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Mitigating the impact of drug shortages for a healthcare facility: An inventory management approach

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ABSTRACT

Despite the importance and value of the pharmaceutical market, a significant portion of procurement spending including pharmaceuticals are lost. Coupling poor and reactive management practices with the inevitable national drug shortages, leads to lack of medicines causing patient suffering and direct life or death consequences. In this paper, we propose a stochastic model to find the optimal inventory policy for a healthcare facility to proactively minimize the effect of drug shortages in the presence of uncertain disruptions and demand.

1. Introduction

According to the World Health Organization (WHO), the United States has the highest healthcare expenditure in the world with $750 billion spent in the global pharmaceuticals market (Boerma, AbouZahr, & Ho, 2009). The United States pharmaceutical market itself is valued at around $306 billion (mar, 2010), with an annual growth of approximately 5 percent. However, a significant percentage of procurement spending (including pharmaceuticals) is known to be lost due to poor management practices around the world (Boerma et al., 2009). Inline with this report, Landry and Philippe (2004) estimate that 48 percent of the costs in the pharmaceutical supply chain can be avoided by better management.

Poor management practices in pharmaceutical supply chain also lead to significant shortages and inefficiencies in the delivery of critical healthcare supplies. A shortage occurs when a product is not commercially available in a sufficient quantity to meet the demand. Arbitrary selection of inventory policies, combined with national drug shortages, cause unavailability of drugs which pose a direct threat to the quality of care received by a patient. Unavailability of drugs also result in patient treatment times being prolonged or procedures (e.g., surgeries) being canceled. Specific examples of medical consequences for critical shortages can be found in Landis (2002).

The majority of the experienced shortages impact oncology drugs and inpatient pharmaceuticals. Recently, National Analysts Worldwide, a marketing research and consulting company, has conducted a survey on the impact of drug shortages on cancer care (Maas, 2012), that reveals 40 percent of oncologists had seen patients die sooner and 95% of physicians had a patient who was unable to receive timely treatment due to drug shortages.

Shortages of drugs can also have serious monetary implications. Medical professionals devote substantial time to find alternatives for drugs in shortage by investigating effects of substitute drugs. Meanwhile, medical staff spends additional time for finding drugs in shortage from other institutions or making new contracts with wholesale distributors for substitute drugs.

Considering the importance of the shortages both from quality of care and cost standpoint, our goal is to minimize the impact of national shortages for hospitals. A national drug shortage occurs as a result of raw material unavailability, manufacturing/regulatory issues, *inventory practices*, unexpected increases/shifts in demand, and natural disasters (Fox et al., 2009). As most of these causes are inevitable, we aim to better manage inventory in a hospital to minimize shortages and maximize quality of care. In this paper, we highlight the positive effect of minimizing the cost of shortage and substitution in conjunction with conventional costs (ordering, inventory holding) by adjusting the inventory related parameters for a hospital.

The remainder of the paper is organized as follows: Section 2 reviews relevant approaches in the supply chain management and inventory control literature. Section 3 presents our mathematical optimization framework that aims to minimize the expected total cost

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under the presence of uncertain national shortages on both mainstream drugs and substitutes. A heuristic solution algorithm for the model is presented in Section 4. Section 5 provides computational results and compares the proposed inventory policy with currently employed policies of two healthcare facilities. Concluding remarks are presented with directions for future research in Section 6.

2. Background

A pharmaceutical supply chain typically consists of four main levels: chemical plants, pharmaceutical plants, distribution affiliates, and healthcare facilities (Burns, 2002; Fox et al., 2009). The pharmaceutical shortage can be addressed through varying strategies introduced in each of these levels. Among the four pharmaceutical supply chain levels, the one that is most affected by shortages is the healthcare facility (e.g., hospital), which is in direct contact with patients. Despite the important role of the hospital in solving the problem of pharmaceutical shortages, formulating strategies for hospitals has been given little attention by researchers. This is likely a result of the complexity of the problem, involving the hospital size, geographic location, diversification, and various specializations (DeScioli, 2005). The study of pharmaceutical supply chains has typically been approached from either managerial analysis or quantitative modeling (Jaber, 2009). Managerial approaches include outsourcing (Li & Benton, 1996; Nicholson, Vakharia, & Erenguc, 2004), vendor managed inventory (VMI) (Kim, 2005), supply chain integration (Meijboom & Obel, 2007), and risk management in pharmaceutical supply chains (Breen, 2008).

Inventory investments in the healthcare industry are estimated to be between 10 percent and 18 percent of net revenues (Holmgren & Wentz, 1982; Nicholson et al., 2004). This percentage is even higher when considering hospitals only. Nathan and Trinkaus (1996) estimate the inventory management costs at anywhere between 17 percent and 35 percent of a hospital's total revenue.

It is noteworthy that general (non-healthcare) models have limitations for managing a pharmaceutical inventory. First and foremost, the primary goal of a healthcare facility is usually maximizing the *quality of service/care* rather than minimization of conventional costs (e.g., inventory holding, ordering). This does not imply that these services have no cost nor does it imply that inefficient management is acceptable. However, there are drastic differences in the perspectives of a production facility versus a healthcare facility. *Shortage* and *substitute* costs are expected to be more significant compared to *inventory holding* and *ordering* costs in a healthcare facility due to potential health consequences.

The second aspect that differentiates the pharmaceutical inventory is the cruciality of demand satisfaction. Shortages in pharmaceutical supply chains affect patients' lives directly, therefore must be avoided. In production or other service supply chains, shortages cause lost or backlogged customers (or might even attract some customers), which has a relatively low (or in some cases opposite) effect compared to the healthcare sector. Another aspect that sets pharmaceutical inventory management apart is that some of the items in shortage may be substituted with alternatives. Furthermore, in this study, zero fixed ordering cost and zero lead time are considered as a delivery vehicle visits our collaborating healthcare institution every day. To the best of our knowledge, a model that aims to minimize shortage and substitution costs where uncertain shortages are present in the form of *supply disruptions* has not been studied in the literature.

There exist several models in the inventory management literature that are somewhat relevant to the proposed work. First, Dellaert and van de Poel (1996) introduce an economic order quantity model for inventory control of an academic hospital in the Netherlands. Jayaraman, Burnett, and Frank (2000) focus on ideas to improve the flow of materials in a healthcare facility. Lapierre and Ruiz (2007) develop a model that optimizes the inventory control and logistics scheduling in a multi-echelon inventory problem to minimize inventory costs and balance the workload over the weekdays.

These models, however, do not take the uncertainties in the supply chain into account. Uncertainty can be short-term or long-term based on the time-frame over which the uncertainty affects the system (Subrahmanyam, Pekny, & Reklaitis, 1994). Long-term uncertainties such as demand uncertainty and changes in availability of a pharmaceutical item can be considered in inventory control models to find the optimal ordering policy to minimize shortages. There also exist short-term uncertainties such as recessions but this is outside our scope of work. We focus on long-term uncertainties in a hospital such as uncertainty in demand and uncertainty in supply in the form of disruptions due to material unavailability, manufacturers' production decisions, Food and Drug Administration (FDA) approval strategies etc.

Demand uncertainty is one of the major challenges in pharmaceutical inventory planning (Fox et al., 2009). Demand uncertainty is studied in forecasting studies (Syntetos, Boylan, and Disney, 2009; Syntetos, Nikolopoulos, and Boylan, 2010; Willemain, Smart, and Schwarz, 2004; Zhao and Lee, 1993) and in inventory control theory (Sani & Kingsman, 1997). Poisson process is widely-accepted for customer arrivals in the literature due to its appropriateness of assumptions (i.e., individual arrivals), except a few studies where compound Poisson distribution (e.g., negative binomial distribution) is more appropriate (Sani & Kingsman, 1997; Syntetos et al., 2009).

Supply uncertainty is presented in two forms in the literature: *yield uncertainty* and *disruption*. Yield uncertainty is considered when the quantity of supply delivered is a random variable and can deviate from the order quantity. Disruption is considered when the supply is subject to partial or complete failure. Disruptions are typically modeled as events which occur randomly and may have random length.

Table 1 shows some of the studies that have introduced inventory control problems with supply disruption. These studies consider disruptions of different forms (e.g., random disruptions from the supplier, natural disasters destroying the inventory etc.), different assumptions on lead time, and demand cancellation. Inventory planning can be modeled for a single or multiple period or more generally for an infinite-horizon. Demand on the other hand can be deterministic, random, or deterministic with dynamic numbers. Different inventory control policies in the studies are Economic Order quantity (EOQ), (s, S), (Q, r) and (Q, r, T) (Nahmias, 2008). EOQ model finds an optimal order quantity to minimize the costs. In an (s, S) policy, inventory is checked periodically and if the inventory level is below a certain level (s), a replenishment will take place to restore the inventory level to maximum level (S). (Q, r) policy finds a fixed replenishment point r and continuously tracks the inventory level. Whenever the inventory level falls below r, an order of quantity Q will be placed. (Q, r, T) is a (Q, r) policy except for the time T that the decision maker should wait before the order is placed if the previous order was placed during a supply disruption. We do not elucidate the contribution of each paper separately, but only present key differences.

Furthermore, there are studies that use integrated modeling for inventory and transportation decisions (Geunes & Zeng, 2001; 2003) investigating the effect of backlogging and expediting policies on inventory and transportation costs.

As mentioned above, another unique aspect of pharmaceutical supply chains is *substitution* (cde, 2006). When considering alternatives for therapies, some may be comparable, whereas others are not ideal considering side effect profiles. Numerous examples of mainstream/substitute drug pairs with varying levels of