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A hybrid inventory management system responding to regular demand and surge demand ☆

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ABSTRACT

This paper proposes a hybrid policy for a stochastic inventory system facing regular demand and surge demand. The combination of two different demand patterns can be observed in many areas, such as healthcare inventory and humanitarian supply chain management. The surge demand has a lower arrival rate but higher demand volume per arrival. The solution approach proposed in this paper incorporates the level crossing method and mixed integer programming technique to optimize the hybrid inventory policy with both regular orders and emergency orders. The level crossing method is applied to obtain the equilibrium distributions of inventory levels under a given policy. The model is further transformed into a mixed integer program to identify an optimal hybrid policy. A sensitivity analysis is conducted to investigate the impact of parameters on the optimal inventory policy and minimum cost. Numerical results clearly show the benefit of using the proposed hybrid inventory model. The model and solution approach could help healthcare providers or humanitarian logistics providers in managing their emergency supplies in responding to surge demands.

1. Introduction

Natural disasters (e.g., earthquakes, disease outbreak, volcanic eruptions, floods, tsunamis, storms, and hurricanes) and man-made events (e.g., massive accidents and terrorist attacks) may create surge demand for medicines or emergency items. Though the frequency of surge demand is very low, the demand volume per event could be high. Providing humanitarian relief supplies, such as water, food, medicines and associated services, to victims could be a major challenge due to the unpredicted nature of surge demand for these items and services. For example, in 2011 Haiti experienced an earthquake that was the biggest earthquake in the last two centuries and affected the capital city of Port-au-Prince. This earthquake frustrated the country because of the lack of a well-planned and coordinated distribution of relief supplies for weeks [1]. For this reason, we believe that disaster management teams are in need of tools that can help with responding in a timely manner to disasters by providing the necessary supplies and services [2]. A well-managed disaster planning could save lives, reduce financial loss, protect assets, facilitate recovery, and provide greater security and safety.

Since many medical items are critical to saving people's lives, healthcare providers or humanitarian organizations need to keep enough inventories for those incidents [3]. Managing the inventory of healthcare or humanitarian service related products is more challenging as compared to managing the inventory of products for regular manufacturing. In traditional manufacturing, if the demand forecasts are inaccurate or the order replenishment does not follow the plan, the results are delayed orders or at worst canceled orders. However, in healthcare delivery or humanitarian service, a shortage could mean a difference between life and death. Therefore, healthcare providers often have to maintain high service levels for life-saving items. This is achieved either by increasing the inventory level or through expedite shipments. Both approaches are expensive. In order to minimize the inventory holding costs, while maintaining high service levels, healthcare providers and their suppliers need to develop sophisticated and proactive inventory management policies for items that may face surge demand. When surge demand occurs in one region, rapid delivery of emergency items to the affected area is important. Such a short-term immediate response could incur high costs. A proactive inventory management system could minimize the occurrence of these shortage costs. Motivated by the issues stated above, this paper proposes a continuous-review hybrid inventory policy that relies on using regular orders and emergency orders in response to regular

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and surge demands to support humanitarian operations. The paper uses the level crossing theory (LCT) to obtain the long-run average cost under a given policy. A mixed integer program is developed to optimize the inventory policy parameters, including regular order point, emergency order point, and regular order quantity.

This paper contributes to the literature in the following ways. First, it provides a hybrid stochastic inventory model responding to regular demand and surge demand. An analytical model based on LCT is developed to derive the stationary distribution of the inventory level for a continuous-review inventory system characterized by 1) regular demand and surge demand, 2) variable lead time, 3) two reorder points and two types of orders, and 4) shortage cost. Second, this paper provides a new approach that incorporates LCT and mixed integer programming techniques to obtain the optimal inventory policy. Third, numerical experiments demonstrate the benefit of using the hybrid inventory policy to respond to regular demand and surge demand. Finally this paper extends the application of LCT by considering discrete inventory levels while most of papers in the literature considered the inventory level as continuous states when applying LCT.

The remainder of this paper is organized as follows. A review of the literature related to humanitarian logistics and inventory management facing combined demand patterns is presented in Section 2. The proposed hybrid inventory policy is modeled based on the LCT presented in Section 3. Section 4 formulates a mixed integer program based on the LCT model to optimize the proposed inventory policy. Numerical experiments and sensitivity analyses are conducted in Section 5. Section 6 concludes the paper and provides future research directions.

2. Literature review

Studies on planning and optimizing emergency item inventory management systems to support humanitarian operations have been mostly focused on strategic or operational planning. Inventory management is often considered together with location decisions and stochastic mixed integer programs (SMIP) are often used. Chang et al. [4] formulated two stochastic models for locating warehouses for emergency response in the aftermath of a flood. They developed a solution procedure to solve the flood emergency logistics preparation problems. Facility locations with inventory planning during disaster were studied by Balçik and Beamon [2]. They proposed a stochastic inventory control model that determines optimal order quantities and reorder points for a long-term emergency relief response. Balçik and Beamon [2] assumed that emergency orders are more expensive than regular orders. Similarly, Yu et al. [5] investigated the benefits of dual sourcing under the situation of increased demand during supply disruption. Lodree and Taskin [6] formulated a model for the question of 'appropriate readiness' regarding inventory planning that accommodates demand and extremely uncertain events. They worked within an insurance risk policy framework to find the optimal inventory for efficient disaster relief in the aftermath of a hurricane. Rottkemper et al. [7] presented a quantitative model and a solution approach for planning and optimizing the supply of a specific relief item to a given number of regions after the occurrence of a disruption or a sudden increase of demand. Ozguven and Ozbay [8] performed a case study-based approach to demonstrate the usefulness of a stochastic humanitarian inventory control model and estimation of the minimum safety stock levels of emergency inventories. They present a two-stage SMIP that provides an emergency response pre-positioning strategy for hurricanes or other disaster threats. Rawls and Turnquist [9] presented another two-stage SMIP that provides an emergency response pre-positioning strategy for hurricanes or other disaster threats considering uncertainty in demand for the stocked supplies as well as uncertainty regarding transportation network availability after an event. Campbell and Jones [10] examined the decision of where to preposition supplies in preparation for a disaster and how much to preposition at a location. Considering the supply location risks, they derived equations for determining the optimal stocking quantity and the total expected costs associated with delivering to a demand point from a supply point. A disaster may also cause supply disruption, pre-propositioning emergency inventory at certain supply locations with extra protection used to mitigate the disruption on the supply side, which often happen during large disasters [11]. Increasing the number of suppliers could mitigate supply disruption risk [12,13].

Stochastic inventory control with two types of demand classes has been studied over decades, resulting in a large body of the literature for various settings. Wang et al. [14] studied the rationing policy in an inventory system with two demand classes and different service criteria for backorders with a continuous review (R, Q) system. Kocaga and Alper [15] considered a single-echelon spare parts distribution system with two demand classes and proposed a static rationing policy that would ration stock to non-critical class. Other models studied continuous-review stochastic inventory models with two demand types [16–21]. Inventory control models with two types of demand classes under periodic reviews are studied by [22–27]. The mixture of demand processes has been studied by [28–30]. Azoury et al. [28] considered a continuous review inventory system where demand is a combination of a constant deterministic component and a random component that follows a compound Poisson process. Presman and Sethi [29] showed the optimality of an (s, S)-policy for a continuous-review stochastic inventory model with demand consisting of a compound Poisson process and a constant demand rate. Sobel and Zhang [30] considered a periodic-review inventory system with deterministic and stochastic demands assuming that the deterministic demand has to be satisfied immediately and the stochastic demand can be backordered.

Hybrid inventory policies with two reorder points and two order quantities have been the subject for a number of studies in the literature. Emergency orders may help to reduce backorder [31]. In the context of continuous-review inventory systems Moinzadeh and Nahmias [32] considered a policy with four decision variables, regular reorder level, emergency reorder level, regular order quantity, and emergency order quantity. Under the assumption of full backorder, constant but different lead times for two order types, and at most one outstanding order of each type, they derived an approximate expression for the average cost per unit time and heuristically provided the procedure of determining four decision variables. Mohebbi and Posner [33] developed a model with non-unit-sized demands that also has four policy parameters, regular order quantity, emergency order quantity, regular reorder point, and emergency reorder point. They presented an explicit expression for the average cost rate function under the following assumptions: a compound Poisson demand process, at most one outstanding order of each order type, and exponentially distributed lead time. There are other continuous-review inventory models involving emergency orders closely related to our model [34–38].

Johansen and Thorstenson [34] considered the problem of determining (R, Q) for a single item inventory system in which emergency replenishments are also available in addition to regular inventory replenishment. Axsater [35] derived a new decision rule for emergency orders under compound Poisson demand. Given the reorder point and lot size for regular orders, and based on real-time information regarding the remaining delivery time, he developed a heuristic decision rule to determine the timing and size of the emergency orders. In another study Huang et al. [36] extended the work of Axsater [35] by focusing on an online retailer facing demand that depends on the committed service time and assuming