Evaluating the Effectiveness of Pre-Positioning Policies in Response to Natural Disasters

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ABSTRACT
Recent natural disasters highlight the complexities associated with planning, coordination and distribution of supplies in a manner which provides timely and effective response. In this paper, the authors present a model to quantify the benefits associated with pre-positioning local supplies. They assume the supplies are in a high-risk location and may be destroyed if an appropriate strategy to protect the supplies is not implemented. A stochastic linear programming model is developed where the first-stage decision pre-positions existing supplies to minimize the supply loss. Second-stage decisions attempt to maximize the responsiveness of the system by allocating supplies to satisfy demand. The benefits associated with pre-positioning versus non-pre-positioning are discussed.

Keywords: Humanitarian Relief, Network Flow, Pre-Positioning, Supply Damage, Stochastic Programming

INTRODUCTION
Emergency response in large scale, catastrophic events is an emerging area of research in the operations research and management science community. Much of the interest has been sparked by frequently occurring natural disasters, most notably hurricanes Katrina and Rita, the tsunami induced floods in India, and the September 11, 2001 terrorist attacks in New York. Furthermore, logistical failures caused by insufficient planning and inadequate resources are often highly publicized in media outlets. Obtaining sufficient supplies and coordinating the distribution of those supplies can be a significant challenge during the response effort. In this paper, we propose a model to address this supply and demand coordination problem, as it relates to pre-positioning local supplies. While pre-positioning is not a new concept, as the military has used this for quite some time (Johnstone, Hill and Moore, 2004), it is

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becoming more realizable that pre-positioning is an effective strategy when planning response to natural or man-made disasters. Before the landfall of hurricane Katrina, the federal government implemented methods for pre-positioning supplies which were described as the “largest pre-positioning of Federal assets in history” (Townsend, 2006). The gulf coast states also initiated local efforts to pre-position responders and identify shelters in preparation for the storm. In general, pre-positioning is an activity which is performed prior to the event, in which locations are selected to store human or material assets in preparation for a future need. The pre-positioned supplies are subsequently used to satisfy the demand post-event. The model presented in this paper identifies a least-cost strategy associated with pre-positioning existing supplies that may be in a high risk path for a particular event.

Research in the area of humanitarian logistics can be classified based on the nature and timing of the decisions (post-event relief vs. preparedness). The nature of decisions can address distribution of relief supplies (Sheu, 2007; Yi and Ozdamar, 2007), stocking of relief supplies (Beamon and Kotleba, 2006a, 2006b; Lodree and Taskin, 2007), or location of supply centers (Jia et al. 2005, 2007). Beamon and Kotleba (2006a, 2006b) focus on inventory planning for a general type of humanitarian emergency. Lodree and Taskin (2007) incorporate information related to hurricane intensity, specifically wind speed data, into a stochastic inventory planning model. Rawls and Turnquist (2006) develop a more comprehensive model incorporating location, inventory and distribution decisions for a multi-product system. Studies such as Sheu (2007), Yi and Ozdamar (2007), and Jia et al. (2007), focus on post event relief and response, while the other models focus on preparedness activities. Several of the planning models that address the optimal placement of resources extend existing facility location and supply chain network design models to incorporate the uncertain characteristics associated with the disaster. Refer to Snyder et al. (2006) for a good discussion of network design models under uncertainty. Jia et al. (2007) develop a model to determine the location of medical services during large scale emergencies. They characterize large-scale emergencies as those that have a sizeable and sudden volume of demand and low frequency of occurrence. They introduce two parameters to characterize this uncertainty and propose location models to (1) maximize the demand covered by a certain number of facilities, (2) minimize the demand weighted distance between the new facilities and the demand points, and (3) minimize the maximum service distance. Rawls and Turnquist (2006) also incorporate location decisions in their model. They consider a multi-commodity pre-positioning and location problem to satisfy demand resulting from a hurricane. The objective is to find the number of new facilities to open, the size of the facilities and the purchase quantities associated with the three commodities considered. The problem is formulated as a stochastic mixed integer programming model with uncertainty in demand, damage to roads, and damage to facilities determined from hurricane scenarios. The research presented in this paper compliments the work done in this area and builds on the work of Rawls and Turnquist (2006). We consider a single commodity supply network that is already established and contains initial amount of inventory to satisfy demand due to normal operations. Therefore, no location decisions are made. We consider uncertainty in demand and available supply, and use a stochastic linear programming model to determine the placement of supply within the network to minimize supply loss. Uncertain demand in transportation planning has also been considered by Sumanta and Jha (2011) and Murakami and Morita (2010). However, this paper focuses on inventory placement and distribution, rather than vehicle utilization.

Stochastic linear programming models (SLP) are linear programming models where uncertainty associated with one or more of the problem data exists; and decisions must be made in such a way that they are balanced against the uncertain data scenarios. Decisions that can be delayed until after some of the un-
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