INVENTORY CONTROL IN SERIAL SYSTEMS UNDER RFID

The goal of supply chain management is to deliver the products at the right time, in the right way to the right customer. The more visible the supply chain is, the better it can fulfill the customer orders. Radio Frequency Identification (RFID) is one of the technologies that can provide supply chain visibility. There are many applications of RFID in supply chain management (AIM, Inc., 2007). We particularly focus on its application in inventory control in this research. After the initial lab experiments and case studies, the real breakthrough of RFID applications has recently occurred with the RFID mandates announced by Wal-Mart and the Department of Defense. Most of their suppliers are required to apply at least pallet level RFID transponder to the products shipping to selected distribution centers. The well-known slap and ship RFID mandate provides valuable information to retailers. The firms are able to streamline their supply systems due to the improved visibility resulting from RFID deployments. Song and Zipkin (1996) provide a modeling framework for the inventory control problem with supply information. On the other hand, the distribution information with respect to the suppliers also contributes to the supply chain system. However, it is not clear how the suppliers can benefit from the mandates even if the real-time distribution information is provided by the retailers. Moreover, it is even ambiguous how the suppliers can make full use of the RFID technology to implement across their production or procurement processes. Refocusing and pushing the RFID tagging further upstream is necessary for the suppliers to generate benefits. It is interesting and promising to help the suppliers to identify the true value of RFID in their businesses. In this research, we discuss the inventory control problems in serial systems with complete visibility upstream and downstream in the supply chain. It leads to interesting new inventory models. We can keep track of goods under RFID. This reduces the inventory inaccuracy, which is a major problem in many firms. As a result, with a more accurate inventory count, an optimal control policy is demonstrated. The value of RFID in the serial distribution process is identified and rigorously proved.

Prior inventory models deal with supply information, i.e. the focus is on the procurement side of the supply chains. Such an analysis is appropriate for the retailers. However, suppliers like to capture more information beyond the supply side. We first propose a comprehensive inventory model for the serial systems that capture both the supply and distribution information. Two random vectors are introduced to depict the upstream and downstream system transitions. In addition, the non-crossover property and the backorder case of unmet demands at the point-of-sale installation are assumed through this research. The stochastic events occur as follows. At the beginning of each time period, the system states are observed. The shipment and replenishment decisions are then made. Next, the replenishment and shipment orders due in current time period are delivered. Finally, demands occur and current time period inventory costs are evaluated. It is important to point that at the end of each time period the holding and penalty costs in the proposed model are differently evaluated from the standard single-stage inventory models. In our proposed model, the holding cost is charged at the supplier at the end of each time period. On the other hand, the penalty cost is evaluated at the point-of-sale installation where the customer demand may not be satisfied. As for the replenishment and shipment orders, we merely charge the procurement and shipment costs when they are placed.

The comprehensive model is quite complex and not easily analyzed. In order to obtain a better understanding of the comprehensive model, we discuss the distribution process with RFID deployments. We provide a special case of instantaneous replenishment in our proposed model. The inventory control problem in the serial distribution is modeled as a dynamic program. Furthermore, the original problem is represented by a state reduction model in order to study the optimal control policy. This reduction is useful in inventory control. The original model contains many state variables. The multi-dimensional state vector results in difficulties in computing the inventory control policies. The reduced model has only two variables: the inventory on-hand and downstream echelon inventory at the point-of-sale. We are able to make the inventory control decisions by the reduced model without considering the internal, detailed transitions.

It is natural to extend the instantaneous replenishment case to the general case, in which the firm faces both supply and distribution uncertainty. We apply multi-echelon modeling techniques to decompose the comprehensive model into two standard inventory problems. With minor assumptions, we show that the optimal control policy in the proposed comprehensive model has a similar structure as the base stock policy. Based on the conclusions from Clark (1958) and Clark & Scarf (1960), we first obtain the optimal downstream stock level. The reduced model of the downstream subsystem is used to determine the shipment into the distribution channel. As soon as we obtain the optimal shipment, we move upstream to focus on the replenishment process to determine the optimal replenishment order. The system decomposition leads to the optimal base stock policy which has two critical numbers at each time period. The decomposition allows the techniques which are widely used in standard single-stage problems to be applied in stochastic multi-echelon problems.

RFID has proven itself to be an emerging and promising technology in inventory management since it has the capability to continuously track the inventory progress. It is known that an RFID implementation improves supply chain visibility. However, how and how much the improved visibility can reduce the inventory levels is unknown. The best the decision makers can do is to make educated guess. Analytically modeling the inventory control system with an RFID implementation is critical to enhance our understanding of the value of RFID. It is clear that the research on the impact of RFID on supply chain performance using analytical approaches is still at the early stage. Previous studies either focus on the labor cost and time savings or examine the inventory reduction by simulation approaches. In addition, the value of RFID identified by prior research is mainly within the boundaries of a firm. The previous studies empirically justify the adoption of the RFID technology into the supply chain. In this paper, the research on the value of RFID is extended across the entire supply chain. In order to better assess the value of RFID in inventory control, the model-based analytical study is conducted in this research.

It is well known that the standard inventory control techniques provide approximate control under the stochastic demand and lead time. RFID integration has potentials to improve the control system. This research analytically shows how RFID can improve the system performance in terms of expected total minimum cost over a finite time horizon. In order to identify the value of RFID in inventory control, we propose partial RFID application scenarios in a serial distribution process, in which only some installations of the chain are covered by RFID. By comparing the systems with different RFID implementations, we are able to identify the value of RFID in the system. Two specific partial RFID application scenarios are discussed. We assume that remaining configuration in the two scenarios is the same with the aim to isolate the contribution of RFID. Through this research, we assume that the outstanding inventories never move from the non RFID zone across the border back into the RFID-enabled area. In addition, in the RFID-enabled area, the shipment transitions depending on a random variable *J* overwrite ones depending on random vector *W*. In order to show the system dynamics, the interface is defined as the position of the youngest outstanding shipment which arrives at the point-of-sale installation at the end of time *t*. Intuitively, the broader the RFID implementation is in the distribution network, the larger the benefits are. If the RFID implementation and maintenance costs are neglected, we are able to show that additional benefits are obtained with broader RFID implementation because of additional information.

The partial RFID application scenarios can transform to either a full RFID application case when *s=n-1* or a standard case without RFID information when *s=0*. According to the well-known optimality principle, which states that for any dynamic program whether we keep track of the history or not we get the same expected total minimum cost. In other words, we can assume that the optimal policy of the full RFID application case has all of the information about the history up to time *t*. As a result, the transformed full RFID application case has the same system cost as the full RFID application model presented before, in which we did not track the inventory history. Results indicate the full RFID application provides the best system payback. In other words, full RFID implementation across the entire supply chain is superior to the partial implementation, which is better than the traditional standard model.

With the nearly real-time information generated from RFID, many new research directions are possible. Analyzing RFID generated supply chain data is a promising line of research. One of the challenges ahead along this line is identifying the opportunities using the new stream of data generated by RFID and developing the decision support system. This research provides a solid analysis of establishing a decision support system by analyzing the RFID generated data in inventory control context. This research discusses the optimal control policy in a serial system and identifies the true value of RFID in a serial distribution process through partial RFID implementation discussions.

Reference:

[1] AIM, Inc., 2007. Retrieved Aug. 1st, 2007. http://www.aimglobal.org/

[2] Clark, A. 1958. A dynamic, single-item, multi-echelon inventory model. RM-2297, the RAND Corporation, Santa Monica, California (December).

[3] Clark A. and H. Scarf, 1960. Optimal Policies for a Multi-echelon Inventory Problem. *Management Science* 6: 4, 475-490.

[4] Song J. and P. Zipkin, 1996. Inventory Control with Information about Supply Condition. *Management Science* 42:10, 1409-1419.