A FRAMEWORK TO ROBUST STOCHASTIC OPTIMIZATION FOR HUMANITARIAN LOGISTICS

[1]WAPEE MANOPINIWES, [2]TAKASHI IROHARA

[1]Faculty of Science and Technology, Sophia University, Chiyoda-ku, 102-8554 Tokyo, Japan
[1,2]College of Arts Media and Information Technology, Chiang Mai University, Muang, 50200 Chiang Mai, Thailand
E-mail: [1]wapee.m@cmu.ac.th

Abstract— We propose a framework to robust stochastic optimization model for disaster management planning; in particular, we address making integrated decisions about the distribution of relief supplies and evacuation operations. Our decision-making approach recommends the best relief distribution centers to use as storage locations and determines their optimal inventory levels. The model also incorporates the priorities for the evacuation of particular communities, as well as specific disaster scenarios with estimates of the transportation needs and demand for aid. Our model attempts to minimize the sum of the expected value and the variance of the total cost of the relief chain. We present a case study that uses a flood hazard map and determines the distribution of aid for a flood emergency in Thailand.

Index Terms— facility location, humanitarian logistics, robust stochastic optimization

I. INTRODUCTION

Humanitarian logistics is central to disaster relief. In both rapid- and slow-onset disasters or emergencies, it is necessary to procure and move the required material (water, food, shelter, clothing, medicines, and other supplies) from storage locations to appropriate destinations in the affected area, and to do this in the most efficient and effective way possible. It can thus be argued that the logistic capabilities required by aid agencies and others who deal with large scale, sudden-onset disasters are similar to those required by commercial organizations. In a previous study (Manopiniwes and Irohara, 2016), we introduced a stochastic approach to planning the storage and distribution of emergency aid packages in a flood disaster with integrated decisions about the evacuation of various communities.

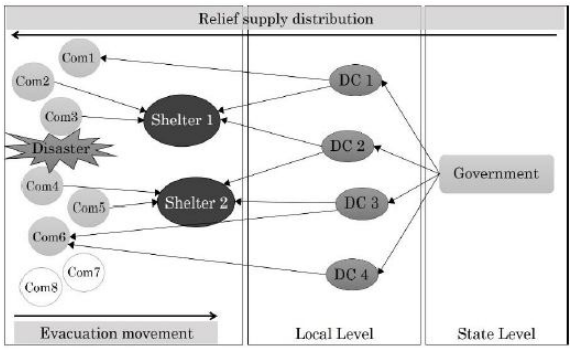


Fig. 1. Supply chain management for disaster relief

Our stochastic model provides a decision-making model for the preparedness stage of a disaster management system, and it considers the outcomes of the various possible responses. While past researches had considered supply distribution and evacuation process separately, we connect both planning contexts as the integrated decision as summarized in Fig. 1 corresponding not only to the demand at evacuation shelters but also to people who remain in the affected area. Our method is able to recommend which of the candidate distribution centers (DCs) will be the best storage locations and to determine appropriate inventory levels. The model incorporates the priorities of evacuating particular communities, as well as specific disaster scenarios, with transportation and demand estimates.

The purpose of this paper is to model disaster planning and response capturing the inherent uncertainty in demand and cost resulting from a disaster. To cope with the challenging problem resulting from the analysis of uncertainty, a novel robust optimization model is therefore proposed. The formulation not only takes into account the expected total cost of relief logistics but also considers the risk reflected by the variability of the total cost.

The remainder of this paper is organized as follows. In Section 2, we provide an overview of the existing literature. Section 3 presents our stochastic approach to disaster preparedness, and Section 4 presents a case study of a flood disaster in Thailand. In Section 5, we evaluate and analyze the results of our approach, and finally, in Section 6, we summarize our contributions and discuss directions for further research.

II. LITERATURE SURVEY

According to the steep increase in the number of articles on relief supply chain management in recent years, a broad overview of the issues is addressed ranging from a principle or conceptual framework to the analytical methodology and case study applied. Among a number of distributions in this field, the

Operations Research (OR) encompasses most objective challenges. Therefore, articles surveying disaster supply chain papers include an OR methodology survey by Altay and Green (2006) and a review of relief supply chain optimization by Manopiniwes and Irohara (2014). Most articles dealing with disaster supply chain are focusing either on the distribution of relief supplies or on the evacuation movement.

A. Humanitarian Logistics

Logistics management in the context of humanitarian organizations has been receiving a lot of attention and discussed by many researchers in recent years (Kovács and Spens, 2011; Ahmadi et al., 2015; Özdamar and Ertem, 2015). In particular, logistics is one of the most critical components to successful humanitarian assistance. Providing the right aid to the right recipients at the right time requires both proficiency and perception of the relief supply chain. To decrease human losses and suffering, a sufficient amount of supplies must be distributed after a catastrophe within some time limit. A severe problem that usually occurs after a disaster is destruction of some parts of the transportation network. As a result, some roads and links in the city network may not be accessible. This will make it very difficult to dispatch and deliver relief goods from local depots to demand points. This issue must be specified in a practical approach for humanitarian relief operations.

While commercial and humanitarian relief supply chains are sharing a number of commonly ways of principle and operation, the different characteristics are able to

Table 1 The different characteristics between commercial and relief supply chain

Characteristics	Commercial supply chain	Relief supply chain
Parties involved	• Well linked with each other • Long-term relationship	• Unknown and voluntary • Develop instantaneously during the relief operations
Network configuration	• Relatively stable	• Unstable and many supplier only supply once during the relief operations
Demand	• Generally quite stable • Past data can be used to forecast the level of demand by standard technique	• Largely unpredictable • Very unstable with time • Need quick assessment and knowledge • No standard technique available
Supply	• Predetermine suppliers • The level of supply activities reflect the level of demand (demand from customer order) • Proper selection and performance monitoring	• Not possible to limit suppliers from certified suppliers • Supply not reflect the demand (demand from aid agencies) • Non-essential and shortages most often seen

The nature of most disasters demands an immediate response, hence supply chains need to be designed and deployed at once even though the knowledge of the situation is very limited. Business logistics usually deals with a predetermined set of suppliers, manufacturing sites, and a stable or at least predictable demand – all of which are unknown in humanitarian logistics (Kovács and Spens, 2007). Furthermore, since most natural disasters are unpredictable, the demand for goods in these disasters is also unpredictable.

Humanitarian organizations is difficult due to a variety of barriers. Amongst other factors, cooperation and coordination between humanitarian organizations is affected by humanitarian organizations' mandates, their organizational structure and employed IT systems, perceived or actual competition between the humanitarian actors, and timely exchange of accurate information before and during humanitarian operations (Schulz and Blecken, 2010).

B. Stochastic Optimization in Humanitarian Logistics

Stochastic programming is one of the most widely used tools for planning in the preparedness stage (Altay and Green, 2006) due to its ability to handle uncertainty by probabilistic scenarios representing disasters and their outcomes (Barbarosoglu and Arda, 2004; Balcik and Beamon, 2008; Rawls and Turnquist, 2010; Salman and Yücel, 2015; Song and Zhang, 2009; Kelle and Yi, 2014). The flood emergency logistics preparation problem with uncertainty is formulated by Chang et al. (2007) as two stochastic programming models that allow for the determination of a rescue resource distribution system for urban flood disasters by applying the data processing and network analysis functions of the geographic information system. Flooding potential maps can estimate the possible locations of rescue demand points and the required amount of rescue equipment. Mete and Zabinsky (2010) developed a stochastic model for the location and delivery of medical supplies in Seattle area regards to the earthquake disaster. The randomness in the location and amount of demand, and in the available transportation routes and transportation times lead to different types of scenarios where the transportation routes and times are directly related to the location and amount of demand. Lately, Verma and Gaukler (2014) evaluate the performance of two models between deterministic and stochastic modeling approaches using large-scale emergencies caused by an earthquake in California. They found that the locations suggested by the stochastic model significantly reduce the expected cost of providing supplies. They also demonstrate that the cost advantage of the stochastic model over the

deterministic model is especially large when only a few facilities can be placed.

Our study makes the following contributions: provides the new approach modeling for the integrated decision on the evacuation planning and relief supplies distribution for floods emergency response. With the stochastic formulation based on the flood hazard map, the value of decision performance is particularly great in a large-scale realistic with budget-constrained situations.

C. Robust Optimization

Robust optimization, one of the most popular topics in the field of optimization and control science the late 1990s, deals with an optimization problem involving uncertain parameters. Mulvey et al. (1995) introduce a model for robust optimization that involves two types of robustness: "solution robustness" (the solution is nearly optimal in all scenarios) and "model robustness" (the solution is nearly feasible in all scenarios). The definition of "nearly" is left up to the modeler; their objective function has general penalty functions for both model and solution robustness, weighted by a parameter intended to capture the modeler's preference between the two. The robust optimization method developed by Mulvey et al. (1995), in fact, extends stochastic programming by replacing traditional expected cost minimization objective by one that explicitly addresses cost variability. We use ξ to represent f (x, y), which is a cost or benefit function, $\xi s = f(x, ys)$, for scenarios. A high variance for $\xi s = f(x,ys)$ means that the solution is a high-risk decision. Mulvey et al. (1995) applied a quadratic form of variance to capture the concept of risk and represent the solution robustness. To cope with the computational complexity due to its nonlinearity, however, Yu and Li (2000) proposed an absolute deviation in place of the quadratic term, which is presented as follows:

$$\sigma(\circ) = \sum_{s\in\Omega} p_s \xi_s + \lambda \sum_{s\in\Omega} p_s \left| \xi_s - \sum_{s'\in\Omega} p_{s'} \xi_{s'} \right| \qquad (1)$$

where λ indicates the weight placed on the solution variance in which the solution is less sensitive to change in data under all scenarios as λ increases. In order to minimize objective (1) efficiently, they proposed an efficient method. The framework of Yu and Li's model is designed to minimize the objective function in (2):

$$\text{Min} \quad \sum_{s\in\Omega} p_s \xi_s + \lambda \sum_{s\in\Omega} p_s \left[\left(\xi_s - \sum_{s'\in\Omega} s_{s'} \xi_{s'} \right) + 2\theta_s \right] \qquad (2)$$

$$\text{s.t.} \quad \xi_s - \sum_{s\in\Omega} p_s \xi_s + \theta_s \geq 0 \quad s \in \Omega \qquad (3)$$

$$\theta_s \geq 0 \quad s \in \Omega \qquad (4)$$

III. PROBLEM DESCRIPTION

This section describes concrete detail of flood characteristics of the case study as well as the specific humanitarian operation management problem regards to this type of disaster. The schemes that usually taken into the consideration to be addressed is stated in a general manner for the most urgent stages in disaster cycle management aspect.

A. Flood hazard map of case study

Out of all the natural disasters, floods are the most common in both developed and developing countries, accounting for approximately 40% of all natural disasters. Southeast Asia is a region that is especially prone to frequent and severe natural disasters (Coker, 2011). The frequency and severity of flooding in Southeast Asia has increased over the past several decades. Flooding is a prominent issue that is currently affecting many regions in Southeast Asia, in particular Thailand, Cambodia, Vietnam, Laos, the Philippines, and areas surrounding the Mekong River.

According to the United Nations Office for the Coordination of Humanitarian Affairs (Torti, 2012) it is estimated that 9.6 million people are currently affected by the flooding in Southeast Asia, with 5.3 million in Thailand alone.

This section presents a case study of a flood disaster in Chiang Mai province, the largest city in Northern Thailand. Chiang Mai is vulnerable to flooding due to its bowl-like shape. Large floods usually occur late in the May–October rainy season due to masses of moist air moving northeast from the Indian Ocean, and tropical depressions moving westward from the South China Sea (Wood and Ziegler, 2008). In 2011, much of Thailand, including Chiang Mai, experienced the worst floods ever recorded there.

Chiang Mai city implemented a flood warning system for the Ping River, which makes real-time predictions of the flood level. This system uses two gauging stations, P.1 located at downtown Chiang Mai, and P.67 32 kilometers north in Ban Mae-tae in Sansai district (Fig. 2). When there is heavy rainfall, it takes about seven hours for the water to travel from Station P.67 to Station P.1. Thus, it is possible to estimate the impact on the downtown area by measuring the level of the Ping River at Station P.67. For example, as shown in Fig. 3, when height of Ping River at Station P.67 reaches 4.0 meters because of the amount of continuous rainfall, it is supposedly that the height of Ping River at



Fig. 2. Map of Chiang Mai, Thailand with two gauging stations along Ping River

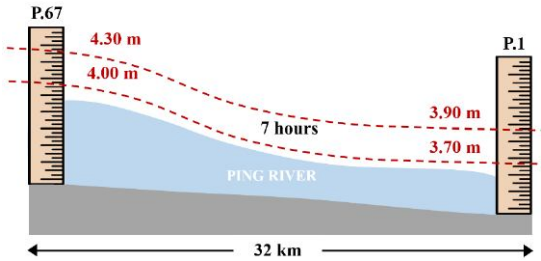
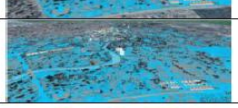


Fig. 3. Station P.1 and P.67 on the Ping River in Chiang Mai, Thailand.

Station P.1 will get to 3.7 meters in the next seven hours. Similarly, Station P.1 reaches the higher level of Ping River when Station P.67 is gaining more amount of water, then Chiang Mai downtown can be flooded in different level. Research Unit of the Civil Engineering Department of Chiang Mai University (CENDRU, 2016) has developed the Chiang Mai flood hazard map according to this characteristics through the collection of historical data. The flood hazard map for Chiang Mai could be categorized into different 7 impact level with details of information

Table 2 Seven impact level of the Chiang Mai flood hazard map. (CENDRU, 2016)

Impact Level	Flood hazard map	Ping River at Station P.1 (m)	Volumetric flow rate (m^3/s)
1		3.7 – 3.9	460-510
2		3.9 – 4.0	510-530
3		4.0 – 4.1	530-560
4		4.1 – 4.2	560-580
5		4.2 – 4.3	580-600
6		4.3 – 4.6	600-673
7		Over 4.6	Over 673

possible based on the Chiang Mai flood hazard map. The mathematical model accounts for the severity of the flood disaster. Unlike other natural disasters, such as earthquake or tsunami, floods typically are known about several hours or more in advance of reaching the areas that will be affected. In this case study, it takes about seven hours for floods to reach Station P.1 from Station P.67. Therefore, the government is able to determine if people should evacuate or not in these seven hours. The evacuation decision in the proposed model is applicable to this real situation.

CONCLUSION AND RECOMMENDATIONS

In this paper, we modeled disaster planning and response capturing the inherent uncertainty in demand and cost resulting from a disaster. To cope with the challenging problem resulting from the analysis of uncertainty, a novel robust optimization model is therefore proposed. The framework not only takes into account the expected total cost of relief logistics but also considers the risk reflected by the variability of the total cost. Our former model (Manopiniwes and Irohara, 2016) consists of two stages; the first stage determines the location of DCs and the required inventory quantities for each type of relief items under storage, and the second stage determines the amount of transportation from DCs to affected area. Furthermore, for the future study is to construct the mathematical formulation regarding to the framework of robust optimization in this study. The model is to minimize expected total cost and cost variability due to uncertain parameters. In this problem, cost parameters for the relief logistics as well as demand are subject to uncertainty. Furthermore, the model considers uncertainty in the locations where those demands might arise as well as the possibility that some of the pre-positioned supplies at DC or supplier might be partially destroyed by the disaster (supply uncertainty).

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