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Using RFID for the management of pharmaceutical inventory — system optimization and shrinkage control

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ABSTRACT

Motivated by a case study at a radiology practice, we analyze the incremental benefits of RFID technology over barcodes for managing pharmaceutical inventories. Unlike barcode technology, RFID enables accurate real-time visibility, which in turn enables several process improvements. We analyze the impact of automatic counting and discuss the system redesign critical to optimizing the inventory policy and eliminating shrinkage. We show that continuous review is superior to periodic review whenever accurate real-time information is available at no additional cost. We explain how RFID-enabled strategies vary with inventory parameters and provide a cost-benefit analysis for the implementation of RFID for the radiology practice.

1. Introduction and motivation

Motivated by a case study conducted at the radiology practice of a major hospital network in Florida, we analyze the incremental benefits of RFID technology over barcodes in the context of pharmaceutical and drug inventory management.

Healthcare has unique and strict guidelines for managing its drug supply chain. E-pedigree requirements and state and federal laws and regulations necessitate that information about the manufacturer, lot numbers, complete shipping information, dosage, etc., be registered in a drug's tag. These regulations seek to protect public health by reducing counterfeiting and facilitating product recalls in the drug industry. Although barcodes help increase security by permitting the tracking of drugs, they are not unique codes that can help pinpoint an item in its distribution network, and they do not have high data storage capacity to provide detailed information about an item; moreover, unless an item's barcode is scanned, its tracking records cannot be updated. Barcodes also have intrinsic scanning problems, creating inaccurate inventory records [11,32].

Within the broad topic of supply chain management, pharmaceutical and drug inventory management also differs from inventory management in other sectors. Drug inventory is closely scrutinized, and drugs are kept in small, locked storage cabinets after delivery. Moreover, certain pharmaceuticals and drugs are expensive and perishable. While the strict regulations on shipping and delivery increase the administrative costs of ordering, the unique item features and secure storage requirements increase holding costs. Certain drugs or items are also required in particular procedures and surgeries (e.g., contrast media to enhance the picture quality of an MRI or blood units in a surgery). Therefore, since a drug shortage can lead to low utilization of machines, doctors, and technologists or, in extreme cases, harm to a patient, stockouts can be extremely expensive.

Before implementation of RFID, the radiology practice used barcode technology to monitor its inventory of contrast media vials. Most of the process was handled by a technologist who checked medical records, scanned barcodes of vials before administration, manually counted the number of vials in stock, and reordered weekly. These manual processes were creating serious operational problems: (1) exam mismatches (i.e., executing a job on the wrong patient), (2) adverse drug events (e.g., administering the wrong dosage), (3) stock and billing issues, and (4) shrinkage (e.g., content expiration caused by failure to use a previously opened vial).

Unlike barcodes, RFID provides accurate real-time visibility of inventory status at the individual item level, as each item has a unique id tag and hence a corresponding unique inventory record. When inventory records are inaccurate and no real-time visibility exists (i.e., under barcode technology), organizations have to use *manual counting* and *periodic review* of items to reconcile the actual inventory on hand and the inventory record. In contrast, when inventory tracking is accurate and timely, managers can implement *automatic counting* and *continuous review* of stock levels. Moreover, being able to identify each item uniquely ensures that any change in the state of an item is automatically registered in the inventory record system (e.g.,

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imminent expiration of a partially used drug vial).[1] An inventory manager therefore can additionally benefit from RFID by employing *automatic counting*, *policy improvement* (shifting from *periodic to continuous review*), and *shrinkage tracking*. The real life practices of RFID implementation in the healthcare industry, however, show that most appreciate only automatic counting and hence lose the potential for larger savings. Our paper shows how cost savings from policy improvement and shrinkage tracking are more important than automatic counting alone by comparing two scenarios: an inventory manager (1) employs old operational strategies and is content with only reducing the cost of counting inventory, or (2) also leverages the technology by changing the inventory control system from a Periodic Review (PR) to a Continuous Review (CR) policy and reducing shrinkage by tracking expiration. Under option (1) the current operational policy costs less, while option (2) uses Business Process Redesign (BPR) to extract the full benefit of RFID.

To account for the impact of three additional benefits of RFID on inventory management, our paper proposes a model for PR that uses continuous costing to allow a correct and direct comparison between different PR policies and with CR policies. This is not possible with the traditional end-of-period costs used for PR models in the inventory literature. Using this model, we show that the attained optimal service level under shrinkage decreases. Also, assuming no shrinkage, we show analytically that the switch to continuous review (CR) from periodic review (PR) decreases the on-hand inventory, the level of backorders, and the frequency of orders and their corresponding costs, making CR the lower cost alternative. We also show that the optimal average order quantity and the review period length are concave increasing in the fixed cost of ordering for both CR and PR. We further look at the change in the ratio of inventory-related costs (the average inventory cost plus the average backorder cost) to average ordering cost with respect to the optimal average order quantity and fixed ordering cost. We found that this ratio is convex decreasing in the optimal average order quantity (review period), and the fixed ordering cost for CR (PR). Under RFID, manual counting is eliminated due to automatic counting of items, resulting in a lower fixed ordering cost. Hence, these results show that a decrease in the fixed ordering cost as a result of a switch to automatic counting for RFID (or CR) from using manual counting for barcodes (or PR) keeps the operational and economic metrics still lower for RFID (or CR) than for barcodes (or PR). Our results also show that for the optimal CR and PR, a decrease in the fixed ordering cost decreases the average ordering cost more than it does the inventory-related costs.

We conduct a sensitivity analysis by varying inventory parameters to provide additional managerial insights in different operational environments. Through this analysis we also account for the benefit from shrinkage tracking numerically. We show that the percentage cost savings from RFID (without BPR) decrease with the service level (or, equivalently, the backorder cost), the mean and standard deviation of demand, the lead time, the shrinkage rate, and the cost per order placed under RFID,[2] while the cost savings from employing BPR increase in all these parameters. The total cost savings from RFID combined with BPR therefore also increase in all parameters except in the cost per order placed under RFID. Hence, RFID is more attractive relative to older technologies in environments with high backorder costs (high service levels), high demand rates, high levels of uncertainty, high shrinkage rates, long lead times, and high manual counting costs.

[1] The items in our study are tagged by passive RFID tags and any information change in the state of an item updates the inventory record system rather than the item's tag. An information update at the tag level requires the use of active RFID tags, however they are more expensive than passive tags and are not required to track partially used items in our study.

[2] The cost per order placed under RFID is equal to the cost per order placed under barcode technology minus the manual counting cost, which is only incurred under barcode technology.

Our case study illustrates that the radiology practice saves 76% of its total inventory management costs by switching from barcodes to RFID and redesigning its business processes. About one quarter of the total savings is attributed to the reduced cost of counting inventory, while business process redesign accounts for three quarters. These significant cost savings result in an internal rate of return (IRR) of over 54% under the assumption that the technology has a life expectancy of ten years.

The rest of the paper is organized as follows. Section 2 contains the literature review. In Section 3 we discuss the operational and economic problems encountered under barcode technology by our case study. We then provide our inventory models and analytical comparisons between periodic and continuous review policies in Section 4. In Section 5 we numerically analyze and quantify the impact of RFID on operational and economic aspects of a single-item (e.g., contrast media) inventory via the two options described briefly above, and in Section 6 we provide a cost-benefit analysis for RFID. Section 7 concludes and provides suggestions for future research.

2. Literature review and contribution

We analyze the operational and economic impacts of RFID technology and, in particular, the impact of real-time tracking on single-item inventory management in this context. Our paper thus tackles several well-known open issues in RFID and inventory theory literature: (1) we outline an innovative continuous-time approach to account for inventory costs more accurately; (2) we provide analytical justification for the choice of continuous review as the inventory control policy; and (3) we analyze the impact of RFID on the ordering cost.

The current RFID inventory literature (and most of the classical inventory theory literature), uses "end-of-period costing," which accounts for inventory on hand and backorders at review epochs only. This prevents an unbiased comparison with continuous review models, since they assess these costs continuously. The comparison between PR and CR is discussed by Hadley and Whitin [20] but never analytically analyzed. Freeland and Porteus [16], using end-of-period costing for PR, mention how PR and CR employ different methods for cost accounting, such that a comparison is not correct. Our proposed continuous time cost model accurately accounts for holding and backorder costs and provides a precise way to compare the economic impact of different inventory review policies. Such costing has been used by Hadley and Whitin [20] and Veinott [43], and more recently by Çakıcı et al. [8], Groenevelt [18], Groenevelt and Rudi [19], Jain et al. [23] and Rao [38]. We refer the reader to Rudi et al. [39] for a discussion between end-of-period and continuous time costing.

The literature on RFID technology and its benefits for inventory management focuses mostly on the cost reduction resulting from elimination of inaccuracy. Before RFID, inventory records were typically assumed completely accurate in the inventory literature. In reality, prior technologies were often prone to error. Atalı et al. [2], Bensoussan [4], DeHoratius et al. [12], Fleisch and Tellkamp [15], Kang and Gershwin [25], and Kök and Shang [27] model the inaccuracy problem and show the benefits of eliminating inaccurate data (e.g., using RFID) from the inventory information system. One of the important factors that affects inventory accuracy is shrinkage. In the studies by Atalı et al. [2], Bensoussan et al. [4], Fleisch and Tellkamp [15], and Kang and Gerschwin [25], shrinkage is included as one of the causes of data inaccuracy. DeHoratius et al. [12] and Kök and Shang [27] study a general error to inventory data that can assume negative and positive values. All of these studies, however, assume either periodic or continuous review without considering which review policy is optimal for RFID technology.

Cheng et al. [10] use both a periodic and a continuous inventory review policy for a three-echelon supply chain and show the economic differences between the two by a simulation study. Çakıcı