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Logistics planning for hospital pharmacy trusteeship under a hybrid of uncertainties

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ABSTRACT

This paper presents two medicine logistics planning models by using a time-space network approach, one with deterministic variables and the other with stochastic variables. Flow dependent variable costs, random demand and random service time are featured in our models in addressing economies of scale and uncertainties in a real-world medical logistics problem. Effective computational schemes are designed, and an evaluation method is proposed to derive and assess a solution to the models. Numerical tests are conducted and show promising results for applications to a real-world problem.

1. Introduction

Medicine logistics planning is a major part of operations management in a hospital that is responsible for the procurement of medicine, setting order quantities and order times, scheduling shipping, the in-house distribution of medicine, and determining the safety stock and service level for the medicine. This study is partly motivated by the concerns of practical medicine logistics operations in many hospitals in China. Because of the culture and the current prevailing health insurance plans in China, most people go to the hospital to see a doctor and obtain prescriptions from the hospital pharmacy rather than going to a community health care center for even mild illnesses, such as a cold. The statistics show that more than 90% of patients purchase their medicine in a hospital pharmacy with a doctor's prescription instead of using retail pharmacies outside of the hospital. Therefore, medicine inventory levels in most hospitals remain high year round, blocking capital flow and increasing the risk of medicine expiration.

In the past decades, two main capital sources were presented in maintaining a high-level inventory of medicines in hospitals: government funding and medicine revenue generated by hospital pharmacies. Government authorities allow hospitals to make a 15–20% profit on medicine sales. For example, the wholesale price of a box of amoxicillin capsules is 15 CNY, and the retail price in the hospital's pharmacy may be 16–18 CNY. However, due to the lack of supervision, the actual retail price of amoxicillin capsules can reach 26–30 CNY in some hospitals.

The Chinese government has been in the process of implementing medical and healthcare system reform, which prohibits hospitals from profiting from medication sales, which means that a hospital's pharmacy will become a not-for-profit department and can no longer generate medicine-related revenue. This is the reason why many hospitals are looking for out-

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sourcing solutions, such as the hospital pharmacy trusteeship (HPT) scheme. HPT is a vendor-managed inventory approach. In this scheme, the internal pharmacy of a hospital will be outsourced to and managed by a pharmaceutical company, which is responsible for ensuring the timely replenishment of the hospital pharmacy's stock and maintaining the required medical service level (Shao and Ji, 2006). Therefore, it is in the core mission of HPT to develop a stable and economic medicine logistics plan to minimize operation costs while ensuring supplies maintenance and managing a combination of uncertainties. However, a stable logistics plan is always disrupted by the following factors.

(1) The first influencing factor is uncertain demand. Although electronic purchase systems and decision support systems are used in medicine inventory management in most Chinese medical institutions, important parameters for decision-making, such as the order quantity, order point, and safety stock, are manually determined by staff members based upon his/her experience. Since most patient requests in a hospital are stochastic and time-varying, experience-based schedules are often insufficient or ineffective in meeting the actual demand. In lacking a systematic analysis and optimal decision making mechanism, the fear of stock-out drives the stock level to be consistently high.
(2) The second factor is the uncertain service time. "Service time" in this paper is a general term (similar to the lead time) that is defined as the total time from when an order is placed until the order is received. This includes the order processing time, sorting time, packaging time, loading and unloading time, and transportation time. Many of these operation links can experience unexpected delays, such as traffic congestion, resulting in the actual receipt time being far from the planned service time. Therefore, designing robust medicine logistics planning entails explicitly addressing the uncertainty in the service time.
(3) The third factor is the variable service cost. Although the price of a medicine does not vary, its cost varies because of the wholesale discount price. Therefore, there are economies of scale in production and distribution. The unit service cost is not a fixed constant but is dependent on the flow in the service arc.

This paper develops two medicine logistics planning models based on a time-space network approach, one for deterministic variables and the other for stochastic variables. Most research on this topic in the existing literature tends to either address demand uncertainty or only service time uncertainty. The SPM model proposed in this paper studies both uncertainties in a unified framework. Meanwhile, the penalty for the time error between the planned service time and actual service time is also introduced into our model for the first time. Incorporating the penalty on an early or late arrival of a delivery into the objective function can effectively reduce excessive holding and shortage costs, as shown in our numerical examples, and further yields an optimal solution as a more robust logistics plan. Our models employ variable service costs accounting for possible economies of scale, such as wholesale price, consolidation in order processing and transportation. This is another step forward toward the reality of modeling with flow independent service costs in the previous works.

The rest of this paper is organized as follows. Section 2 provides a brief review of the related literature on this topic. Section 3 presents the time-space network for the medicine logistics planning and develops two mathematical models, one for deterministic and one for stochastic variables. Section 4 designs an algorithm to effectively solve the optimization models and proposes an evaluation method to assess the solution. Numerical tests are conducted in Section 5, and the conclusion and suggestions for future research are presented in Section 6.

2. Literature review

2.1. VMI in hospital

The VMI strategy originated in the U.S. in the 1980s; early adopters of this strategy included large retailers such as Wal-Mart and JC Penney (Çetinkaya and Lee, 2000). However, most of the existing studies addressing the issue of VMI have focused on manufacturing firms and retailers (Park et al., 2016). The literature has largely ignored the application of the VMI system within the healthcare domain.

In recent years, some studies highlight the advantages of implementing the VMI system in the hospital's pharmacy. Kim (2005) discussed the adoption of the VMI system between a wholesaler and a hospital warehouse in South Korea. The VMI system has several advantages, the most significant one being a reduction of the inventory level. Furthermore, it decreases the workload of the pharmacy staff in the hospital and facilitates information integration between the wholesaler and the hospital. Tsui et al. (2008) also stated that the VMI can help the hospital reduce the number of required staff members, reduce stock holdings and improve customer service. According to their report, 3.5 full-time equivalent staff members were redeployed to clinical pharmacy support duties, and the stock holding decreased by $352,000. Lin and Sun (2009) developed a mathematical model based on VMI to describe the supply chain in a hospital. They proposed a quantitative model of a two-stage supply chain to compare the inventory cost of hospitals and their suppliers before and after the adoption of VMI. Through a quantitative comparison, it is confirmed that the adoption of VMI can effectively reduce the overall inventory cost of the hospitals and the supply chain. Mustaffa and Potter (2009) also suggested that the application of a VMI system leads to higher customer service levels (i.e., delivering the correct quantity of the product to the clinic) and improvements in key supply chain variables such as decreasing stock-outs and eliminating the bullwhip effect.