Int. J. Production Economics 139 (2012) 634–641

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

The impacts of RFID implementation on reducing inventory inaccuracy in a multi-stage supply chain

Hongyan Dai [a,*], Mitchell M. Tseng [b]

[a] Business School, Central University of Finance and Economics, Room 1403, Main Building, No 39, Xueyuan Nanlu, Haidian District, Beijing 100081, China
[b] Department of Industrial Engineering and Logistics Management, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

A R T I C L E I N F O

Article history:
Received 2 November 2009
Accepted 1 June 2012
Available online 15 June 2012

Keywords:
Inventory inaccuracy
RFID
Information distortion

A B S T R A C T

Mismatch of inventory information between the reality and what is on the record of information systems has been generally accepted as inventory inaccuracy. Its financial impacts go beyond the cost of direct inventory loss at each stage of the supply chain. The discrepancy also results in increasing holding and shortage cost because information distortion propagates along the supply chain. With the growing emphasis on responsiveness and cost of inventory, inventory inaccuracy has become a critical hurdle to achieve high performance supply chains. The emergence of RFID technology offers a possible solution to alleviate the growing cost of inventory inaccuracy. However, differs from tangible justification based on shrinkage reduction, adoption of RFID technology has to be justified with improvement in intangible information flow. The objective of this paper is to present a systematic approach with analytical models to quantify the extent of saving from timely information as well as reduction in information distortion and its amplification. With the increasing dynamic and complexity of global supply chain, this paper may shed some new light on framing the discussion of investing in RFID technology.

1. Introduction

Inventory inaccuracy has been referred to as the discrepancy between the available inventory in the supply chain and recorded inventory in the IT system. This issue is mainly due to three sources (Atali et al., 2005): (1) shrinkage, a permanent inventory loss, resulting in smaller actual inventory compared with the record in the IT system; (2) misplacement, which are not available to sale but can be recovered to inventory by physical audit; (3) transaction errors, such as scanning errors, leading to inventory deviation. Inventory inaccuracy was identified as a potential obstacle to operations management by Rinehart (1960) five decades ago. It has later been reported that inventory inaccuracy is widespread in industry (Raman et al., 2001; DeHoratius and Raman, 2008; Khan et al., 2011; Agrawal and Sharda, 2012). IBM Business Consulting Services (Alexander et al., 2002) conduct an investigation on seven product categories in supply chains and report that the retailers suffer shrinkage losses of 1.75% of US$58 billion revenue and the manufacturers suffer that of 0.22%–0.73%. Kök and Shang (2006) document that a large distribution company faces inaccuracy of 1.6% of the total inventory costs, *viz.* $48 million, at the end of 2004. These sets of data imply that the inventory inaccuracy incurs significant loss and targets not only the retailers but also the upstream stages in a supply chain.

The loss of inventory inaccuracy can come from two main aspects. The first can be called physical loss due to shrinkage, obsolescence and supplier fraud. The second can be called informational loss. The current process and technology, such as barcode system, can only support infrequent audit due to the cost and time constraints. It turns out the physical audit cycle is usually much longer than the order cycle. Information distortion stemming from the failure to obtain the accurate inventory information at the decision making point becomes unavoidable, resulting in additional costs.

As inventory inaccuracy control plays a key role to achieve a high performance supply chain, there is an increasing interest in investigating how to resolve the inventory inaccuracy problem. By far the most promising technology-based solution is RFID implementation. Two key advantages that RFID has over barcode are frequent monitoring and non-line-of-sight reading. These two characteristics enable two types of RFID benefit. (1) Visibility: RFID provides accurate inventory information to align the recorded and actual inventory data in a timely manner. Visibility cannot reduce the errors, but informs the amount of errors in a timely manner, which equips the managers to make better decisions by taking the timely discrepancy information into consideration. (2) Prevention: RFID further reduces inventory error together with other supporting technologies, such as closed-circuit television systems. Prevention brings more products

* Corresponding author. Tel.: +86 18618481372; fax: +86 010 62288080.
E-mail address: daihy223@gmail.com (H. Dai).

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http://dx.doi.org/10.1016/j.ijpe.2012.06.005

available to sale. Recent studies have shown that owing to RFID implementation, shrinkage can be reduced by 67% at manufacturer level, and by 47% at retailer level (Alexander et al., 2002), which suggests RFID technology can tackle this problem effectively.

However, large scale RFID application is still not common in industry by far. Most of the white papers and reports by technology solution providers proclaim various RFID values, but fail to quantify and articulate how they can be realized. Lee and Özer (2006) argue that this credibility gap of measuring RFID value discourages practitioners from implementing the technology. To close the credibility gap, explicit analytical solutions are needed to concretely quantify the economic returns of RFID implementation, therefore stimulating some pilot research works.

Atali et al. (2005) explicitly model multiple sources of inventory inaccuracy using dynamic programming, and further establish inventory control methods that help quantify the true value of RFID. Rekik et al. (2008a) analyze the impacts on retail stores as a result of product misplacement and compare three approaches to identify the benefit of implementing RFID to eliminate the errors and the benefit of optimizing order policy with consideration of the discrepancy. They show that the second benefit can produce significant saving under certain conditions. Liu et al. (2007) consider a retail environment in which a company needs to make both marketing effort and stocking quantity decisions. They quantify the RFID benefit and illustrate how various factors may affect the RFID adoption. One interesting finding is that one firm is willing to pay more to reduce inventory accuracy, such as implementing RFID, for products with a lower profit margin. A recent paper by Kok et al. (2008) incorporates the inventory shrinkage into a periodic review inventory control model and explicitly takes the length of the inspection cycle into consideration. They derive an analytical break-even price of an RFID tag and provide its lower bound as an approximation, which performs well indicated by the experimental results.

The above-mentioned works are limited to one stage of the supply chain, most focusing on retailing. In contrast, our work addresses the RFID impacts on the whole supply chain as inventory errors exist all along the chain. A few related works are summarized as follows. Heese (2007) quantifies the RFID value in a two-stage supply chain and shows that a decentralized chain often benefits more from RFID implementation as RFID improves the supply chain coordination, therefore reducing the double marginalization effect. It provides some managerial insights about the impacts of information sharing on RFID justification. Rekik et al. (2008b) consider a two-stage decentralized supply chain with the retail store subject to misplacements. The Newsvendor model is applied to quantify the profit difference between taking into account inventory error or not. This enables the calculation of RFID benefit of obtaining inventory error information, which is positive for the retailer but negative for the manufacturer. Rekik (2011) further studies a wholesale supply chain and provides a general framework to analyze the inventory inaccuracy. Sahin et al. (2008) and Sahin and Dallery (2009) study a three-stage supply chain with the wholesaler facing errors from the manual barcode systems. They introduce a new cost component for the conventional Newsvendor framework, capturing the cost of not satisfying an initial commitment directly due to inventory inaccuracy.

In essence, there are three main areas that this paper contrasts with other works.

First, the RFID benefits of visibility and prevention are differentiated. Compared with RFID applications with visibility, those also providing prevention may reap more benefits but at the same time incur bigger investment. Making the right investment decision to balance between more investment and less benefit is critical to the return of investments and risk control, which also paves the way to large adoption of RFID. In order to choose the right RFID applications in different industries, the prerequisite is to quantify RFID visibility and prevention benefits, respectively. However, most of current literature do not differentiate the two benefits (Lee and Özer, 2006) and just assume RFID totally eliminate the errors. This paper thus intends to provide a framework for the quantitative analysis of different RFID benefits, which enables the calculation of justification for different RFID implementations.

Second, instead of applying RFID to improve estimation of the statistics of inventory inaccuracy (such as mean, variance), our model aims to generate more information out of the data captured by RFID and thus quantifies the benefits of RFID through knowing the exact errors in a timely manner. This is in merits of achieving supply chain responsiveness, which helps alleviate the information distortion, making for better demand forecast and order decisions.

Third, we focus on calculating RFID benefit of reducing information distortion amplification. The consequence of information distortion is not only inefficiencies in inventory management and process control at one stage; it by nature will propagate through the supply chain as seen in the bullwhip effect. The reduction in inventory inaccuracy by RFID in one stage alleviates the information distortion in all its upstream stages and therefore brings additional saving, which extends the scope of RFID impacts.

Currently, practitioners are exposed to increasing dynamics and complexity of global supply chain, and making the right investment decisions of RFID technology becomes more challenging. In this work, analytical models are established and numerical studies are conducted to help practitioners understand: (1) the impacts of inventory inaccuracy on the supply chain performance in terms of information distortion and costs; (2) the impacts of RFID visibility and prevention on the extent, amount and economics of inventory inaccuracy, respectively; (3) the larger scope of RFID benefit by including information distortion amplification in the overall benefit calculation with consideration of multi-stage settings. Ultimately, we expect this paper may shed light on framing the discussion of investing in RFID technology.

The structure of this paper is as follows. We begin in Section 2 by describing the modeling framework. In Section 3, the analytical models of the order making decisions are derived. RFID impacts on information distortion and cost are analyzed in Section 4. A numerical study of different cases is presented in Section 5 with conclusions drawn in Section 6.

2. Modeling framework

A decentralized serial supply chain is considered here: a retailer, a wholesaler, a distributor and tiers of suppliers with a single product, all stages suffering from inventory shrinkage. Three scenarios are investigated and compared to articulate the RFID impacts.

Scenario 1 "The base case": without RFID implementation, the shrinkage per time period $\xi_t^{i,1}$ is invisible to the decision maker as the physical audit cycle is usually much longer than the order cycle. However, the decision maker at stage i may notice the shrinkage problem and estimate the shrinkage mean $\mu^{i,1}$ and variance$(\sigma^{i,1})^2$ based on historic physical audit data[1].

Scenario 2 "The RFID case with visibility": item-level RFID implementation in the supply chain (one RFID tag is attached to one product in the most upstream stage and used in the entire supply chain) helps to align the recorded and actual inventory by

[1] There are various statistical tools to estimate the mean and various for a stochastic variable based on a set of samples. Please refer to Montgomery (2005) for detail techniques.