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Inventory control in serial systems under radio frequency identification

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ABSTRACT

The widely adopted slap-and-ship radio frequency identification strategy provides valuable information to retailers. On the other hand, suppliers struggle to find benefits even though they are submerged with new data. Radio frequency identification provides complete visibility of their shipments, including the time and location of every pallet, case or even item. We provide a novel model relying on such data that is capable of producing better inventory and shipping control policies. We first propose a comprehensive inventory model for serial systems that captures both the supply and distribution information. We show that the underlying cost-to-go can be decomposed into two lower dimensional functions. In a special case, the optimal replenishment and shipping policies are base stock with respect to the underlying positions. In addition, we also analytically study the value of radio frequency identification in terms of the expected total minimum cost over a finite time horizon by introducing partial radio frequency deployment scenarios. Results indicate that additional cost reductions are possible with broader deployments.

1. Introduction

A basic radio frequency identification (RFID) system includes two components: a transponder and an interrogator. A transponder is a tiny microcomputer consisting of a microchip, antenna and memory connecting these two. In the simplest form, the so-called passive RFID transponders, transponders are idle until woken up by an interrogator via radio wave signals. Interrogators are, therefore, constantly emitting signals to provide power to the transponders within their antenna's field of work. When a transponder receives a signal from an interrogator, it absorbs some of the radio energy to power itself and sends back a response, which among other data stored in its memory, includes the transponder's unique identification number. The interrogator decodes this information and passes it to information systems. In a typical RFID deployment within a supply chain, interrogators are mounted at critical locations. Every time goods affixed with transponders come within the read range of an interrogator, the location, time, and identification are recorded. Under normal conditions a typical interrogator may interrogate hundreds of transponders per second.

One of the recent information technology advances is the adoption of RFID technology in inventory control systems. Early benefits earned from RFID deployments are inventory asset tracking, advance shipping notice, real-time order progress information for retailers, and real-time shipping visibility for suppliers. The additional RFID generated information could possibly result in improved inventory control policies and potential new business applications. One of the biggest setbacks to a wider RFID adoption is the lack of return of investment. Many entities in supply chains are overwhelmed with data generated from RFID deployment, yet this data is seldom used to enhance business intelligence.

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As an emerging auto data-capture enabler, RFID technology intrigues supply chain researchers and practitioners. Companies have rushed to develop RFID solutions without having a clear idea about the potential value of RFID to their business. One of the values of RFID in supply chains is derived from better supply chain visibility. An RFID deployment improves supply chain visibility; however, many benefits in inventory control are still untapped. The value of RFID obtained from labor cost reductions and similar basic benefits can be satisfactorily assessed by case studies. Empirical studies and proofs of concepts are of limited scope since they have to rely on existing processes and data. It is not clear how RFID can further reduce supply chain costs via improved visibility. Educated guesses are currently driving such estimates. Analytically modeling inventory control systems with an RFID deployment is critical to enhance our understanding of the value of RFID.

Beyond replenishment inventory control on the supply side, the distribution side deals with shipping decisions. As is the case with the supply, RFID deployments yield real time visibility of shipments. To achieve such capability, it is typical to install portals with readers at important locations (e.g., in and/or outbound docks) and tag the corresponding goods. Consider an RFID mandate imposed by a retailer. A supplier places transponders on the products and ships them to the retailer's distribution centers, thus complying with the corresponding RFID mandate. Since typically transponders are affixed just before leaving the final facility of the supplier, this strategy is known as slap-and-ship. Clearly, to obtain further benefits from RFID, it is advised to push the tagging process further upstream in the supplier's own supply chain. The main drawback of slap-and-ship is the inability to produce return on investment. As already discussed, the retailer could benefit from continuously monitoring the inventory levels and outstanding order progress in its own chain. However, it is not clear how the supplier can benefit from the mandate even if real-time distribution information is provided by the retailer. This is a typical quote about such suppliers: "They (an apple supplier to Wal-Mart) know exactly what day and time the container was scanned through its portal, when it entered a distribution center and what day and time it went to the store. The company has yet to determine how best to use this data.", Inbound Logistics, June 2006. The main objective of this research is to show how suppliers can benefit under such circumstances even under slap-and-ship. We assume a decentralized system where each entity in the chain acts independently. The main entity is an installation somewhere in the middle of the entire chain. The firm makes two decisions: (1) the replenishment decision from its own supplier and (2) the shipment decision how much to ship downstream.

We study a single-product, multi-echelon serial supply chain system, in which the supplier streamlines both its replenishment and distribution processes by using the RFID data. We propose a dynamic programming model to capture the real time inventory information generated from an RFID deployment across the entire supply chain. The paper is organized as follows. A comprehensive inventory model is first presented in Section 2. In addition, we provide a special case with an instantaneous replenishment process. We apply multi-echelon techniques to decompose the proposed model into two sub-problems. The optimal control policy under certain conditions is characterized as the echelon base stock policy. The value of RFID in a serial distribution process is clearly identified and rigorously proved in Section 3 through discussions of partial RFID deployment scenarios. We conclude the introduction with a brief literature review.

1.1. Literature review

Our models assume stochastic lead times. In standard single-stage stochastic inventory models, the lead time is considered either as a known deterministic constant or a random variable with known distribution. In these models (Kaplan, 1970; Nahmias, 1979; Ehrhardt, 1984) the lead time is assumed to be time-independent with known distribution. The non-crossover property is also assumed in order to make the study tractable. In our analysis, we borrow concepts from multi-echelon systems. The seminal work on the serial multi-echelon inventory problem was conducted by Clark and Scarf (1960). In their research, the global system is decomposed into separate subsystems. At each echelon, it is optimal to follow the base stock policy with respect to the echelon inventory.

RFID is the most promising technology providing complete and comprehensive supply chain visibility. It is a surprisingly simple computing and communication architecture since only two basic building blocks are needed—a tag and a reader (AIM Inc., 1999; Clampitt et al., 2006). We have already argued that RFID is an enabling technology for visibility that is assumed by our model. There are estimates about the value of RFID in supply chain management, including labor cost savings, reduced inventory holding costs, and stock-outs (Lee and Özer, 2007; Hardgrave, 2005). Most studies regarding RFID in inventory control concentrate on supply chain simulations (Lee et al., 2004; Fleisch and Tellkamp, 2005; Kang and Stanley, 2005).

Bottani and Rizzi (2008) describe profitability of deploying RFID in a three-tier supply chain. They show by a real world case in a fast-moving consumer goods market the benefits of pallet-level tagging, and much more lenient results of case- and item-level tagging. Ustundag and Tanyas (2009) investigate impacts of different factors, such as product value, lead time, and uncertain demand on the supply chain cost performance at echelon levels in conjunction with RFID tagging.

Among the few studies that analytically deal with RFID in inventory control, Song and Zipkin (1996) provide a modeling framework for the inventory control problem with supply information. While this study dates back to pre-era of modern RFID, it requires data available only through today's RFID deployments. The replenishment lead time is time-dependent and evolves over time. We borrow their modeling technique and enrich their study by focusing on the distribution side, thus dealing with two concurrent decisions. We also present results addressing