



Pre-positioning hurricane supplies in a commercial supply chain

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ABSTRACT

Inventory control for retailers situated in the projected path of an observed hurricane or tropical storm can be challenging due to the inherent uncertainties associated with storm forecasts and demand requirements. In many cases, retailers react to pre- and post-storm demand surge by ordering emergency supplies from manufacturers posthumously. This wait-and-see approach often leads to stockout of the critical supplies and equipment used to support post-storm disaster relief operations, which compromises the performance of emergency response efforts and proliferates lost sales in the commercial supply chain. This paper proposes a proactive approach to managing disaster relief inventories from the perspective of a single manufacturing facility, where emergency supplies are pre-positioned throughout a network of geographically dispersed retailers in anticipation of an observed storm's landfall. Once the requirements of a specific disaster scenario are observed, supplies are then transshipped among retailers, with possible direct shipments from the manufacturer, to satisfy any unfulfilled demands. The manufacturer's pre-positioning problem is formulated as a two-stage stochastic programming model which is illustrated via a case study comprised of real-world hurricane scenarios. Our findings indicate that the expected performance of the proposed pre-positioning strategy over a variety of hurricane scenarios is more effective than the wait-and-see approach; currently used in practice.

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1. Introduction

1.1. Disastrous hurricanes and emergency management

Hurricane Katrina was a daunting reminder that hurricanes represent one of Nature's most destructive forces. This catastrophic storm, which left a trail of destruction along the United States Gulf Coast in August 2005, was responsible for more than 1800 casualties, 250,000 displaced residents, and \$125 billion in expenditures making it the costliest disaster in United States history [1]. Although the significant environmental, socio-economic, and cultural repercussions of Hurricane Katrina are evident, disastrous hurricanes are certainly not a new phenomenon. For example, the 18th century storm known as the "Great Hurricane" claimed 22,000 lives throughout the Caribbean and is the deadliest hurricane of recorded history [2]. The deadliest hurricane in United States history was responsible for an estimated 8000 to 12,000 casualties in Galveston, Texas during the year 1900 [3]. More recently, hurricanes Ike, Gustav, and Dolly in 2008 and Dennis, Katrina, Rita,

and Wilma in 2005 each accounted for over \$1 billion in expenditures and numerous casualties [4].

The field of Emergency Management outlines a framework for protecting civilization from the adverse effects of natural and man-made disasters caused by hazards such as hurricanes, tornadoes, earthquakes, drought, and terrorist attacks. This framework entails the following functional areas: (i) mitigation, (ii) preparedness, (iii) response, and (iv) recovery. *Mitigation* refers to "a sustained action to reduce or eliminate risk to people and property from hazards and their effects" [5]. Mitigation activities focus on long-term solutions such as construction design and structural control (e.g., strengthening levee systems), and tend to be the most expensive emergency management options. In contrast to mitigation, *preparedness* targets short term activities directly related to response and recovery such as preparing large-scale evacuation plans or securing emergency supply items. The objective of the *response* function is to provide immediate short term relief following disaster by saving lives, protecting property, and meeting basic human needs. Activities include search and rescue, medical assistance, law and order, and immediate food and shelter. The final stage of the disaster-relief lifecycle is the *recovery* effort, which seeks to restore communities to pre-disaster conditions, and also to curtail future vulnerability. Examples of recovery activities include debris

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removal, rebuilding residential properties, and restoring businesses.

1.2. Pre-positioning

The focus of this paper will be strategic positioning of emergency supplies in anticipation of a threatening hurricane or other predictable hazard, which can be considered a cross-section of the preparedness and response activities of the Emergency Management framework described in Section 1.1. Pre-positioning is defined as the “stockpiling of equipment and supplies at, or near the point of planned use” [6]. Although originally applied within military contexts (e.g., [7,8]), public and private sector organizations have adopted pre-positioning strategies to prepare for civilian response and recovery operations. For example, the U.S. Federal Emergency Management Agency (FEMA) oversees a variety of permanent and temporary staging locations for pre-positioning commodities, equipment, and personnel. Permanent facilities include nine FEMA Logistics Centers, which are traditional distribution centers for commodities geographically dispersed throughout the Continental United States, as well as a number of commercial storage sites owned and operated by private firms [9]. On a smaller scale, locating ambulances and fire stations can also be considered a form of public sector pre-positioning (e.g., [10,11]).

Private sector firms implemented a most noteworthy application of temporary staging and pre-positioning in response to Hurricane Katrina. In particular, The Home Depot and Wal-Mart independently pre-positioned commodities at temporary staging locations near New Orleans prior to Katrina’s landfall in 2005 (e.g., [12]). As a result, emergency supplies, equipment, and personnel were readily available for initial response efforts in contrast to the government’s slow and uncoordinated response. The logistics response of Wal-Mart and The Home Depot to Hurricane Katrina accentuates the pivotal role of private sector firms in facilitating effective disaster relief operations, which is a perspective that has been acknowledged in the humanitarian logistics research literature.

2. Problem description: commercial pre-positioning of commodities

In an effort to encourage a critical mass of private sector firms to follow the lead of Wal-Mart and The Home Depot in responding to domestic disasters as described in Section 1, this study examines a humanitarian logistics problem from the perspective of a traditional profit-driven private sector firm. Specifically, the problem presented in this paper is motivated by a real-world supply chain scenario consisting of one manufacturer, multiple retailers, and one or more observed storms that threaten the consumers served by these retailers. The manufacturer produces items such as bottled water, non-perishable foods, or portable electronic devices that are in high demand during the hurricane season, especially in the presence of an ominous hurricane or tropical storm. In particular, it is common for retailers to experience a spike in demand for these and other emergency supply items during the inventory cycles that precede an observed storm’s probable landfall. Such “pre-storm demand surge” is predominantly driven by consumers who are preparing for emergency evacuation, or by consumers planning to “ride out the storm” and risk the inconvenience of potentially pervasive power outages. A temporary spike in demand can also be observed subsequent the actual landfall of a major storm as a result of disaster relief and recovery activities.

Based on conversations between one of the authors and supply chain managers from a manufacturing firm that encounters potential post-storm demand surge as described above, orders for

emergency supplies are typically initiated by retailers in response to a realized pre- or post-storm demand spike. In other words, the retailers served by this manufacturer exhibit a propensity for adopting reactive inventory policies that respond to an actual demand surge as opposed to proactive inventory policies that anticipate a likely demand surge. Such reactive approaches to stock control coupled with the delivery lead-times associated with order fulfillment often lead to widespread stockout of emergency supplies during peak demand surge periods, which in turn exacerbates the vulnerability of the populace affected by an approaching storm, inhibits post-storm response and recovery efforts, and proliferates lost sales and/or backorders for the above-mentioned supplier-retailer supply chain.

In order to alleviate the negative effects of supply shortages that often occur during pre- and post-storm demand surge periods, this paper will explore inventory pre-positioning strategies from the standpoint of the manufacturing firm described at the beginning of this section. The proposed pre-positioning strategy is characterized by a manufacturer that proactively pushes inventory upon geographically dispersed retailers in anticipation of pre- or post-storm demand surge, which is a strategy that contrasts the reactive wait-and-see approach indicative of current practice. After the storm subsides and actual demands become known, inventory is then transhipped among the retailers and manufacturer. Specifically, the following assumptions related to the sequence of events during the disaster relief/demand surge planning and response periods are considered for illustration:

1. The pre-positioning process is initiated three days prior to the landfall of an observed storm. For reference, this can be thought of as day 1. This three day allotment is assumed because (i) many National Hurricane Center forecasts are three day predictions and (ii) hazardous and congested road conditions are less likely to impede the pre-positioning effort.
2. On day 4, landfall occurs and landfall locations are impacted for a one day period.
3. Demands occur one day after landfall (on day 5) and are known with certainty by the end of the day. All shortages are back-ordered and replenished the next day. Therefore,
4. Redistribution of inventories through transshipment takes place on day 6, which is two days after landfall.

The proposed pre-positioning strategy assumes that the manufacturer bears all the costs and risks of pre-positioning, similar to vendor-managed inventory (VMI) systems. These costs may be attributed to production at the manufacturing facility, material handling at the manufacturing facility, and transportation of products from the manufacturer to the retailers. On the other hand, risks are driven by the uncertainty of which retailers will experience a demand surge for emergency supplies as a result of a storm making landfall at their location. These risks include the expected costs due to inventory shortages or excess inventory at each retailer location, and the possibility of additional transportation costs for redistributing improperly pre-positioned supplies. If there is a shortage of inventory at a retailer location, the items are backordered, and the manufacturer will incur a shortage cost representing loss of customer goodwill for not providing the item immediately after the effects of the storm have subsided. Additionally, conversations with the representative manufacturer also revealed the risk of a prohibitively constrained post-storm logistics system characterized by a scarcity of available third-party logistics providers (3PLs). This environment inhibits post-storm redistribution efforts, or significantly increases the cost of doing so. Within the above-mentioned context, this investigation will be driven by the following research questions.

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