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Inventory decisions for emergency supplies based on hurricane count predictions

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ABSTRACT

This paper addresses a stochastic inventory control problem for manufacturing and retail firms who face challenging procurement and production decisions associated with hurricane seasons. Specifically, the paper presents a control policy in which stocking decisions are based on a hurricane forecast model that predicts the number of landfall hurricanes for an ensuing hurricane season. The multi-period inventory control problem is formulated as a stochastic programming model with recourse where demand during each pre-hurricane season period is represented as a convolution of the current period's demand and an updated estimate of demand for the ensuing hurricane season. Due to the computational challenges associated with solving stochastic programming problems, recent scenario reduction techniques are discussed and illustrated through an example problem. The proposed model specifies cost minimizing inventory strategies for simultaneously meeting stochastic demands that occur prior to the hurricane season while proactively preparing for potential demand surge during the season.

1. Introduction

Planning inventories of supplies for the hurricane season can be challenging. For instance, in 2004, manufacturing and retail firms experienced stock-outs because they were not prepared for responding to the demand caused by several hurricanes that swept through southeastern United States. In 2005, these firms again experienced shortages due to the extreme demand surge caused by Hurricane Katrina. These experiences motivated firms to be pro-active and more aggressive in their approach to stocking hurricane supplies in 200. However, large amounts of excess inventory was commonplace because of an inactive season.

This paper introduces stochastic programming methodologies to investigate proactive inventory planning for the hurricane season based on an expert hurricane count prediction model. Demand predictions for the hurricane season during the pre-hurricane season planning horizon are assumed to evolve according to a discrete-time Markov chain. The approach allows the inventory manager to adjust inventory decisions as new information regarding the hurricane season and realizations of pre-hurricane season demands are acquired.

The stochastic inventory model is characterized by multiple periods before the hurricane season in which the inventory manager has the option to adjust the target inventory level of emergency supplies that should be available at the beginning of the ensuing hurricane season. During these pre-hurricane season months, manufacturing and retail organizations determine inventory levels that account for stochastic demands that occur during each period prior to the hurricane season as well as stochastic demand that will occur at the beginning of the season. The hurricane season demand predictions are revised at the beginning of each pre-hurricane season planning period, and these demand predictions are correlated to landfall hurricane count rate predictions. This multi-period stochastic inventory problem is formulated as a stochastic programming model. The solution specifies cost minimizing order/production quantities in which the decision-maker (DM) has flexibility to adjust the inventory policy based on updated hurricane season demand information and as pre-season demand realizations occur.

The paper is organized as follows: In Section 2, related work from the academic literature is reviewed. In Section 3, the stochastic programming model is presented followed by a discussion of how demand scenarios are constructed, which also includes a description of the selected hurricane count prediction model. In Section 4, optimal and heuristic scenario reduction strategies are discussed and illustrated through numerical examples. Finally, in Section 5, the paper is summarized, and ideas for further research are presented.

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2. Literature review

Papers from the supply chain and inventory control literature that address the following topics will be discussed in this section: information updating and sharing, humanitarian relief, and Markovian demand.

Information updating has consistently been an active area of research in inventory control theory. Therefore, only the recent research from the relevant literature is reviewed. For instance Tang et al. (2004) explore the benefits of "Advance Booking Discount" program that enables retailers to update demand forecasts and to respond demand fluctuations by replenishing stocks during the season. The optimal discount price that maximizes the retailer's expected profit is also discussed. Cheng and Wu (2005) examine the impact of information sharing on inventory and expected cost in a two-level supply chain with multiple retailers. Ray et al. (2005) evaluate a make-to-stock firm's different pricing policies to determine the profit-maximizing values for the decision variables. Initially, the price is considered as an independent decision variable, then a mark-up pricing policy is explored. Teng et al. (2005) develop a pricing/lot-sizing model for a retailer to whom the supplier offers a permissible delay in payments. Choi (2007) investigates a dynamic optimization problem that considers pre-season inventory and pricing decisions for fashion retailers to determine the optimal stocking policy. Wenkateswaran and Son (2007) examine the stability conditions for a production and inventory control system using *z*-transformation techniques considering the frequency of information updates. The stability of the system operating under sufficient and insufficient inventory is examined and stability boundaries are established. In another paper, Choi and Chow (2008) study an inventory management strategy called "Quick Response Program" that requires quick response to market changes by implementing a mean–variance approach. They examine various policies under which the supply chain as a whole will be better-off in terms of expected profit and risk. Finally, Wu and Cheng (2008) derive the optimal ordering policy for a three-echelon supply chain by considering information sharing on inventory and expected cost.

Qualitative descriptions of supply chain management for humanitarian relief have appropriately been the emphasis of this emerging area of research, which is more commonly referred to as *humanitarian logistics.* For instance, Beamon (2004) compares and contrasts the commercial supply chain and the humanitarian relief chain and identifies the unique challenges of relief logistics planning. Similarly, Kovács and Spens (2007) and Oloruntoba and Gray (2006) also describe the unique characteristics of humanitarian logistics while emphasizing that it would be beneficial to leverage best practices and lessons learned from commercial supply chains. Other researchers focus specifically on disaster relief. Kapucu (2007) examines the role of non-profit organizations with respect to responding to a catastrophic disaster via a case study while Smirnov et al. (2007) addresses the similarities of industrial environment and disaster relief operations in decision-making. A comprehensive synthesis of performance measurement in humanitarian logistics is presented in Beamon and Balcik (2008). They compare performance measurement in the humanitarian relief chain with in the commercial supply chain and develop new performance metrics for the humanitarian relief chain.

Only a few papers directly address inventory control problems that are related to humanitarian relief. Beamon and Kotleba (2006) consider a multiple supplier inventory model that determines optimal order quantities and reorder points for long-term emergency relief response. Lodree and Taskin (2008) introduce variations of the newsboy problem to assess the risks and benefits associated with inventory decisions related to preparing for supply chain disruptions or disaster relief efforts. Lodree and Taskin (2009) and Taskin and Lodree (2009) address inventory planning specific to hurricane events. The difference is that this paper focuses on inventory planning *before* the hurricane season, whereas the latter two papers investigate inventory decisions based on forecasts associated with an observed storm.

The inventory models where the demand distribution is defined via a Markovian process is also relevant to this research. It seems that Karlin and Fabens (1960) introduced the idea of Markovian demand to the inventory control literature. They claim that if each demand state is defined by different numbers, a base-stock type inventory policy can be obtained. Iglehart and Karlin (1962) prove that a base-stock policy is optimal for a demand process modeled by a discrete-time Markov chain. Song and Zipkin (1993) examine an inventory model in which fluctuations in the demand rate are represented by a continuous-time Markov chain. Beyer et al. (1998) show the existence of an optimal Markov policy for the discounted and average-cost problems where demand is unbounded and costs have polynomial growth. Cheng and Sethi (1999) examine an inventory-promotion decision problem in which the demand state is represented both by environmental factors and the promotion decisions. Hari and Graves (2001) consider a Markov-modulated Poisson demand process and determine closed-form approximations for both inventory and service levels. Finally, Chen and Song (2001) examine a serial multistage inventory problem with Markov-modulated demand.

This paper can also be described as an inventory model with more than one period to prepare for the selling season. The reader is referred to Silver et al. (1998) for an extensive list of references related to this problem. Some earlier papers are Murray and Silver (1966), Hausman and Peterson (1972), Bitran et al. (1986), Matsuo (1990), and Kodama (1995). More recent papers include Choi et al. (2004, 2006).

This paper addresses a stochastic inventory control problem faced by manufacturing and retail firms who expose to challenging procurement and production decisions triggered by hurricane events. The hurricane stocking decisions made in advance of the season are affected by the general predictions regarding the ensuing hurricane season. Hurricane season demand predictions, which are updated and observed at the beginning of each pre-season period, are considered in planning for emergency supply inventory levels as well as pre-hurricane season demand. The contribution of this paper to inventory theory in general is that the proposed model accounts for the possibility of reserving stock in a multi-period setting based on information updates about a demand surge that might occur in a future (and terminal) period, while also accounting for demand uncertainty associated with the current period. Another contribution is that unlike previous inventory models that explicitly incorporate hurricane predictions into demand forecasts, this model allows inventory decisions to be modified during the planning horizon. Finally, our model and its solution methodology contribute to empirical research by analyzing historical hurricane counts and observed index values. These data are used to predict landfall count rate probabilities associated with the upcoming season. The hurricane season demand distribution is ultimately described over these predicted values.

3. Stochastic programming model

The objective of this study is to determine an optimal ordering policy such that (i) demand in each pre-hurricane season period is met and (ii) reserve supplies are stored for the ensuing hurricane