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Inventory policies for humanitarian aid during hurricanes

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ABSTRACT

In this work we present a stochastic programming model minimizing costs, to support the decision process of inventory policy which best satisfies the demand for food in shelters when hurricane winds are about to impact a town. In this model we consider perishable products as well as the first in first out (FIFO) system for their consumption. In order to make the model closer to reality ordering cost is time-varying and we add a penalty cost in case the shortage exceeds a known limit for two days in a row. Finally the cost to dispose of expired food is greater than the purchase cost of the product since throwing away food has ethical implications. Starting from a stochastic programming model, we present a procedure to transform it to a deterministic mixed integer programming model (MIP) with non-convex objective function over its entire domain, which closely states the situation in reality. Preliminary computational results and discussion are presented.

1. Introduction

The objective of this work is to propose an inventory policy to support the special conditions faced by those who manage shelters when a natural event like a hurricane, source of potential damage, puts the population at risk. In the case of such event, government or non-profit organizations operate shelters for the people in the affected areas. In Mexico, in many cases, the intervention of the Army is required because of the magnitude of the disaster and because of their expertise in handling of these kinds of situations. When that happens, Officers from the Army, evaluate in rough numbers the situation, estimate the supplies needed as a first approach, take them from their own inventory and then move to the target. All this procedure can take around six hours to be ready to start supporting operations. Once they are in the affected region, they organize all the workers and shelters. The specialists evaluate the real situation: count all the people affected as well as their needs and ask for supplies from Headquarters on a weekly basis. When the Army takes control or when the local authorities take the relief efforts under their control, in both cases they follow special procedures to ask for funds from the Federal Government to support all these special works.

From all the products needed for shelters' operation we will focus on food. The inventory policy will be the result of a stochastic programming model that will represent the situation when the shelter's manager needs to place food orders – under probabilistic scenarios – that a distribution center must supply. Other works, e.g. Lodree and Taskins (2009) [10] was presented for general inventory problems for supplies such as flashlights, batteries, etc. However, to the best of our knowledge, there is no prior work on the food inventory problem based on the dynamic hurricane information.

The measure of performance for the problem is to minimize all the expected costs incurred during the inventory management as it is usually done in inventory control problems. However, the ordering cost is not a fixed number over the planning horizon; as the hurricane approaches, the ordering cost is much higher compared to the time periods after the hurricane strikes. In this model, the shortage cost is much greater than the purchase cost because a shortage will result in not being able to feed the refugees. We also include a disposal cost because the products have an expiration date. Finally, because the same shortage of food for two or more days in a row causes much bigger problems compared to the shortage for two days or more apart from each other, besides the shortage cost we include a penalty cost for shortage in excess for two days in a row; the underlying assumption is that the refugees can probably not withstand two days without food and if that happens, medical equipment should be mobilized to help them. Those two days in the penalization process can be easily modified to three, four or any other number of days as needed. The other difference given by the nature of the products is that our scenario refers to lost sales, which means the product in shortage will not be supplied later. It is important to remark that we will try

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to avoid the nonlinear representations, to keep the model relatively simple and solvable with readily available commercial software.

Some background information about the scenario developed in our work is described in the following paragraphs.

Tropical cyclones are natural phenomena originated in the tropical zones of the planet, integrated by great masses of winds moving clockwise or counterclockwise. Besides their rotational movement, they present a translation movement. Along their way toward the earth's surface, weather conditions produce changes in their speed. When the rotational speed reaches 118 km/h or more, the phenomenon is then called hurricane. Despite the benefit of the rain, a hurricane is a potential source of destruction that grows according to its intensity and to the vulnerability of the region that it is likely to hit.

Although all of us had heard about hurricanes and their devastation, it was not until Katrina's arrival in August 2005 that more people became aware of the importance of supply chain vulnerability and response; more than the events themselves, it was amazing to realize the lack of preparation authorities have to face the damage caused by hurricanes every year. The good news is that these events could be probabilistically predicted; scientists forecast the expected number and type of hurricanes that could arise every year, as well as their intensity and trajectory once every one of them appears.

Regarding food supply, in most cases this activity is carried on "whenever needed" basis; there is no previous or specific inventory decision support. Moreover, as Wassenhove (2006) [14] points out, this process is extremely complex. To understand the magnitudes, it is enough to take a look at the number of unsolicited donations, excess in emergency orders, saturation of terrestrial transportation and so on when an emergency situation occurs. As we will see in this paper, there are some attempts to improve this situation but nothing with the scope we are presenting.

In the next section previous works related to this topic are discussed; then we present the stochastic programming models we used to solve the problem. The models are presented according to the modifications they went through until we considered one model that accurately reflects the situation we wanted to represent; at the end we discuss the feasibility of the programming model and the convexity of the total cost function.

2. Literature review

To the best of our knowledge there is no paper related to inventory policies for perishable products in case of disaster. Altay and Green (2005) [1] did not find any work related to inventory management during disaster operations, however they suggest that future research in this area will be in the direction of "Decision rules about methodologies to apply on specific disaster problem". Beamon and Kotleba (2006) [2,3] wrote two papers about inventory models; they developed their work as an application to the South Sudan situation: people displaced because of continuous war. They found specialized handbooks which have been designed for the Health sector. Whybark (2007) [15] said that in the disaster relief inventories, the topic looks almost empty with the exception of the health service area. He presents some of the important differences between usual business inventories and disaster relief inventories. The differences are significant enough that impede the use of current inventory research as direct practices to relief disaster inventories management. Lodree and Taskin (2008) [9] developed variations to the newsvendor problem for one period in order to plan the inventory for the initial disaster response that some organizations face.

Some other documents related to hurricane relief topics are: Tarief (2007) [12] who in her dissertation presented a joint-location-allocation-inventory problem in order to solve the shelter planning problem, where density probability function of demand is known, one unit of supply is provided to each evacuee during all their stay at the shelter, trajectory of the hurricane could be predicted by a Markovian chain approach. The objective is to minimize total evacuation costs. The closest to the current topic was written by Lodree and Taskin (2009) [10] who present a method to solve the problem of how much to order and when to order by a manufacturer of non-priority product (flashlights, batteries, and gas powered generators) that experiences demand surge in the presence of hurricanes; they classify hurricanes into two classes: regular and extreme; the probability distribution of demand for both types of hurricanes is known. They present the problem as a sequential statistical decision problem based on a newsboy problem technique, Bayesian statistics and optimal stopping time. The major difference to our work is that the food as an inventory item is quite different regarding requirement and cost structure compared to other commodities as we described in the first section. Later, Taskin and Lodree (2010) [13] develop a multi-period inventory model where decisions are based on the number of landfall hurricanes forecasted for the whole ensuing season; the optimal order policy is such that it meets current demand and prepares for the potential surge in demand because of the hurricane season while keeping costs at minimum; they do not consider perishability.

Duran et al. [6] used a mixed integer programming inventory location model that minimizes average response time given an investment to decide how to configure the supply chain network in terms of warehouse location and quantity of inventory to pre-set in each one. This network is dedicated to supply relief products in case of a natural disaster worldwide.

In an attempt to classify inventory management articles published from 1976 to 1999 in specialized journals, Williams and Tokar (2008) [16] reported that from the 62 reviewed articles, just 5 considered stochastic demand, lost sales and none of them were developed regarding perishable products; the article that works with perishability is the one written by Bhattacharjee and Ramesh (2000) [4], where the objective is the profit maximization through a multi-period inventory and pricing model considering that the demand is deterministic and shortages are not allowed. Keisuke (2006) [7] presented a solution to the newsvendor multi-period problem where the objective function is to maximize the expected profit and where backlogs are allowed. Lee and Kang (2008) [8] proposed an MIP model that includes price quantity discounts and constraints related to storage space and lot size; they assume deterministic demand and then shortages are not allowed. Zhang et al. (2009) [17] and Singh et al. (2010) [11] included measures of risk in their models.

According to our research on available literature, this paper is the first to present an MIP programming model for the multi-period stochastic inventory problem for perishable products consumed using a FIFO system and developed to find the optimal ordering policy for products moving from a distribution center to a shelter opened in case of hurricane.

3. Model construction

The scenario where we propose to use the model is as follows: once a cyclone is observed and represents a potential danger for one town, the authorities in charge will follow the evolution of the event so they could decide at a certain moment whether or not to place an order to a distribution center and if so, determine how much to order. In the next paragraphs we will develop the mixed integer stochastic programming model, starting from the model that considers the objective function and the usual inventory balance constraints through the modifications needed to build the scenario we want to model.