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# An assessment model for RFID impacts on prevention and visibility of inventory inaccuracy presence

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ABSTRACT

Bullwhip effect has been considered as one of major research topics in supply chain management. Most of the studies disregarded the mismatch between the recorded inventory and the reality. However, it is shown that the inventory inaccuracy under uncertainty is a widespread phenomenon in both retail and distribution centers. Due to the propagation of information distortion along the supply chain, the financial impacts of inventory inaccuracy include not only the cost of direct inventory loss but also the increasing holding and shortage cost at each stage. The emergence of RFID technology offers a possible solution to alleviate the growing cost of inventory inaccuracy. By making full use of RFID technology, this paper attempts to compare the inventory inaccuracy impact on bullwhip effect in terms of order variance amplification and supply chain performance under two scenarios: (1) all members are aware of the inaccuracy and optimize their operations; (2) all members deploy RFID technology to reduce inventory inaccuracy. Informed order policy is used as benchmark to capture the true RFID value and differentiate two types of RFID impacts, prevention and visibility, to provide more manageable insight. In particular, the incentive of sharing information in supply chain is also provided by comparing the cost of two supply chain settings.

## 1. Introduction

In real industry, the recorded and actual inventory in a supply chain may be quite different, but this inventory inaccuracy has not drawn much attention [25,7]. It is a widespread phenomenon in both retail and distribution environments. Iglehart and Morey [14] may be the first scholars to discuss this problem. Raman et al. [25] figured out that more than 65% of stock keeping units (SKU) in retail stores are inaccurate and the difference of recorded and actual inventory is on average 35% of the target inventory. For distribution and manufacturing industry, according to Kök and Shang [16], the inventory inaccuracy in most of distribution companies with an average inventory of US$3 billion, is 1.6% of the total inventory value, *viz.* 48 million, at the end of 2004. The above data indicates that the inventory inaccuracy may result in significant loss not only for the retailers but also for the whole supply chain.

There are many causes of inventory inaccuracy. Fleisch and Tellkamp [9] characterized three key sources: theft and unsaleables, misplaced items, and incorrect deliveries. Theft and unsaleables refer to product shrinkage which results in permanent inventory shrinkage. Misplacement relates to temporary inventory shrinkage and can be recovered by physical inventory audit [12]. Incorrect deliveries can also be called unreliable suppliers resulting in difference between received and stated product quantities. It was observed that the inventory shrinkage has the biggest impact on supply chain performance compared to other causes [10].

Since inventory inaccuracy incurs high inventory level and cost, low service level and lost sales, there is an increasing interest in investigating its impact on management performance of a supply chain. Atali et al. [2] explicitly modeled three kinds of demand stream: shrinkage, misplacement and transaction errors using dynamic programming (DP), and quantified the effect due to inventory inaccuracy based on different benchmarks under a given cycle count policy. Kök and Shang [16] proved that an inspection adjusted base-stock (IABS) policy for solving inventory inaccuracy is optimal for the single-period problem. Rekik and Dallery [26] analyzed the impact on retail stores due to product misplacement. Liu et al. [21] considered a retail environment in which a company needs to make both marking effort and stocking quantity decisions. However, the abovementioned works are restricted to a single stage in the supply chain. The first study of the

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impact of inventory inaccuracy on the multi-stage supply chain may be conducted by Fleisch and Tellkamp [9]. They used a simulation model to capture the impact of inventory inaccuracy on bullwhip effect in a multi-stage supply chain. The relationships between the information inaccuracy and distortion, which cause the bullwhip effect [20], are still not well investigated.

As inventory inaccuracy control plays a key role in achieving a high performance supply chain, how to improve inventory accuracy and reduce the cost simultaneously has attracted increasing investigation. Kök and Shang [16] provided a guideline to design effective cycle count programs to reduce the cost caused by inventory inaccuracy. The inventory inaccuracy can also be tackled by using benchmarking, awareness building, and process improvement [9]. All these approaches are termed as non-technology awareness. When contemplating technology solutions, radio frequency identification (RFID) could be possible due to its advanced identifying ability [28]. Recent study shows that due to RFID applications, shrinkage can be reduced by 67% of the current 0.22–0.73% of sales at manufacturers, and by 47% of the current 1.75% of sales at retailers [1]. According to Lee and Özer [19], the cost due to inventory inaccuracy can be reduced by information visibility [34]. The visibility provides accurate inventory information to align the recorded and actual inventory data in a timely manner [3,33]. Most of the studies claim the benefits from using RFID technologies [8,31,17,32], but RFID impacts on prevention and visibility of inventory inaccuracy presence is scarcely reported. To close the credibility gap, explicit analytical solutions are needed to concretely quantify the economic returns of RFID implementation.

This paper is going to fulfill the gap by specifically addressing the following research questions: (1) What is the impact of RFID implementation on bullwhip effect when inventory inaccuracy exists in a supply chain? (2) How to quantify the benefits of RFID to reduce the inventory inaccuracy from visibility and prevention respectively in a multi-stage supply chain?

To answer these questions, this paper examines a multi-stage supply chain subject to inventory shrinkage. A detailed model-based analysis is presented to identify the impact of reducing inventory inaccuracy on bullwhip effect due to RFID applications so as to reveal the specific RFID value. An analytical model is established at first and the order variance amplification with close form expressions is then quantified. Furthermore, some special insights of the supply chain performance (in terms of average cost and service level) are captured and summarized.

The organization of this paper is as follows. Section 2 describes the modeling framework by specifying two scenarios under analysis. In Section 3, the analytical model of different scenarios is derived. In Section 4, the value of RFID implementation is justified by examing the supply chain performance. Numerical study of the two scenarios is given in Section 5 and conclusion is drawn in Section 6.

## 2. The modeling framework

A $K$-stage serial supply chain with retailer, distributor, manufacturer and tires of suppliers suffering from inventory shrinkage is considered. Each stage has only one member who adopts the order-up-to policy. This is an optimal policy that minimizes the holding cost $h$ and shortage cost $p$ over the infinite horizon [11]. These costs may be different for different stages but keep constant through time horizon for a given stage and the holding costs consist entirely of interest on money tied up with inventory [13]. The ordering decisions of every member are made within a Newsvendor framework [22]. The underlying assumption in typical Newsvendor model formulation is that the recorded and actual inventory are the same. Therefore, in presence of inventory inaccuracy, the Newsvendor model should be revisited.

Suppose the external demand faced by the first stage of the supply chain (e.g. retailer) is an auto-correlated $AR(1)$ process, which is borrowed from Lee et al. [20].

$$D_t = d + \rho D_{t-1} + \varepsilon_t \tag{1}$$

where $D_t$ is the demand in period $t$, $d > 0$ is the stable demand in every period, $-1 < \rho < 1$ is the correlated factor and $\varepsilon_t$ is normal distributed with zero mean and variance $\sigma_d^2$, which is dependent upon $D_t$ while independent upon $D_{t-1}$.

We assume shrinkage exits in every stage of the supply chain and can be modeled as[1]:

$$S_t = s_t - \xi_t \tag{2}$$

where $S_t$ is the order-up-to level in period $t$ relating to the recorded quantity, and $s_t$ is the inventory level without shrinkage. Since shrinkage never increases the product quantity, $\xi_t$ should satisfy:

$$\xi_t = \begin{cases} \mathrm{N}(\mu_s,\sigma_s^2), \mu_s > 0 & \text{if } \mathrm{N}(\mu_s,\sigma_s^2) \geqslant 0 \\ 0 & \text{if } \mathrm{N}(\mu_s,\sigma_s^2) < 0 \end{cases} \tag{3}$$

where $\mathrm{N}(\mu_s,\sigma_s^2)$ stands for a normal distribution with mean $\mu_s$ and variance $\sigma_s^2$. According to $\mathrm{Prob}\{\mu_s - 3\sigma_s < \xi_t < \mu_s + 3\sigma_s\} > 90\%$, if $\xi_t$ satisfies $\mu_s - 3\sigma_s < \xi_t < \mu_s + 3\sigma_s$, a normal distribution with positive mean $\mu_s$ and variance $\sigma_s^2$ could be determined. And we assume that $\xi_t$ is dependent upon $S_t$ while independent upon $S_{t-1}$.

The particular value of RFID technology is to provide accurate information timely, especially the visibility to the whole supply chain. In this paper, we assume that the end customer demand and inventory shrinkage information in every stage is shared in the whole supply chain, which is called centralized demand information. Therefore, each member in the supply chain is based on the end customer demand information to make decisions instead of the order quantity from its direct downstream.

The ordering process of every stage in period $t$ is: at the beginning of period $t$, $t = 1,2,3,\ldots$, each stage reviews its inventory and places an order based on the predicted demand. At the end of this period, this order is received with the assumption that the delivery lead time is 1.[2]

In presence of inventory discrepancy, the supply chain may take different strategies based on the awareness of the existence of discrepancy for different parties. If they are unaware of the inventory discrepancy, it is assumed that the recorded inventory is as the same as actual, which is called ignorant policy Lee and Özer [19]. In this paper, we assume that the non-technology solution uses the informed policy which recognizes the existence of inventory discrepancy. The order quantity can be adjusted with the mean of shrinkage in each period under the precondition that the average shrinkage quantity in long run can be obtained. RFID technology is deployed to provide accurate inventory quantity timely or even catch some shrinkage and therefore reduce the shrinkage to $\xi_t'$. If $\xi_t' = \xi_t$, RFID can only provide visibility to identify inventory shrinkage, which leads to no inventory discrepancy with inventory shrinkage. The other extreme case is $\xi_t' = 0$, which means it can not only identify inventory shrinkage, but also prevent it totally resulting in no inventory discrepancy and no shrinkage simultaneously. For $0 < \xi_t' < \xi_t$, RFID applications can provide both visibility and partial prevention, which is so called imperfect RFID

[1] This kind of shrinkage model is so called additive model. An alternative way to model the effect of inventory inaccuracy is a multiplicative model which implies the magnitude of shrinkage is dependent of the actual inventory quantity which is more realistic and complexity. One on hand, as our focus is to obtain manageable insights, we do not want to increase the complexity of the problem formulation; on the other hand, to be more realistic, we set the shrinkage quantity to be a given percentage of the actual inventory in our numerical study.

[2] We assume the delivery lead time is 1 since this assumption may lead to close form solution for order variance in any given stage in multi-stage supply chain settings, otherwise, we cannot get close form solution for exponential growth complexity. Although lead time is a very important factor in bullwhip effect and people has done intensive analysis of lead time impact on bullwhip effect (see Chen et al. [5] and Kim et al. [15]). Whereas, our focus is the impact of inaccuracy not the lead time and lead time as a supply chain performance measure indicator is more suitable for different production and distribution processes not inventory inaccuracy problem [9]. Based on the above-mentioned considerations, we hold that it is reasonable to set the delivery lead time 1.