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Humanitarian Logistics Network Design for an Effective Disaster Response

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ABSTRACT

In this paper we address the problem of pre-positioning emergency supplies prior to a disaster onset. The goal is to ensure a fast and effective response when the disaster strikes. Pre-positioning of emergency supplies is a strategic decision aimed at determining the number and location of local distribution centers as well as their inventory levels for emergency supplies. These decisions must be made in a highly disruption-prone environment where a timely response is vital and resources are scarce. We present and discuss a scenario-based model that integrates location, inventory and routing decisions.

Keywords

Pre-positioning, disaster, location, inventory, transportation, stochastic, scenario-based model.

INTRODUCTION

When a major disaster strikes, a timely response is critical to saving lives and mitigating affected population sufferings. In fact, the first 72 hours of a disaster relief effort are critical as the chance for survival beyond that time window without water or food decreases drastically. The challenge is to deliver the appropriate emergency supplies in sufficient quantities exactly when and where they are needed. Thus humanitarian logistics is one of the most crucial functions of an effective disaster response. In the event of large-scale disasters, the logistical function becomes more challenging as vital decisions must be made in a highly dynamic disruption-prone environment where urgent demand is high and resources are scarce. Relief operations after a major disaster onset such as hurricane Katrina in 2005 or the recent Haiti earthquake are often criticized (GPO, 2007; OIG-08-11, 2008). Haiti earthquake left more than 2 million people homeless with no access to basic needs such as water and urgent care. While emergency supplies were reportedly stacking up at Port-au-Prince airport, The Haitian government and its partners including the non-governmental organizations and foreign governments have been struggling to distribute these available supplies to populations in need. The slowness of aid distribution apparently resulted in some violent incidents marked by looting out of desperation and frustration. In an interview with CBS, when asked about how to overcome this problem, a USAID administrator emphasized the importance of identifying appropriate distribution centers and securing sufficient commodity flow there. With the worldwide increasing trend in the number of large-scale natural disasters and the number of people reportedly affected (see figure 1), disaster preparedness becomes a necessary strategy to insure adequate and effective relief efforts.

In this paper we consider a distribution network operated by a humanitarian relief organization aimed at delivering different types of emergency supplies to disaster-affected populations in order to mitigate their suffering. Emergency supplies are generally of two types: consumable items such as clothing and food; and non-consumable items such as shelters and electricity devices. In a relief distribution network, emergency supplies are first received and stored in permanent facilities (logistics centers) generally located in large cities. These supplies are then shipped to temporary supply units (local distribution centers) in theater where they are pre-positioned for distribution to people in need. Since disasters are generally low probability high impact events, demand size and location are random factors that

Reviewing Statement: This paper represents work in progress, an issue for discussion, a case study, best practice or other matters of interest and has been reviewed for clarity, relevance and significance.

are hard to forecast. Moreover, demand of each type is characterized by its degree of urgency and its targeted response time. Non-consumable items are critical to a timely disaster-response (Akkihal, 2006) and must therefore be delivered in the early stages.

Prior to the disaster onset, design decisions including the number and location of local distribution centers needed as well as their inventory levels for each type of emergency supply are made. In addition, the assignment of demand points to these distribution centers may also be considered as a pre-disaster decision since local distribution centers usually operate independently (Balcik et al., 2008). This activity is commonly called Pre-positioning of emergency supplies and is part of pre-disaster preparedness. Design decisions are typically constrained by budget limitations that restrict the number of local supply units to establish as well as their storage capacity (Balcik and Beamon , 2008).

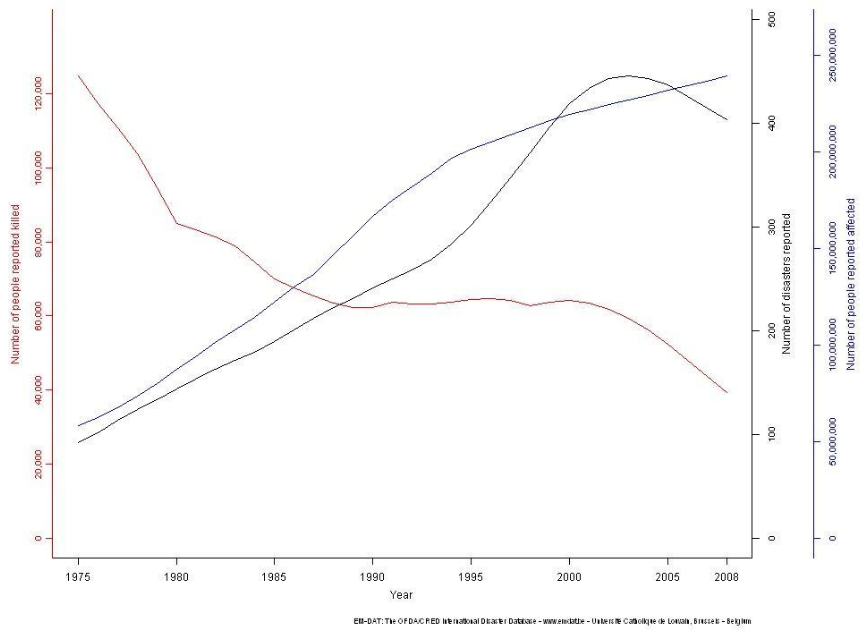

Figure 1: Natural Disaster Summary 1975-2008 (linear-interpolated smoothed lines). Source: EM-DAT DATABASE

Prepositioning emergency supplies which is is a strategic decision aimed at designing the relief distribution network away before the disaster strikes. After the disaster onset, the organization will use the designed network to conduct daily operational decisions over a planning horizon that covers the disaster duration. These decisions include emergency supplies allocation among demand points as well as routing and scheduling of a limited fleet of capacitated vehicles.

In the following sections, we first describe the problem of Pre-positioning emergency supplies and present a brief review of work reported in its literature. We then present and discuss a scenario-based model that integrates location, inventory and routing decisions. Finally, we conclude and discuss current and future work.

PRE-DISASTER PREPOSITIONING OF EMERGENCY SUPPLIES

In this paper, we address the problem of pre-disaster prepositioning of emergency supplies. We consider a network where a limited set of distribution centers with restricted storage capacity must be established to deliver different types of emergency supplies over a planning horizon to a set of demand points with stochastic locations, demand arrivals and demand quantities. Emergency supplies can be divided into two major categories: consumable and non-consumable items. The problem is to determine the number and location of these distribution centers, their inventory levels for each type of emergency supply as well as demand points assigned to them. The objective is to optimize the expected transportation costs and the expected covered demand while taking into account the degree of urgency of each demand type as well as its targeted response time.

Depending on whether uncertainty is taken into account or no, work reported in the literature of this problem can be classified into two major categories: stochastic or deterministic. In the deterministic case, it is assumed that all problem inputs like demand quantities and demand locations are known in advance with certainty (Iakovou et al. 1996; Akkihal, 2006; Tzeng et al., 2007; Clark and Culkin, 2007; and Ghanmi and Shaw, 2007). In the stochastic case, problem inputs such as demand size and/or location are prone to random variations over time (Jia et al., 2007; Ukkusuri and Yushimoto, 2008; Baclik and Beamon, 2008; Chang et al., 2007; Mete and Zabinsky, 2009; and Duran et al., 2009).

It is worth noticing that all models that we found in the literature are solved using exact methods that are tested on relatively small sized instances.

A SCENARIO-BASED MODEL

Pre-disaster prepositioning of emergency supplies is aimed at designing relief distribution networks that will be used later to conduct daily operational decisions over a planning horizon that covers the disaster duration. Thus, the effectiveness of the designed relief distribution networks is inherent to a judicious integration of these two decision processes. However, integrating the two processes is not an easy task since they take place at different points of time relying on information of different levels of accuracy. Strategic decisions, as described in the previous section, are made at instant t_0 based on vague information available at that time (e.g. estimate demand of each type over the operational time horizon, estimate travel costs, etc…). Operational decisions on the other hand rely on more recent and precise information (e.g. demand of each type per period, available routes, travel times, etc...). This leads to a typical decision time hierarchy situation as defined in Schneeweiss, 2003. To integrate strategic and operational decisions, we propose a two-stage stochastic programming model inspired by Schneeweiss's distributed decision process (Schneeweiss, 2003). At the first stage, design decisions are made based on information available at instant t_0 such as feasible locations for the distribution centers and the matrix of distances between these locations. These strategic decisions minimize the expected cost of establishing the distribution centers while taking into account an anticipation of the operational level. The operational level anticipation is determined in the second stage given some strategic decisions and is aimed at optimizing total satisfied demand and total transportation costs under anticipated information available at instant t_0. Hence, an estimate unit cost of transporting an item type from a distribution center to a demand point is used instead of actual routing costs, and demand of each type is aggregated over the time horizon T. These estimated parameters are obtained using a set of probabilistic scenarios.

A sample average approximation program based on Monte Carlo sampling technique (Ahmed and Shapiro, 2002; and Shapiro, 2003) is proposed to develop and solve the proposed two-stage stochastic programming model.

CONCLUSION

We presented an on-going work dedicated to the problem of prepositioning emergency supplies as a strategy for ensuring an effective disaster response. We used a scenario based model to formulate the problem and proposed to solve it using a sample average approximation program. A key element to the success of this approach is the accuracy of the scenarios used. Our current work is aimed at generating scenarios that are inspired by real-life situations. We are also currently working on using OPL-Cplex optimization software to solve the problem to optimality for scenarios with small sized problems. In fact, the proposed sample average approximation program leads to a large-scale mixed integer program solvable for problems of limited sizes and for a limited number of scenarios only. Future work will be aimed at developing a meta-heuristic approach that can handle the large-scale computation issues inherent to the problem.

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