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Innovative Applications of O.R.

The 2Bin system for controlling medical supplies at point-of-use

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ABSTRACT

The increase in cost of supplies and services is outpacing the increase in revenues at many hospitals. To address this cost increase hospitals are seeking more efficient ways to store and manage vast inventories of medical supplies. A parsimonious and efficient inventory system which we call 2Bin is becoming increasingly popular in North American hospitals. Under the 2Bin system inventory is stored in two equal-sized bins. 2Bin systems are reviewed periodically and empty bins are replenished. In recent years the adoption of RFID technology for 2Bin systems is allowing continuous-time tracking of empty bins, increasing inventory visibility. In this paper we model the 2Bin inventory system under periodic and continuous review. For periodic review we show that the long-run average cost per unit time is quasi-convex, enabling a simple search for the optimal review cycle. For continuous review, we present a semi-Markov decision model, characterize the optimal replenishment policy, and provide a solution approach to obtain the long-run average cost per unit time. Using data obtained from hospitals currently using RFID-enabled 2Bin systems, we estimate the economic benefits of using the best periodic review length (i.e., parameter optimization), and of using a continuous review inventory policy (i.e., policy improvement). We characterize system conditions such as the number of medical supplies used, replenishment costs, stock-out costs, etc. that favor each option, and provide insights to hospital management on system design considerations that favor the use of periodic or continuous review.

1. Introduction

Hospitals are part of complex supply chains including purchase, storage, distribution, and inventory control of drugs and medical supplies. Several factors increase the complexity of hospital supply chains, including the large variety of items used by clinicians. Hospitals often manage hundreds of different items. Inventory availability is critical for patient care. However, high inventory levels increase costs and create a significant economic impact for the hospital. In North America, more than 40 percent of hospital expenses are related to supply chain activities (AHRMM, 2010). While excess inventory is undesirable, enough inventory must be available to avoid disruption to nursing activities that may hinder patient care. Per the report by Meyer and Meyer (2006), one of the future research areas in health care delivery is the study of inventory management practices within hospitals.

In response to the need for storing and managing a large number of low-cost but critically important medical supplies, hospitals have relied on inventory systems such as exchange carts and automated storage cabinets. The use of automated storage cabinets has increased in recent years (Pedersen, Schneider, & Scheckelhoff, 2009), but given the capital investment these systems require and the limited storage space available, many hospitals are using this technology mostly to store and dispense drugs or expensive supplies. In contrast, the inventory system studied in this paper provides an efficient yet simple way to control and dispense hundreds of high-volume, low-cost items without investing in expensive storage units (Denton, 2013).

We use the term 2Bin system to denote an inventory-control method similar to a kanban system in which an item's inventory is divided and stored in two bins (Hall, 2012). Under a 2Bin inventory system only empty bins are tracked in lieu of unit-level item consumption. This reduces the data collection costs and the inventory control parameters are on bin level as well, such as the bin replenishment frequency or the number of empty bins that trigger a replenishment. More traditional inventory replenishment policies found in the literature are on unit level, which require unit-level demand tracking and inventory control parameters per item, such as reorder points and order-up-to levels (Rosales, Magazine, & Rao, 2014a; Khouja & Goyal, 2008).

In our experience with 2Bin systems, bins are usually denoted as primary and secondary. Although the number of units contained

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in each bin will differ by item, the primary and secondary bin of the same item have equal capacity. For each item the amount of inventory stored in a bin is typically determined based on the number of desired inventory turns per year. Bins are usually located back-to-back in racks with the secondary bin placed behind the primary bin. When the primary bin is exhausted, it is removed from the racks, and the inventory in the secondary bin becomes available. When the empty primary bin is replenished the bins are exchanged, i.e., the secondary bin becomes the new primary bin, supporting product rotation, and the recently replenished bin becomes the secondary bin. Traditionally 2Bin inventory systems used in hospitals are replenished using periodic reviews (Landry & Beaulieu, 2010), with empty bin replenishments carried out at the beginning of every review interval, usually once daily.

Although the simplicity of 2Bin systems allows hospitals to efficiently replenish a large number of items, policy parameters such as replenishment frequency are often based on values historically used and are typically suboptimal. Performing the replenishment of empty bins requires time from materials management personnel, incurring a fixed cost for each replenishment carried out. In addition, materials management personnel has a limited availability to perform the replenishments. On the other hand, replenishments avoid stock-outs, which can be costly as nurses typically waste valuable time obtaining any items that are short, potentially disrupting patient care. To balance fixed order costs and stock-out costs can be challenging. One of the goals in this paper is to find optimal values for the periodic review interval to improve the inventory systems of hospitals that use a periodic review 2Bin system.

Hospitals are investing in technology such as RFID or barcodes in order to avoid stock-outs, to reduce inventory cost of supplies and to increase inventory tracking. Item-level RFID tags can be prohibitively expensive for low-cost items but not for bins (Johnson & Lee, 2002). The second goal in this paper is to study the use of RFID tags on hospital bins. This research is motivated by our interactions with consulting company Logi-D (www.logi-d.net/en/) which developed such a system, called the 2BIN-iD system. In the 2BIN-iD system a passive radio frequency identification (RFID) transponder is attached to each bin. When a bin becomes empty, the passive RFID tag is removed and placed on an RFID-enabled replenishment board that has an RFID reader capable of reading all tags on the board. The replenishment board is connected to the IT network alerting the system that a product is due to be replenished, which increases inventory visibility. The use of this technology provides hospital management the opportunity to achieve additional economic benefits by using a continuous-review 2Bin system.

Hospitals currently using traditional 2Bin systems have two alternatives to improve their inventory management practices, (1) parameter optimization—starting with a typical hospital periodic review system and optimizing parameters such as the periodic review interval, or (2) policy improvement—changing to a continuous review policy with the use of technologies such as bin-level RFID or barcodes. Therefore the two goals in this paper are referred to as parameter optimization and policy improvement, respectively. We model the 2Bin system under both periodic and continuous review. The periodic review model provides a performance benchmark representing current hospital practice and it allows us to estimate the cost benefit of optimizing the periodic review interval. To achieve this, we show that the long-run average cost per unit time is quasi-convex in the review interval, enabling a simple search to obtain the optimal review cycle length. Conversely, the continuous review model allows us to estimate the benefits of using a new inventory policy enabled by the presence of new technology, we present a semi-Markov model to characterize the optimal policy (i.e., find the optimal number of empty bins over all items that should trigger a replenishment), and to provide an approach to estimate the optimal long-run average cost per unit time. We use data from hospitals currently using 2BIN-iD systems, to conduct a performance comparison between both types of review systems as well as a sensitivity analysis.

In the sensitivity analysis, the following questions are answered: When is the benefit of using a continuous-review policy sufficiently greater than the benefit of using an optimal periodic review policy to warrant investments in new continuous-review technology? How are the relative benefits of using new technology affected by system conditions such as the number of stocked medical supplies, the cost of performing a replenishment, or the cost of material stock-outs? In addition our study allows hospitals to evaluate the cost impact of having several storage locations with few items or fewer storage locations with more items, and how these costs can be affected by using optimal periodic or continuous review policies.

This paper is organized as follows. In Section 2 we review the literature, in Section 3 we describe the 2Bin system and introduce basic notation and assumptions common to both periodic and continuous-review models. In Section 4 we present closed form expressions for the average cost per unit time under periodic review as well as a Golden Section search approach to estimate the optimal periodic review interval. In Section 5 we present a semi-Markov decision model for the continuous-review 2Bin system, as well as a proof of the optimal replenishment policy. We also present a linear programming approach to obtain the optimal threshold value for the continuous-review 2Bin system. In Section 6 we provide a numerical comparison of both models, and finally in Section 7 we summarize our findings and indicate future research directions.

2. Literature review

2Bin systems have been in use at hospitals since the 1980s, and kanban-type inventory systems are widely used particularly in lean manufacturing environments. Inventory models in the literature that are closest to the periodic review 2Bin systems are (nQ, r, T) replenishment policies. In such policies, every T time periods an order is placed whenever the inventory position falls to or below reorder level r. The order size is always and integer multiple of Q such that the inventory position exceeds r after ordering. This policy can be mapped to the 2Bin formulation by setting $r = Q$ equal to the bin size capacity. Inventory systems with the (nQ, r, T) policy are first studied by Hadley and Whitin (1963). However, the authors require a fixed order cost per item and it is based on unit-level demand (assumed to be Poisson distributed). Larsen and Kiesmüller (2007) study the same single-item inventory policy using a generalized Erlang distribution.

In the hospital setting, a fixed order cost is incurred per replenishment order regardless of the number of items or number of units ordered. Therefore, our work is related to the joint inventory replenishment literature. Research on multi-item replenishment policies with stochastic demand include the work of Balintfy (1964), Renberg and Planche (1967), Atkins and Iyogun (1988), Pantumsinchai (1992), Viswanathan (1997), Rao (2003), and Özkaya, Gürler, and Berk (2006) among others. Khouja and Goyal (2008) provide a detailed discussion of these papers. More recently Mustafa Tanrikulu, Sen, and Alp (2010) consider a multi-item inventory system in which the setup costs for orders have a step-wise structure. The authors propose a new $(\mathbf{s}, Q)$ policy, where $\mathbf{s} = \{s_1, s_2, \ldots, s_N\}$ representing a vector of reorder levels for each item in the system. Under this policy a combined replenishment order of size Q is triggered whenever the inventory of one item falls to its corresponding s_i value. Under the $(Q, \mathbf{S})$ policy proposed by Renberg and Planche (1967), whenever the combined demand of all items reaches a value Q, an order of size Q is placed to raise the inventory position of all items up to the vector $\mathbf{S} = \{S_1, S_2, \ldots, S_N\}$. The $(\mathbf{s}, Q)$ policy outperforms the $(Q, \mathbf{S})$ when back-order costs are high and lead times are short. None of this multi-item research deals with kanban-type 2Bin inventory systems that we study in this paper.