



## Analysis of simple inventory control systems with execution errors: Economic impact under correction opportunities

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### ARTICLE INFO

#### Article history:

Received 13 July 2007

Accepted 16 January 2010

Available online 29 January 2010

#### Keywords:

Inventory control

Simulation

RFID

Inventory record inaccuracies

Execution errors

### ABSTRACT

Motivated by recent empirical evidence, we study the economic impact of inventory record inaccuracies that arise due to execution errors. We model a set of probable events regarding the erroneous registering of sales at each demand arrival. We define correction opportunities that can be used to (at least partially) correct inventory records. We analyze a simple inventory control model with execution errors and correction opportunities, and demonstrate that decisions that consider the existence of recording errors and the mechanisms with which they are corrected can be quite complicated and exhibit complex tradeoffs. To evaluate the economic impact of inventory record inaccuracies, we use a simulation model of a  $(Q,r)$  inventory control system and evaluate suboptimality in cost and customer service that arise as a result of untimely triggering of orders due to inventory record inaccuracies. We show that the economic impact of inventory record inaccuracies can be significant, particularly in systems with small order sizes and low reorder levels.

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### 1. Introduction

Global pressures for high customer service levels have placed a strong emphasis on the control of material flow in today's production and retail environments. Companies are constantly in search of efficient systems and procedures to manage the levels of various types of stocks in their systems. For that purpose, many of them have made substantial investments in Information Technology (IT) to automate various functions, such as supply chain operations. It is estimated that US retailers spend close to \$30 billion annually to make supply chain decisions like merchandise tracking, automating transactions, and inventory level optimization (Raman et al., 2001).

IT system implementations in supply chains have made abundant data available, which has motivated many possibilities of system improvement through the use of that data. The research community has been analyzing the various types of savings inherent in sharing and analysis of these data to show the importance of IT for effective supply chain management. One issue that has been somewhat neglected, however, is the effect of inaccurate data in decision making. Strategies that have been shown to be optimal or near-optimal assuming availability of perfect information may not behave so if implemented in a system with sensors that are only able to provide inaccurate data.

Monitoring and replenishment of stocks is becoming an automated function in many companies. These systems use advanced database structures as well as a set of sensors, such as barcode readers and Radio Frequency Identification (RFID) tags, to track the number of products in the system and place timely orders to the supplier(s) according to the inventory control policy in place. Management infrastructures, such as ERP systems, control almost all functions regarding finance, marketing, logistics, and manufacturing of goods based on this data. Optimality or effectiveness of decision policies can only be valid under the conditions that data is perfect; inaccuracies in data can often result in suboptimal performance, sometimes without the apparent knowledge of decision makers. Hence, accuracy of data regarding the location and quantity of goods is critical for the profitability of a company.

The introduction of IT systems, which replaced manual inventory record keeping, held a lot of promise for the elimination of inventory inaccuracies. Today, these IT systems as well as the sensors that collect the data are improving (and requiring additional investments) everyday; however, errors in inventory records still exist. In fact, discrepancies between inventory records in information systems and physical inventory are quite common. The existence and extent of such discrepancies, which we refer to as inventory record inaccuracies, have been documented in the literature by several researchers as well as industry reports. Raman et al. (2001) studied the inventory records of two leading retailers and found that inventory records of almost 65% of the SKU's were inaccurate. Furthermore, the magnitude of

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errors on average was found to be 35% of the target stock levels. Similar observations were made by Kang and Gershwin (2005), based on their experiences with several retailers considering the adoption of an RFID-based IT technology.

Inventory audit reports from various environments ranging from hospital pharmacies to the grocery industry echo the prevalence of inventory record inaccuracies. These reports document the excess inventories that companies carry as a result of inventory record inaccuracies, and the significant economic impact. On one of these audits, for example, the Office of Inspector General estimated that at any given time the value of Veteran's Health Administration-wide excess inventory was worth \$64.1 million, which was 61.8 percent of the \$103.8 million total inventory. Of the \$64.1 million in excess inventory, at least \$10.8 million was inventory for which there was no demand. The report<sup>1</sup> also draws attention to the fact that the excess inventories occurred because of inadequate or erroneous monitoring of stock levels.

In general, the actions that companies take to respond to inventory record inaccuracy can be grouped in three categories: (1) prevention, (2) correction, and (3) integration (DeHoratius et al., 2008). Prevention strategies aim to reduce or eliminate the root causes of inaccuracies through improvements in education of workforce, product and shipment labeling, shelving and storage of items, foolproofing of procedures, information technology, and product tagging, etc. While these actions will obviously reduce inventory record inaccuracies, factors such as labor turnover, human error, sensory and tracking equipment failures imply that it is extremely hard, if not impossible, to eliminate inventory record inaccuracies. For this reason, most companies resort to correction of inventory records. These mainly consist of auditing policies to identify and correct record discrepancies. While annual physical inventories are performed at the end of every year by all companies for accounting purposes, many companies also perform cycle counting, which is the practice of periodically counting all or a fraction of the on-hand inventory. The third category, integration, involves the use of inventory management strategies that explicitly consider the existence of inventory record inaccuracies and incorporate this into the decision making process. These approaches include the use of appropriate auditing cycles (e.g., Iglehart and Morey, 1972; Morey, 1985; Morey and Dittman, 1986; Kok and Shang, 2007), compensation methods that take stochastic behavior of stock loss into account (e.g., Kang and Gershwin, 2005), modified replenishment policies (e.g., Lee and Özer, 2007; Atali et al., 2009), and policies based on the Bayesian inventory record for replenishment and audit triggering (DeHoratius et al., 2008).

Regardless of the mix of actions companies choose to take to tackle record inaccuracies, costs for prevention, correction and integration can be significant. Therefore, it is important to determine the “true” economic impact of inaccuracies due to various major causes so that costs to address these causes can be justified. In particular, the impact of inaccuracies due to different causes (which we detail in Section 2) should be accounted for separately, since actions to address different causes may be quite different. Consider for example, theft and execution errors at the cash registers: while increasing security may be a way to address inventory shrinkage due to theft, it would do little to reduce inaccuracies due to execution errors. To justify the costs for actions to minimize execution errors (such as those for training, labeling, shelving) one needs to determine the economic impact

of various execution errors that cause over- and under-registering of demand.

To come up with reliable estimates of economic impact, it is necessary to use a model that represents reality as closely as possible. In particular, one should consider various types of naturally occurring events that “help” companies keep the inaccuracies under control on a daily basis. One such event, for example, is the case in which a customer brings to the cash register an item that appears to be stocked out. This event triggers at least a partial correction of the inventory records and can be used to trigger other types of record correction mechanisms. As we outline below, it is possible to come up with other such events, which we refer to as “correction opportunities”. Modern IT systems are capable of collecting, storing and processing massive amounts of data, which means that it is also possible to take corrective action using correction opportunities on a real-time basis. To our knowledge, there is very limited work on how to take advantage of correction opportunities in retail/production environments. In addition to providing more accurate estimates of economic impact, consideration and modeling of these events are important building blocks that could lead to the development of self-healing systems.

In this paper, we focus on modeling execution errors and various events that indicate record inaccuracies in the system to provide reliable estimates of the economic impact of execution errors. Our approach isolates execution errors and allows for positive and negative record inaccuracies, as opposed to studies that only consider positive record inaccuracies due to theft and inventory shrinkage. We pay close attention to the stochastic modeling of errors as they occur at demand arrival epochs, which allows us to tie the economic impact to the scale of errors and to generalize our results to various retail environments with possibly different levels of execution errors. To show the complexity of the problem, we start our discussion with a simple model with execution errors and correction opportunities to demonstrate the impact of over-registering demand and how the optimal ordering quantity changes as a function of the error level and correction probability. We then present parallel results using a simulation model of a single item inventory system managed by a continuous review inventory control policy. We compare the expected total cost (sum of holding, ordering and lost sales costs) of the optimal  $(Q,r)$  policy and fraction of lost sales with and without execution errors. We provide some results on using indicator events as opportunities to completely or partially correct inventory records. Finally, we summarize a set of managerial insights that practitioners can use to assess the economic impact of record inaccuracies.

In Section 2, we present an overview of the prior work on the subject as well as a categorization of common inventory record inaccuracies. A statement of contribution in contrast to other work in the literature is also provided. Section 3.1 provides a detailed description of the inventory control system we consider, as well as a definition of correction opportunities. In Section 3.2 we present a simplistic analytical inventory control model as well as several managerial insights derived from its analysis. Section 4.1 includes an outline of the simulation model and experimental design. In the remaining subsections we discuss our findings from the simulation experiments. In Section 5 we provide some managerial insights. We finally present conclusions and directions for future work in Section 6.

## 2. Literature review

Inventory inaccuracies have been known to exist, which is the reason why most companies have adopted a policy of conducting

<sup>1</sup> Available at <http://www.va.gov/oig/52/reports/1999/9R8-E04-052.pdf> as of 12/31/2009.

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