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Cooperative maximal covering models for humanitarian relief chain management

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ABSTRACT

Observing the growing risks of disasters and challenges in humanitarian relief chain management, this study examines the general structure in humanitarian relief chain logistics, and focuses on developing a maximal cooperative covering model with budget considerations to maximize the benefits to the affected population in disastrous regions. Disasters affect regions depending on their severity, and the demand of the disastrous regions cannot be exactly predicted. We incorporate demand uncertainty to capture the uncertain nature of disasters. We include financial efficiency and appeal coverage as two key performance indicators to evaluate humanitarian relief chain management, and preform extensive sensitivity and robustness analysis. We analyze the impact of availability of items through distribution centers on relief chain management, and compare the performance of the proposed model under cooperative and non-cooperative scenarios.

1. Introduction

In past few decades, the impacts of disasters have aggravated economically, socially and environmentally. By The International Disaster Database (2012), the number of natural disasters, along with the people affected by the disasters, has significantly increased compared to last decade, even with decreasing number of total deaths over the years (see Fig. 1). In 2010, the earthquake in Haiti recorded estimate of over 200,000 deaths; thousands of people required immediate assistance and were evacuated, injured, or lost their livelihoods (World Health Organization (WHO), 2011). The case like earthquake and tsunami in Japan in 2011 claimed 19,846 lives and caused economic damages of $210 billion (Center for Research on the Epidemiology of Disasters, 2012). The trend of increasing number and escalating impact of natural disasters and massive scale of recent global relief efforts have brought growing attention to effective and efficient disaster relief chain management that can deliver materials and services to the people in need in an adequate and timely fashion.

Humanitarian relief chain accounts for 80% of humanitarian logistics (Wassenhove, 2006). It engages international relief organizations, governments, the military, local and regional relief organizations, and private sector companies, each of which may have different mandates, capacity, and logistics expertise to implement and controls material flows, storage of goods, and related information to minimize human sufferings and deaths (Balcik, Beamon, Krejci, Muramatus, & Ramirez, 2009). Due to the magnitude and geographical scale of a disaster, no single organization has enough resources to alleviate the effect of a disaster (Bui, Cho, Sankaran, & Sovereign, 2000).

Many factors can increase coordination difficulties in relief operations. For instance, the lack of leadership among a variety of relief actors, and diverse political agendas and religious issues may lead relief chain management to a less coordinated and efficient fashion. It consequently compromises the interests of beneficiaries (Tomasini & Wassenhove, 2009). Moreover, dominating characteristics of humanitarian relief chain in terms of unpredicted demands, strategic goals, high stakes associated with timely delivery, and lack of resources can bring additional complexity and challenges to the relief chain management (Balcik et al., 2009; Beamon, 2004; Thomas & Kopczak, 2005; Wassenhove, 2006).

To recover and rehabilitate disastrous regions, relief chains need significant amounts of resources, e.g., relief items, money, etc., which heavily rely on the scale and type of the disaster (Yadav & Barve, 2015). Thus, to provide life necessities and monetary resources to the disastrous regions in a time efficient manner, relief chain requires highly well-organized management among a large number and variety of relief actors in the operation. The relief actors for years have been viewed as necessary expenses rather than an important strategic component in relief chain, even though their logistical activities are central to a disaster relief operation. Humanitarian organizations only recently have begun to understand the criticality and importance of relief chain management on the success of disaster relief operations (Wassenhove, 2006). In addition to the complexity and variety of relief actors, there

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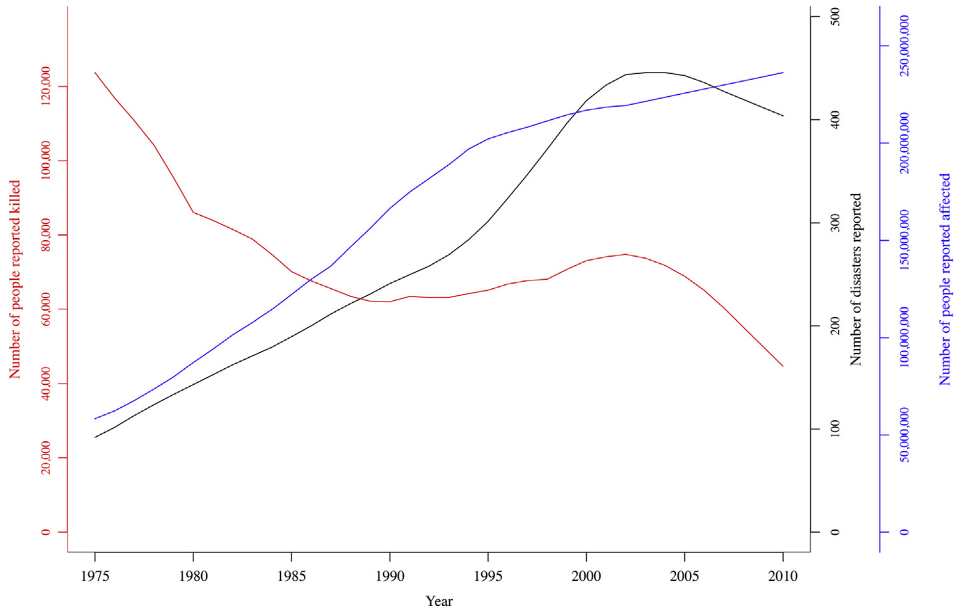

Fig. 1. Total number of deaths, reported disasters, and people affected from year 1975–2010.

are challenges and risks associated with post-disaster relief operation. To name a few, acquisition and delivery of adequate relief supplies from local and international suppliers are typically time consuming and expensive; functionality or survivability of relief chain network usually involves with significant cost and efforts; and some relief actors are required to engage in pre-disaster activities and enhance their logistics capabilities in emergencies response and delivery of sufficient relief aid within relatively short time frame. Although improving the ability of relief actors to mobilize relief supplies and delivery can be financially restricted, some large relief organizations manage to implement and operate relief chain management system successfully. For example, under the system of World Vision International, relief supplies are stored in four locations globally, and can be immediately shipped anywhere in the world; and the United Nation Humanitarian Response Depot in Italy managed by the World Food Program is capable of working with various partners to send relief supplies anywhere in the world within 24 to 48 h to meet the needs of people affected by natural disasters (Beamon & Kotleba, 2006b).

The need for high-performance relief chain management has been imperative in humanitarian logistics. Despite continuing challenges, relief chain management in humanitarian logistics has been undoubtedly receiving global attention due to the scarcity of the resources, accountability concerns, and the potential opportunities provided by advances in global information technologies (Balcik et al., 2009). As such, we focus on relief chain management in humanitarian logistics in this study. We take the first step on describing typical relief chain structure observed in disaster operations. Then we concentrate on developing maximal covering type model that considers multiple types of relief items, cooperative coverage requirement, budgetary constraint on logistics cost, and decisions on distribution facilities. We further extend the study to incorporate coordinated activities among relief actors in relief chain management on a conceptual network model. Although the research on maximal covering problems is extensive, in terms of theory and applications, these problems have not received much attention in the domain of relief chain management, and have not been considered under the cooperative coverage constraints.

The rest of this study is organized as followings: Section 2 provides an overview on relevant research. Section 3 elaborates the general relief chain management structure. Section 4 focuses on developing mathematical model formulation. Section 5 presents a numerical experiment and the performance comparison between cooperative and non-cooperative covering models, and Section 6 concludes the study.

2. Literature review

The quantitative tools and optimization methods that analyze relief chain management are typically categorized into facility location models, relief distribution and transportation models, and multi-commodity network flow models to optimize the flow of relief supplies through existing distribution networks (Caunhye, Nie, & Pokharel, 2012). Haghani and Oh (1996) present a large-scale multi-commodity, multi-modal network flow model to minimize the loss of life and maximize the efficiency of the disaster relief operation based on the concept of time-space network, and propose two heuristics as the solutions to the model. By examining the logistics planning in the emergencies that involves the dispatching of commodities from the distribution center (DC) to the affected area, Ozdamar, Ekinci, and Kucukyazici (2004) develop a mixed integer multi-period multi-commodity network flow model for the vehicle routing problem, and treat vehicles as commodities that accompany the actual goods in the context of humanitarian logistics. Barbarosoglu, Ozdamar, and Cevik (2002) focus on the use of helicopters for aid delivery in the relief operation, which is mainly concerned with developing mathematical models that solve tactical and operational routing and loading decisions regarding the helicopter activities at two hierarchical levels. Barbarosoglu and Arda (2004) propose a two-stage stochastic programming model to plan the transportation of relief goods and formulate a multi-commodity, multi-modal network flow to describe the material flow with the consideration of uncertainty and vulnerability arising from the disaster scenario. Balcik, Beamon, and Smilowitz (2008) structure a model that aims on delivery schedules for vehicles and resource allocation in the last mile distribution in relief operation with the objective of minimizing transportation cost and maximizing benefits to aid recipients. Tuzkaya, Heragu, Evans, and Johnson (2014) and Sheu and Pan (2015) concentrate on post-disaster response in the emergency logistic network and propose an approach to minimizing the imbalanced supply-demand impact.

In another research direction, to incorporate demand or population coverage in maximal covering problems, Current, Revelle, and Cohon (1985) introduce the notation of population coverage to the network design problem by formulating the model of maximum covering/minimal path cost. They associate some fraction of the population with each node, which is labeled as the demand of that node, and define a demand node covered if the path includes the node or passes through another node that is within a predetermined distance from that node