own storage use	\$10/unit	
Cost of UN storage use	\$5/unit	
Cost of Swap Use	\$5/unit	
Cost of White Stock Use	\$5/unit	
UNHRD Warehouse		
White stock availability	1000 units/month	
Operation modes		
Budgeting behaviors	C1: Flexible Budget Regime C2: Constrained Budget Regime	

Source: authors

4.1. Flexible budgeting regime

Under the flexible budget regime (termed C1), it is assumed that a member organization may request for further stock-swaps or white-stocks to meet the high demands created by catastrophic humanitarian crises. This budget flexibility allows for an individual member to meet its demand target even in the case of catastrophic disaster events. During the 2-year simulation period, Member Organization 1 and Member Organization 2 had 18 and 24 days respectively in which success rates (as determined by the proportion of relief items delivered within a lead-time target) dropped below 1. Under this regime, both Member 1 and Member 2 had the tendency to reduce their own stocks stored both at their own facility and the UN facility (Fig. 3 C1). The uses of stock-swap were on average 2.2 units for Member 1 and 1.9 units for Member 2 (Fig. 4 C1). The uses of white stocks were on average 5.5 units for Member 1 and 17.5 units for Member 2 (Fig. 5 C1).

Given there was no tight limitation of white stock availability, the system tended toward the uses of white stocks when acute spikes were observed. As a result, member organizations reduced storing their own items. At the UN facility, for example, the level of own items stored peaked at 12 units during days 90-120 for Member 1 (Fig. 3 C1 Member 1 UN storage) and at 35 units during days 90-120 for Member 2 (Fig. 3 C1 Member 2 UN storage). For both members, the level of own items stored never recovered to their original levels. This is because

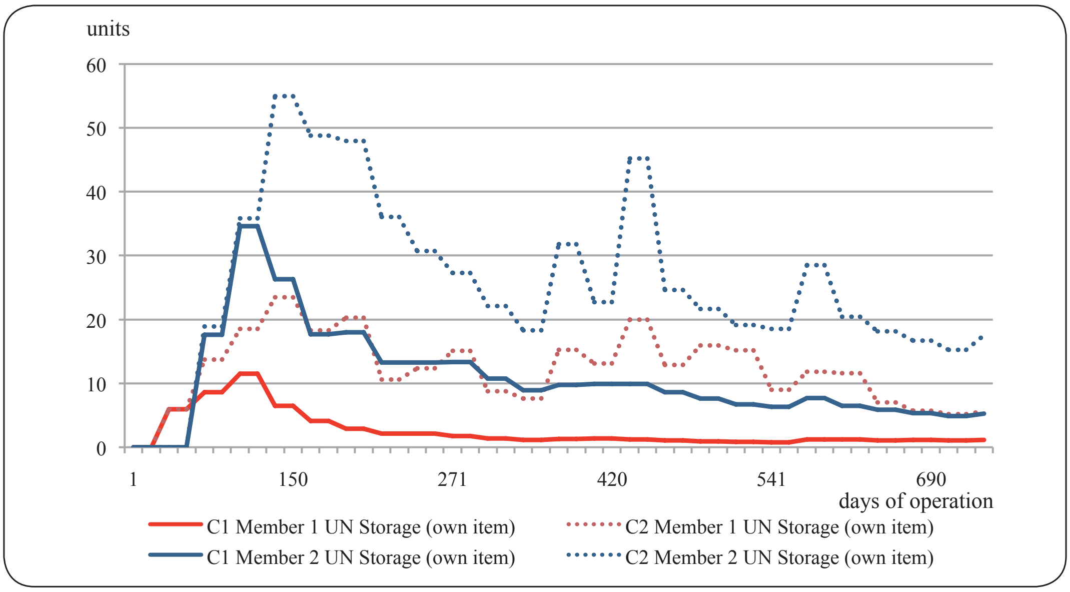

Figure 3: Changes in members' decision to store own items at the UNHRD warehouse
Source: simulation results by the authors

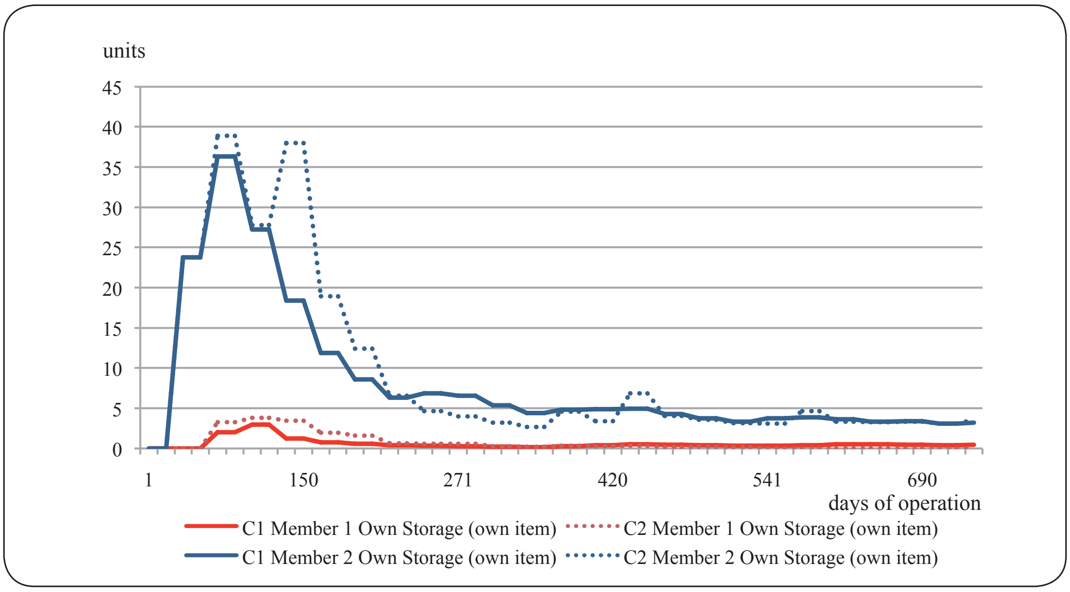

Figure 4: Changes in members' decision to store own items at own warehouses
Source: simulation results by the authors

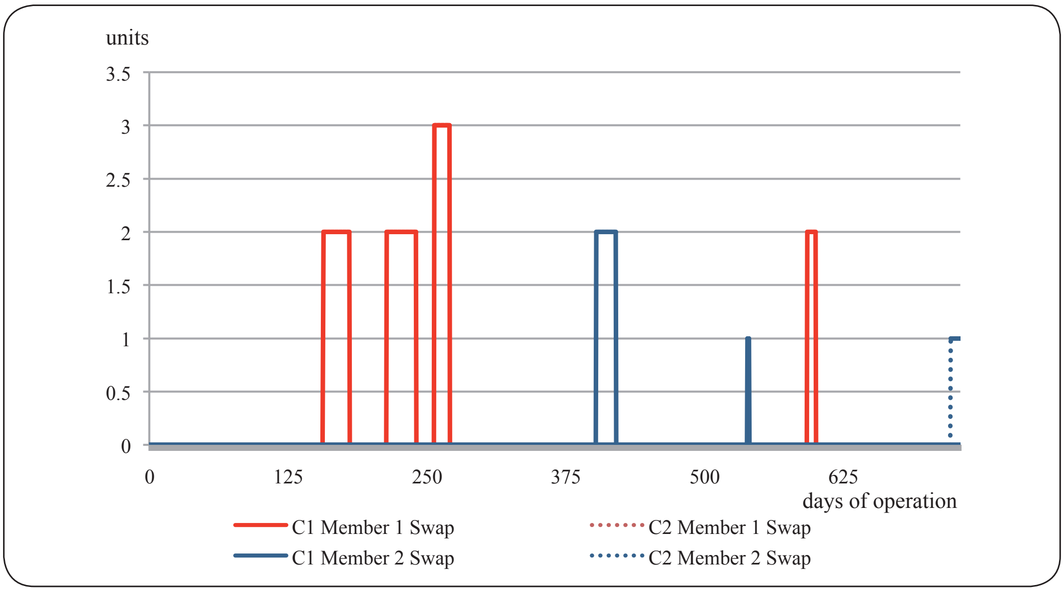

Figure 5: The number of items swapped during the 5-year simulation periods
Source: simulation results by the authors

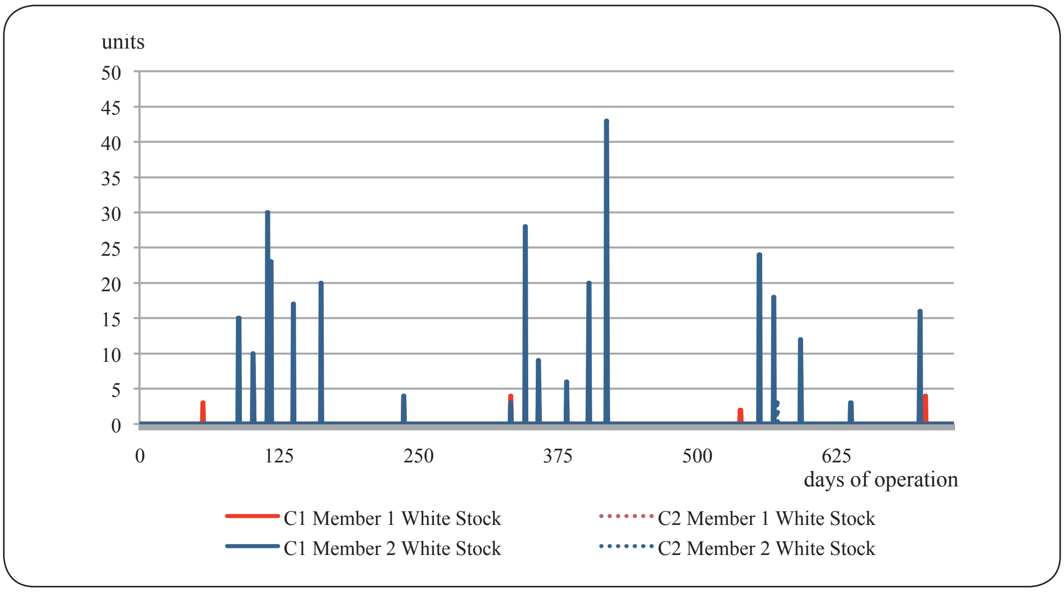

Figure 6: The number of white stocks used during the 5-year simulation periods
Source: simulation results by the authors

sourcing decisions were strongly predicated on the past successes of each sourcing option. As a member organization experienced and learned that white stock options were dependable in the case of catastrophic events, there was a tendency for members to develop dependency toward this reliable option. Such tendency did not respond strongly to changes in the variance of underlying distribution of humanitarian demand: when the variance of distribution was doubled (Fig. A.1-2 in Appendix 3) or halved (Fig. A.1-3 in Appendix3), member organizations continued to store less of their own items in the UN storage under the flexible budget regime.

The modeling outcome will likely change, of course, when white stock availability is tightly constrained. In this case, direct trade-offs may be observed between white stock availability, delivery success and member decisions to store own items at both the UN and own facilities. Under a flexible budget, it is unlikely that a member organization on its own volition will continue to store own items at the UN storage and have adequate capacities to swap items in the case of acute demand hikes. Quantitative measures (such as minimum storage requirement at the UN storage) may be effective to induce continued storage of own items in such case.

4.2. Budget constrained regime

Under the constrained budget regime, a different system behavior was observed. Assuming that a member organization may not request any additional stock-swaps or white-stocks in the case of catastrophic humanitarian events, success rates drop as a result. Under tight budget constraints, Member Organization 1 and Member Organization 2 experienced 24 days and 22 days in which success rates dropped below 1. Ironically, the member organizations' inability to access stock-swaps and white stocks in catastrophic cases ensured that they continued to store own items at both UN and own facilities (Fig. 3 C2). The levels of own items stored at the UN facilities were recorded on average at 12.3 units and 26.2 units for Member 1 and Member 2, respectively. The uses of stock-swaps on average were recorded at 0 units for Member 1 and 1 unit for Member 2 (Fig. 4 C2). The uses of white stock were on average 0 units for Member 1 and 3 units for Member 2 (Fig. 5 C2).

5. Initial lessons drawn and for further research

The modeling results indicate the system behaved sensitively to changes in few parameters and assumptions, highlighting the importance of understanding and incorporating individual decision heuristics of member organizations. Given the diverse characteristics of humanitarian organizations participating in horizontal cooperation, it is highly plausible that the increasing number of organizations with different purchasing, pre-positioning and dispatching preferences will affect overall system behaviors.

Even with a simple set of assumptions and a few agent interactions, this stylized model offers important insights into the system behaviors of voluntary humanitarian cooperation. Due to the highly stochastic nature of rapid onset humanitarian crises, it is difficult for member organizations to accurately forecast and pre-position relief items that also meet their monthly budgets. When demands were particularly high, therefore, organizations often failed to meet their delivery target. Budget flexibility was an important element that allowed member organizations to meet their coverage targets under highly stochastic demands, confirming the observations made by the existing studies such as Toyasaki and Wakolbinger (2014).

When we further assumed that member organizations' past success influenced their future sourcing decisions, the system began to exhibit undesirable dependency. As more demands were met by buffering capacities, organizations were discouraged from stocking their own items. Under such arrangement, simultaneously meeting goals of providing sufficient buffering capacities and serving highly stochastic demands within a short lead-time (of 24 to 48 hours) under the fully voluntary nature of common stock pooling becomes increasingly difficult as diverse members with a range of behavioral preferences enter into the system. The service provider approach currently taken does not offer any explicit incentives or penalties to influence member decision-making. In extreme cases, therefore, pure free-riding is possible whereby an organization does not store any items at the UN facility while still availing itself of the buffer capacities offered by horizontal cooperation.

Currently, the model lacks sophistication in many aspects such as budget behaviors, sourcing decisions and entry and exist options. Further research is therefore required to realistically model humanitarian cooperation. Key research questions that remain include:

- **Inter-temporal budget constraints and seasonal forecasting:** The current budgeting rule simply assumed that members must meet monthly budget limits and any excess budgets were carried over to following months. It did not, however, allow for the uses of future budgets to meet current demands. In the case of highly stochastic and varying demands, some organizations may decide to serve current demands in the hope that they will face lower demands in following periods. This type of decision rule may be plausible under seasonal demand fluctuations (such as high relief demands during cyclone and followed by low demands during non-cyclone seasons). These types of inter-temporal flexibility should be explored for more realistic model humanitarian coordination.

- **Sourcing preferences and alternative resource allocation rules:** The current sourcing rules simply assumed that member organizations chose sourcing options based on the past performance. While such learning behavior is plausible, some organizations may employ other heuristics such as cost minimization and minimum storage levels. Further sophistication in terms of alternative sourcing decision rules should be explored in the future.

- **Stochasticity of lead time:** In the interest of ease in interpretation, the current model simply assumed that the lead-time of each sourcing option did not change due to locations or delivery orders. This may be unrealistic since the time it takes to deliver relief goods may affect factors such as distances to crises, administrative processes required at each location, and the number of organizations that are making simultaneous shipment orders. Further studies exploring these aspects will be useful.

- **Entry and exist decisions:** The current model is simplistic in that no entry and exist decisions are explicitly modeled (i.e. member organizations may reduce stock levels at but never completely exit the system). This is unrealistic since member organizations at any time may decide to exit, when continued membership conflicts with their strategic and operational goals. Likewise, it is reasonable to assume that a new member may enter at any time, potentially altering system performance. How their individual experience as well as member linkages and reputations (Stephenson Jr and Schnitzer, 2006) may influence horizontal cooperation is an important area for further research.

- **Detailed incorporation of additional costs including consolidated transport and penalty for unused stocks:** The current model lacks many details regarding inventory and operation costs including detailed costs for storage, transportation (e.g. evaluation of individual versus consolidated transportation under horizontal cooperation as discussed in Gatignon A., et al. (2010)), and potential penalty costs for unused stocks.[5] Further studies incorporating empirical information in these regards will be helpful.

- **Multiple depot locations and relief items:** While this stylized case only considered one collective depot and one relief item, the actual UNHRD operation is far more complex where six depots located globally hold as much as 400 types of relief items (UNHRD 2015). Although modeling full complexity may be impractical, further inclusion of some of these aspects such as additional search costs that may arise from unstandardized relief items (Toyasaki and Wakolbinger 2014) and under multiple depot locations may be useful to answer key policy and coordination questions.

5 While the UNHRD system does not specify such penalty cost at the time of writing, member interviews indicate that there has been discussion where organizations may either be encouraged to remove unused stocks that are stored for more than two years at the common warehouse or to pay penalty fees.

6. Conclusion

This article proposed a multi-agent simulation model of horizontal cooperation using the UNHRD system as an example. A stylized model of one service provider, two member organization and multiple humanitarian crises was developed to evaluate four sourcing options, namely: i) own storage ii) UN storage for own items iii) stock-swap and iv) white stock uses under two budgeting regimes of fixed and flexible constraints.

Under the plausible assumption that member organizations choose sourcing options based on how well each have performed in the past, the simulation found that the additional buffer stock capacity offered by horizontal cooperation (i.e. stock swaps and white stocks) seems to induce system dependency. The buffer capacity gives members more flexibility to meet highly stochastic demands. At the same time, it encourages member organizations to store less of their own relief goods as a result. The tendency was particularly notable under the flexible budgeting regime where additional funding became available in the case of a catastrophic event. The model therefore highlights the difficulty in meeting multiple system goals such as providing sufficient buffering capacities, meeting highly stochastic demands, and also maintaining the fully voluntary nature of individual storage decisions.

While the model was kept simple to allow for clear interpretation of results, further fine-tuning and evaluations are certainly useful to explore aspects such as the impact of inter-temporal budget constraints and alternative allocation rules, stochasticity of lead time, entry and exist decisions, and the potential incorporation of multiple depot locations and relief items.

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APPENDIX

Appendix 1:

Table A.1: List of Interviews conducted

Organizations	Countries	Positions	Dates
Cooperative for Assistance and Relief Everywhere (CARE)	US	Senior Manager Logistics and Operations Emergency	08.07.2014
United Nation Humanitarian Response Depots (UNHRD)	Italy	Chief	22.07.2014
Japan International Cooperation Agency (JICA)	Japan	Deputy Director General	30.07.2014
Lutheran World Relief (LWR)	US	Emergency Program Manager	04.11.2014
MercyCorps	US	Strategic Emergency Response Team	04.11.2014
Norwegian Church Aid's (NCA)	Norway	Head of Global Logistics	17.11.2014
World Vision	Australia	Global Lead - Emergency logistics	18.12.2014
ShelterBoX	UK	Supply Chain Manager	18.12.2014

Appendix 2: Pseudo-Code for Shipment Decision-Making by Member Agents

To **calculate distance and make shipment**
at each timestep, ask each member agent:
[ask each crisis
if (remaining demand > 0)
[determine if the location of the crisis is closer to UNHRD storage or own storage of the member
if (UNHRD storage is closer and UNHRD stock is sufficient)
then **schedule a delivery** from the UNHRD facility that will satisfy all the demand and designate the delivery as 'UNHRD storage'

if (UNHRD storage is closer but UNHRD stock is not sufficient)
then **schedule a delivery** from the UNHRD facility first that will satisfy part of the demand ('UNHRD storage'), then schedule a delivery from your own facility ('own storage')

if (own storage is closer and own storage stock is sufficient)
then **schedule a delivery** from own facility that will satisfy all the demand and designate the delivery as 'own storage'

if (own storage is closer but own storage stock is not sufficient)
then **schedule a delivery** from own facility first that will satisfy part of the demand ('own storage'), then schedule a delivery from the UNHRD facility ('UNHRD storage')]

if demand is still unsatisfied at this stage schedule (remaining demand > 0) a delivery from unused sources (own/UN storage) to fulfill remaining demand]
end;

To **swap**
if demand is still unsatisfied at this stage (remaining demand > 0)
[then select other member with the largest remaining stock at the UNHRD facility for stock swap
if (found and available swap stock is sufficient)
then **schedule a delivery** from UNHRD that will satisfy all the demand and designate it as ('swap')

if (found but available swap stock is insufficient)
then **schedule a delivery** from UNHRD that will satisfy part of the demand and designate the delivery as 'swap']
end;

to **use white stock**
if demand is still unsatisfied at this stage [
then see if UNHRD has white stock available
if (white stock available is sufficient)
then **schedule a delivery** from UNHRD that will satisfy all the demand and designate the delivery as 'white stock'

if (white stock available is insufficient)
then **schedule a delivery** from UNHRD that will satisfy part of the demand and designate the delivery as 'white stock']

end;

To **schedule a delivery** [member ID, Crisis ID, quantity of shipment, lead-time, origin of shipment]
create a tuple that describes a member organizations' delivery order
allow delivery (list quantity of shipment, crisis ID, scheduled delivery time, origin of shipment, time of initial crisis, end time for record)
add a new tuple at the end of their list of deliveries
decrement stocks levels at each sourcing option accordingly
end;

To **process a delivery**
at each timestep, ask each member agent to search through its list of deliveries to see if there are any orders that are ready [
    if (scheduled delivery time <= ticks) [
        ask each crisis agent to receive relief items by decrementing their remaining demand variable.
        remove the current delivery from the list of deliveries entry from the
        add the delivery information to the list of recorded deliveries]

        proceed to the next tuple]

end;

Appendix 3:

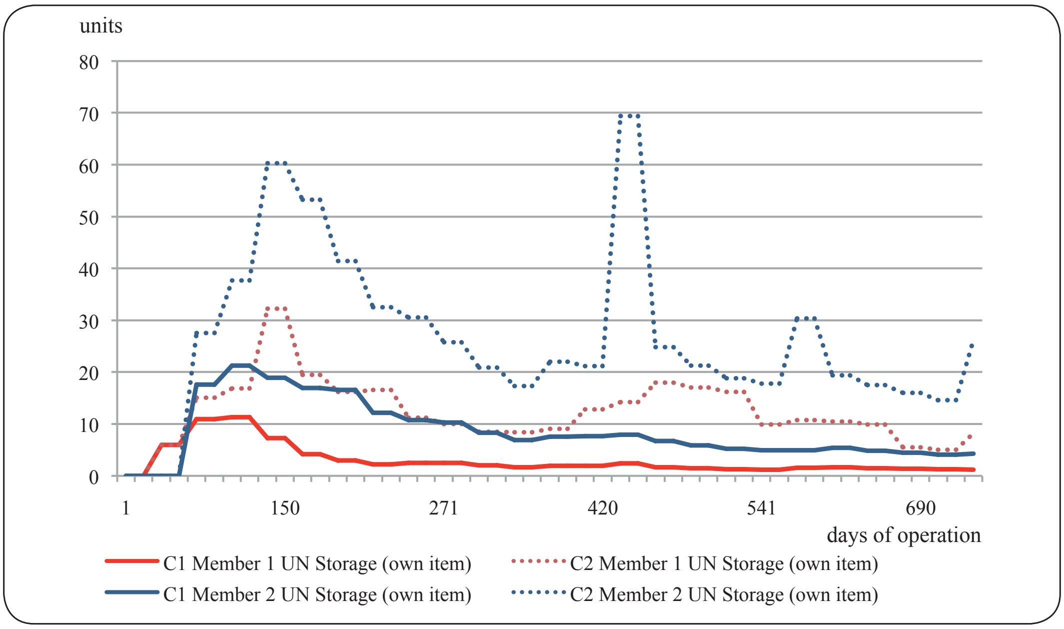

Figure A.1: UN storage use from an alternative stochastic run with (alpha = 2, gamma 0.08)

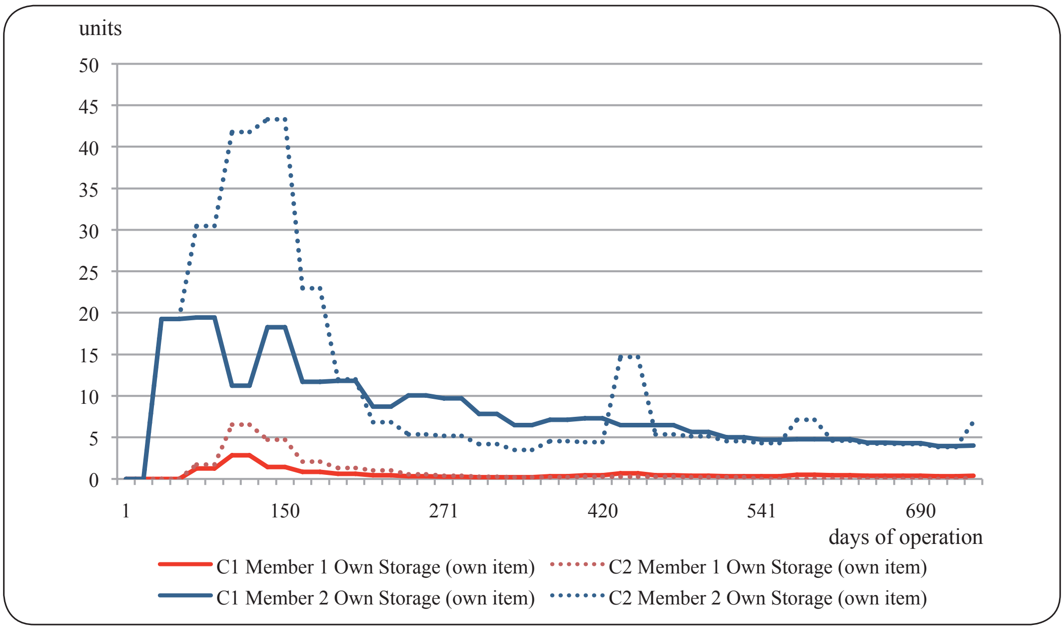

Figure A.2: Own storage use from an alternative stochastic run with (alpha = 2, gamma 0.08)

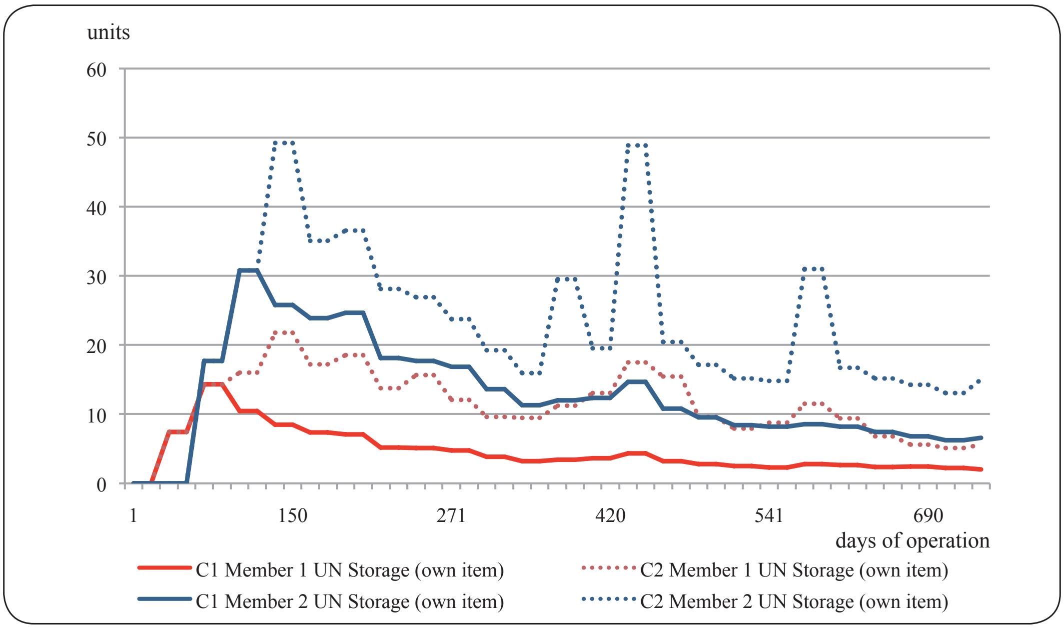

Figure A.3: UN storage use from an alternative stochastic run with (alpha = 8, gamma 0.32)

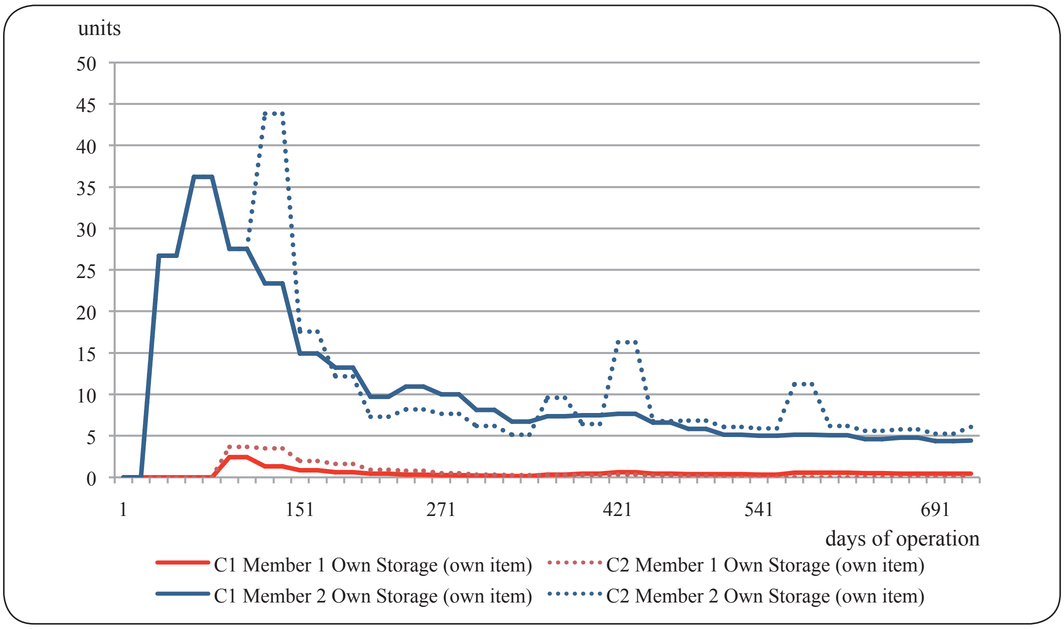

Figure A.4: Own storage use from an alternative stochastic run with (alpha = 8, gamma 0.32)