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Exploring the Impact of RFID on Supply Chain Dynamics

Young M. Lee, Feng Cheng, Ying Tat Leung
IBM Research Division
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598

EXPLORING THE IMPACT OF RFID ON SUPPLY CHAIN DYNAMICS

Young M. Lee

IBM T.J. Watson Research Center
1101 Kitchawan Road
Yorktown Heights, NY 10598, U.S.A.

Feng Cheng

IBM T.J. Watson Research Center
1101 Kitchawan Road
Yorktown Heights, NY 10598, U.S.A.

Ying Tat Leung

IBM T.J. Watson Research Center
1101 Kitchawan Road
Yorktown Heights, NY 10598, U.S.A.

ABSTRACT

Radio-frequency identification (RFID) as an emerging technology has generated enormous amount of interest in the supply chain arena. With RFID technology, inventory can be tracked more accurately in real time resulting in reduced processing time and labor. More significantly, the complete visibility of accurate inventory data throughout the entire supply chain, from manufacturer's shop floor to warehouses to retail stores, brings opportunities for improvement and transformation in various processes of the supply chain. We developed a simulation model to study how RFID can improve supply chain performance by modeling the impact of RFID technology in a manufacturer-retailer supply chain environment. Our study provides a quantitative analysis to demonstrate the potential benefits of RFID in inventory reduction and service level improvement.

1 INTRODUCTION

Wal-Mart's initiative of requesting their top 100 suppliers to deliver products with RFID tags by January 2005 has accelerated the pace of adopting the technology in industry. While companies are trying to follow Wal-Mart's request to become RFID compliant, the potential long-term benefits of implementing the technology to different players in the supply chain still need to be identified and explored. Many return-on-investment (ROI) type studies have been conducted based on a direct cost and benefit analysis, which typically take into account the reduced labor cost, reduced inventory shrinkage, and other directly measurable benefits contributed by an RFID deployment. However, dynamic effects of RFID on supply chain performance and benefits brought by process transformations enabled by RFID may not be captured by a traditional ROI-type analysis. For example, the direct loss due to inventory shrinkage is just the value of the unaccounted inventory itself. The indirect loss of inventory shrinkage may include losses from stockouts as the result of poor replenishment due to inventory inaccuracy (caused by the unaccounted shrinkage). A study by the MIT Auto-ID Center (Kang and Koh, 2002) concluded that the indirect loss can be 30 times greater than the direct loss.

Among a large number of white papers and reports published recently, most of them are qualitative studies providing business cases for RFID deployments. For example, IBM Business Consulting Services have published a series of papers (Alexander et al. 2003a,b,c,d) on discussing the impact of RFID technology on supply chain performance with a focus on consumer goods and retail value chains. Topics of the white paper series range from analyzing the benefits of RFID in terms of improving product availability at the retail shelf, reducing losses associated with product obsolescence, product shrinkage, as well as the inventory inaccuracy, to articulating how RFID would affect the DC and store replenishment policies to achieve better customer services and at the same time reduce the inventory cost. Other reports of a similar nature include Agarwal 2001 and Kambil and Brooks 2002.

Research on the impact of RFID on supply chains using analytical approaches is still at an early stage. In addition to the work by Kang and Koh (2002), Gaukler et al. (2004) analyzed the benefits, roll-out strategies and cost sharing agreements for the item-level RFID implementation in a retail supply chain. Kang and Gershwin (2004) studied the effect of inventory inaccuracy and provided evaluations of various methods including RFID that can be used for improving inventory accuracy. Joshi (2000) also used a simulation approach to evaluate the value of information visibility through RFID.

In our study, we use a simulation model to quantify the indirect benefits provided by RFID, such as those as a result of the dynamic effects or of process transformations enabled by RFID. In this paper, we describe a supply chain model that consists of a supplier and a retailer, and focus on analyzing the effects of three factors that will be impacted by RFID technology. These factors as described below will in turn affect the performance of the supply chain in various ways.

- Inventory accuracy. Shrinkage or stock loss, transaction error, inaccessible inventory, and incorrect product identification are some of the commonly observed causes for inventory inaccuracy which leads to erroneous replenishment decisions.
- Shelf replenishment policy. With the ability provided by RFID to track inventory continuously in real time, the inventory inaccuracy problem can be effectively controlled if not eliminated completely. RFID also offers the opportunity to manage the shelf replenishment more efficiently. In particular, the capability to smartly replenish the store shelves from the backroom stock may reduce lost sales significantly in a retail environment.
- Inventory visibility through out the entire supply chain. The improved inventory visibility will benefit every player of the system. Studies have shown that sharing of inventory information between suppliers and retailers not only improves supply chain fill rate but also reduces the supply chain inventory (see Li, et al., 2001).

For simplicity, we will assume that the RFID tags are applied at the item level. However, some of the scenarios analyzed here will be applicable (at least to some extent) when the tags are applied at the case level.

The rest of the paper is organized as follows. We describe the setting for our simulation study in the next section. The three case studies with detailed quantitative analyses based on the simulation results are presented in Sections 3-5. We conclude the paper with some concluding remarks in Section 6.

2 SETTING FOR SUPPLY CHAIN SIMULATION

In this paper, we model a simple manufacturer-retailer supply chain in a Consumer Product (CP) business. The focus of our study is to analyze the dynamic and stochastic behaviors of the supply chain, which are affected by deployment of RFID technology. The key business metrics that we measured are inventory profile, inventory shortage (lost sales or back order), overage, and costs.

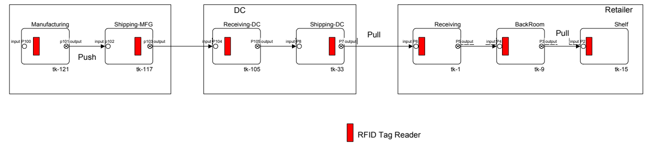

Figure 1. Three Echelon Supply Chain Model for CP Retail Business

We developed a three echelon supply chain simulation model, which consists of a manufacturer, a distribution center (DC, that belongs to the manufacturer) and a retail store. The impact of RFID technology is modeled for each of echelons in the supply chain. In the manufacturer, we modeled RFID tag reading at the points of production and shipping. In the DC, we modeled tag reading at the receiving and shipping docks. In the retailer, we modeled that tag reading occurs at receiving, the backroom and the shelf in the store. Various simplifications and assumptions are made to capture the essence of the supply chain process without making the model unnecessarily complicated.

For the retail store, we modeled that four products are sold to customers with equal probability. Customers arrive according to a log-normal distribution, and their purchase quantity on each purchase occasion is assumed to be uniformly distributed between 1 and 3. The store replenishment is based on an [s, S] policy: re-order point (s) and target inventory (S). Shelf replenishment is also based on an [s, S] policy. We assumed that physical inventory counting is done once every 3 months. The shrinkage of products in the retail store is assumed to be uniformly distributed between 0 and 2 every 10 days, which is equivalent to 1.6% loss, and occurs in both the shelf and backroom.

For the manufacturer, we assumed that the daily production quantity for each product is decided based on a certain policy, and is shipped to DC once a day. Several different production policies are simulated. The lead time for shipment from manufacturer to DC is one day. For the DC, the products are pulled from the retailer based on the retailer's replenishment policy and frequency. The lead time for shipment from DC to retailer is one day.

3 CASE STUDY 1: EFFECT OF INVENTORY ACCURACY

In this case study, we studied the impact of inaccuracy of inventory data as a result of shrinkage at the retailer, which occurs at a rate of 1.6%. We simulated a case where RFID technology is not deployed, and two cases where RFID technology is deployed. Without RFID, the inventory reduction due to shrinkage is not known, and the retailer's replenishment decision is made based on the inaccurate inventory information. With RFID, shrinkage occurs as before but the replenishment decision is expected to improve due to more accurate inventory information, thus improving the supply chain performance.

3.1 Without RFID, Replenishment Policy:(s=36, S=48)

We first simulated the quality of replenishment decisions due to shrinkage at the retail store where RFID technology is not deployed. Since physical inventory tracking is done only once every 3 months at the store, the inaccuracy of inventory in the retailer's information system accumulates over time until a physical inventory is carried out, at which time system inventory is synchronized with physical inventory. The retail store's replenishment policy, with the reorder point (s) of 36 and the target inventory (S) of 48, is based on the system inventory, not on the physical inventory. As shown in the Figure 2, the inventory of one (P1) of the four products for the first 200 days of simulation gradually decreases until the physical inventory checking is done. Towards the end of the 3 month period, product shortages start to appear, shown as lines below zero in the Figure 2. In this case study, we used a back order model in handling the shortage. The deviation of physical inventory from the system inventory for a product, P1, is shown in Figure 3. For this case, the total back order quantity is 2,086, and the average retailer inventory is 22.58.

3.2 With RFID, replenishment policy:(s=36, S=48)

With RFID deployment, inventory is tracked more accurately and in real-time, and better replenishment decisions can be made. To clearly illustrate this effect, we assumed that the accuracy of RFID is 100% and the system inventory is same as the physical inventory. With the same replenishment policy as the case in Section 3.1 (Without RFID), the inventory profile of the physical inventory is more stable as shown in Figure 4. In this case, the total back order quantity for the four products was decreased to 17 (99% reduction). However, since the fluctuation of inventory profile is much smaller and stable than the case of Section 3.1, the overall inventory on average is 27.11, which is higher than the case in Section 3.1. This presents an opportunity to decrease the inventory by modifying the replenishment policy; e.g. lowering the re-order point (s), and target inventory (S), without sacrificing customer service; e.g., back order quantity, from the case in Section 3.1.

3.3 With RFID, replenishment policy (S=38, s=26)

In this scenario, we lowered re-order point (s) to 26 from 36, and lowered the target inventory to 38 from 48. The simulation results, as shown in the Figure 5, indicates that the back order quantity for all four products is 1627 (22% reduction from the case in 3.1) and the average inventory is 17.24 (16% reduction). By shifting the replenishment policy (s, S), various combinations of customer service (back order quantity) and inventory improvement were evaluated in this simulation study.

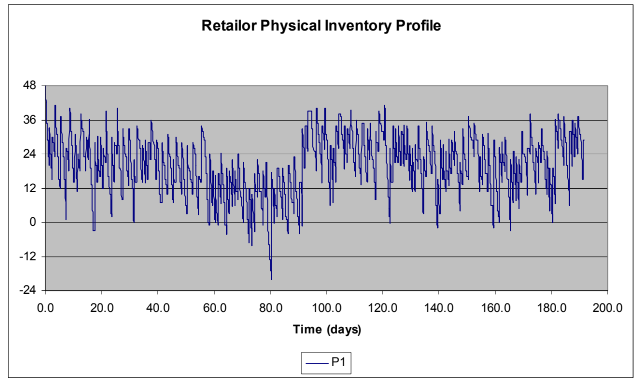

Figure 2. Physical Inventory Without RFID Deployment (s=36, S=48)

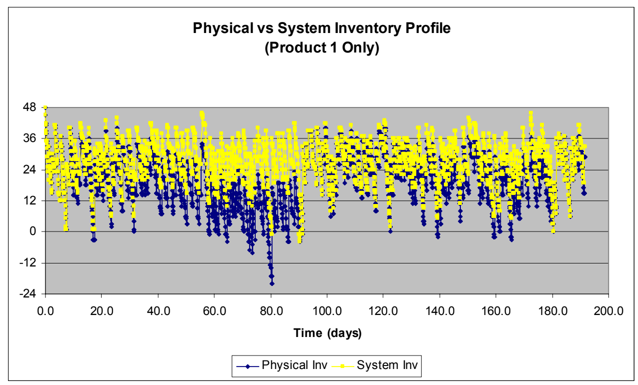

Figure 3. The Discrepancy between Physical Inventory and System Inventory

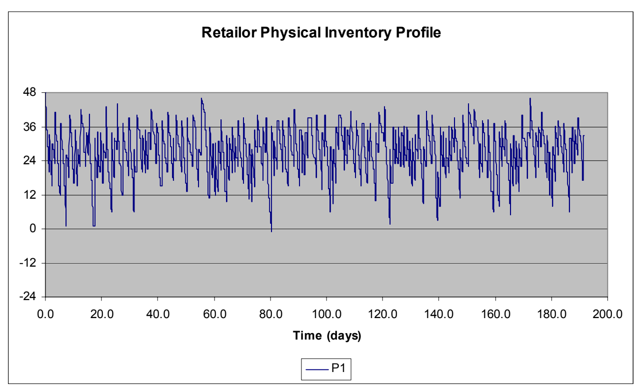

Figure 4. Physical Inventory with RFID Deployment (S=48, s=36)

In summary, better replenishment decisions can be made when RFID technology is deployed since accurate inventory data are readily available with RFID. The improvement in the quality of the decision brings an opportunity of reducing store inventory and improving customer service.

The simulation results from the three scenarios in this section are summarized in Table 1. Note that this summary is based on the four products, and the percentage improvements in case 3.2 and 3.3 are with respect to case 3.1. This serves as a good example of what we mean by the dynamic effects of RFID. Even though RFID did not directly reduce the shrinkage, its ability to identify the shrinkage losses contributes to potential improvements in inventory levels and/or customer service levels. (Direct losses of the shrinkage in material costs could also be reduced after identifying where the losses are occurring.)

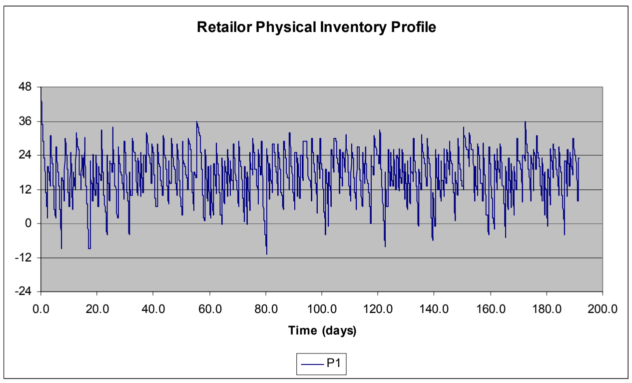

Figure 5. Physical Inventory with RFID Deployment (S=38, s=26)

Table 1. Simulation Case Study 1: Summary of Benefits

	Without RFID (case 3.1)	With RFID (case 3.2)	With RFID (case 3.3)
Replenishment Policy (s, S)	s=36, S=48	s=36, S=48	s=26, S=38
Retailer Back Order Qty	2,086	17 (99% own)	1,627 (22% down)
Retailer Avg. Inventory	22.58	27.11	17.24 (16% down)

4 CASE STUDY 2: IMPACT OF SHELF REPLENISHMENT POLICY

In this case study, we investigated how the shelf replenishment process affects shelf inventory, backroom inventory and lost sales at the retail store. Wong and McFarlane (2001) also suggested using RFID to automate and/or change the shelf replenishment process, but did not perform a quantitative analysis. For this case we used a lost sales model in handling the shortage at the store. Without RFID technology, shelf inventory is checked only periodically in person; therefore, it is difficult to replenish shelf continuously. On the other hand, with RFID technology deployed in store (e.g., using “smart shelves”), the shelf inventory can be continuously tracked; therefore, it is much easier to decide when to replenish the shelf and how much to replenish. As soon as the shelf inventory reaches the re-order point, more product can be pulled out from the backroom to replenish the shelf.

4.1 Once a Day Shelf Replenishment (s=12, S=24)

We first simulated a retail store environment where RFID technology is not deployed. In this case the shelf inventory is checked once a day by a store clerk. At that time, if the shelf inventory is below the re-order point (s), then the shelf is replenished from the backroom. The shelf replenishment here is based on an (s, S) policy with s=12 and S=24. Figure 6 shows the inventory profiles of the shelf and backroom for a product, and figure 7 shows the lost sales quantity encountered at the shelf with four products. In this simulation scenario, the total lost sales quantity is 480. The average shelf inventory is 13.24, backroom inventory is 13.99, and store inventory is 27.73.

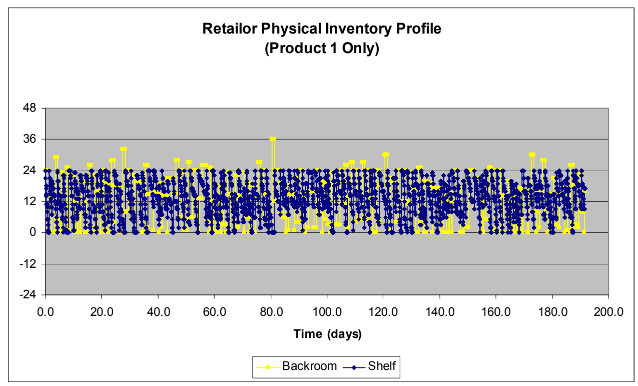

Figure 6. Shelf and Backroom Inventory with Once-a-Day Shelf Replenishment (s=12, S=24)

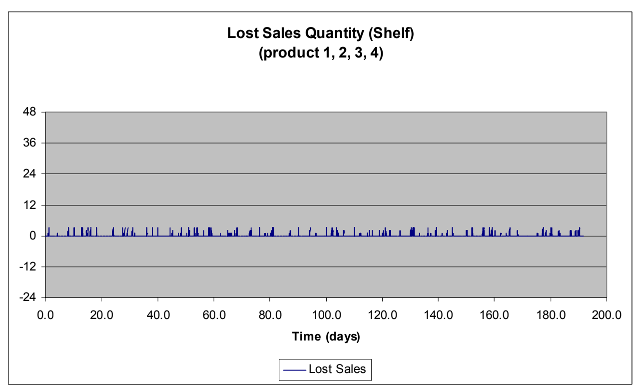

Figure 7. Lost Sales with Once-a-Day Shelf Replenishment (s=12, S=24)

4.2 Continuous Shelf Replenishment (s=12, S=24)

In this scenario, we assume that RFID technology is deployed in the retail store, and shelf inventory is checked continuously in real time. Whenever the shelf inventory reaches the re-order point (s), the information system automatically calls for shelf replenishment, and the shelf is replenished to the target inventory level (S) by pulling products from the backroom. In this simulation setting, we allowed a maximum of one replenishment per one hour. The shelf replenishment policy was set to be the same as the case in Section 4.1. The simulation results are shown in Figure 8. In this scenario, the total lost sales quantity went down substantially to only 7 from 480 with respect to the case in Section 4.1. The shelf inventory fluctuated much less, staying mostly within a much narrower range between 12 and 24. The average shelf inventory is higher at 17.13, and the backroom inventory is lower at 9.80. The overall store inventory is about the same as the previous case in Section4.1, because the store replenishment policy stayed unchanged.

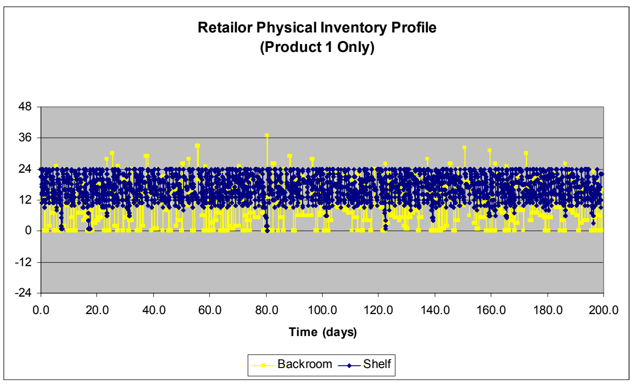

Figure 8. Shelf and Backroom Inventory with Continuous Shelf Replenishment (s=12, S=24)

4.3 Continuous Shelf Replenishment (s=6, S=18)

The simulation results in the previous case indicate that the shelf replenishment policy can be changed substantially to reduce the shelf inventory level because the shelf inventory profile stays in a narrow range. In this simulation scenario, we lowered the shelf re-order point (s) to 6 from 12, and lowered shelf target inventory (S) to 18 from 24. As shown in Figure 9, the simulation results indicate that the shelf lost sales quantity still stayed low at 7, but the shelf inventory went down to 11.75, which is 11.3% reduction from the case in Section 4.2. Since the shelf inventory level is lower but the store inventory is kept about the same, the backroom inventory in this case is higher than that of the previous case. Therefore, this simulation scenario in turn suggests an opportunity to reduce the backroom inventory, thus lowering the overall store inventory.

4.4 Continuous Shelf Replenishment (s=6, S=18) with Lower Store Inventory Target

In this scenario, we investigated the opportunity to decrease the overall store inventory level by reducing inventory on the shelf and in the backroom as a result of continuous shelf replenishment. In the previous scenario in Section 4.3, we noticed that the backroom inventory is unnecessarily high. Therefore, in this scenario we reduced the store inventory target. The results are shown in Figure 10 and Figure 11. Comparing with the case in Section 4.1, which represents a situation without RFID technology, the lost sales dropped to 79 from 480. The average inventories on the shelf, in the backroom, and in the retail store overall went down to 79, 11.17, and 21.49 respectively, representing reductions of 15.6%, 29.7%, and 22.5% respectively.

In summary, with RFID technology deployed in the retail store, there is an opportunity to replenish the shelf more often and at the right time, which will reduce inventory on the shelf, in the backroom, as well as the store as a whole. Customer service can also be substantially improved by reducing lost sales encountered at the shelf. The simulation results from the four scenarios in this section are summarized in Table 2. Note again that the percentage improvements in case 4.2, 4.3, and 4.4 are with respect to case 4.1. This case serves as an example of process transformations enabled by RFID technology, which are not easily captured by a traditional, spreadsheet based ROI analysis. It goes one step further than automating an existing process, and is possible because of the application of RFID technology.

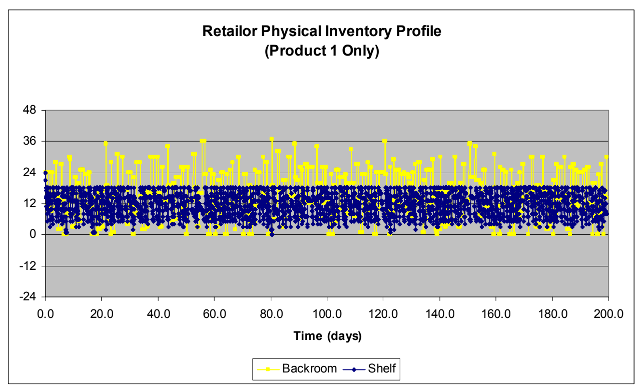

Figure 9. Shelf and Backroom Inventory with Continuous Shelf Replenishment (s=6, S=18)

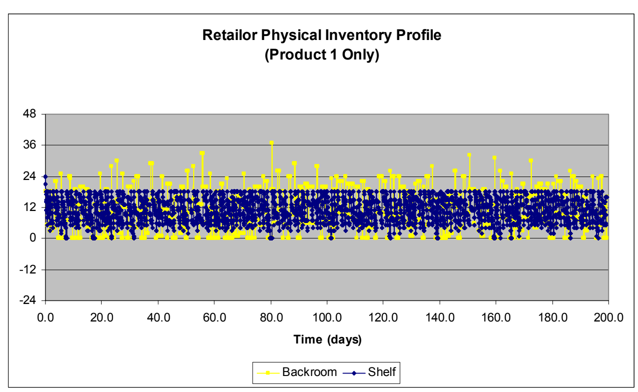

Figure 10. Shelf and Backroom Inventory with Continuous Shelf Replenishment (s=6, S=18) and Lower Store Inventory Target

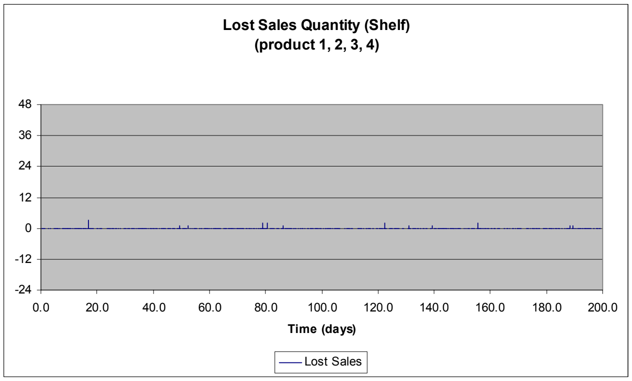

Figure 11. Lost Sales with Continuous Shelf Replenishment (s=6, S=18) and Lower Store Inventory Target

5 CASE STUDY 3: IMPACT OF VISIBILITY OF INVENTORY DATA IN THE SUPPLY CHAIN

In this case study, we investigated how complete visibility of inventory data across the entire supply chain, (manufacturer, DC, and retail store) affects the manufacturer's decision on production quantity. The quality of decision is manifested in the inventory profile in the manufacturer's distribution center in this work.. In the simulation setting, we assume that the manufacturing quantity decision is made once a day, and products are shipped (pushed) to the DC once a day. The lead time for shipment from manufacturer to DC is 1 day.

5.1 Without RFID, Manufacturing Quantity = Average Daily Sales Quantity at Retailer

In this most basic setting, we assume that RFID technology has not been deployed in the supply chain, and a manufacturer does not have access to inventory data at the DC or the retail store. The manufacturer, though, has information on the average daily sales quantity of products, on which the daily manufacturing quantity is based. The simulation results for a product, P2, are shown in Figure 12. A fixed quantity of products are pushed into DC once a day; but varying quantities of the products are pulled by the retail store based on its inventory position. The balance between the inflow to and the outflow from the DC results in the fluctuation of inventory as shown in Figure 12. The range of inventory in this case is between -10 and 140, and the average inventory quantity is 54.14 for all four products. The total back order quantity is 44.

5.2 With RFID, Manufacturing Quantity = (Target Inv. – Current Inv.) at DC

In this setting, we assume that the manufacturer has access (due to RFID) to real time inventory data at the DC, and the manufacturing quantity is calculated as the target DC inventory minus the current DC inventory position. The simulation results for a product are shown in Figure 13. Since the manufacturing quantity is adjusted based on the inventory level at the DC, the fluctuation of inventory at the DC is much smaller; the range of inventory for all four products is between 6 and 90. The average inventory is 40.18, which is a 26% reduction from the previous case in Section 5.1. The DC back order quantity disappeared completely.

Table 2. Simulation Case Study 2: Summary of Benefits

	Without RFID (case 4.1)	With RFID (case 4.2)	With RFID (case 4.3)	With RFID (case 4.4)
Replenishment Policy (s, S)	s=12 S=24	s=12 S=24	s=6 S=18	s=6 S=18
Shelf Lost Sales Quantity	480	7 (99% down)	7 (99% down)	79 (84% down)
Shelf Avg. Inventory	13.24	17.13	11.75 (11% down)	11.17 (16% down)
Backroom Avg. Inventory	13.99	9.80	15.20	9.83 (30% down)
Retailer Avg. Inventory	27.73	27.41	27.40	21.49 (23% down)

5.3 With RFID, Manufacturing Quantity = (Target Inv. - Current Inv.) at (Manufacturer + DC + Retailer)

In this setting, we assume that the manufacturer has real time inventory information not only at the DC but also at the retail store. The manufacturing quantity is calculated as the total target inventory of the manufacturer, DC, and retailer minus the current inventory of manufacturer, DC, and retailer. The simulation results for a product, P2, are shown in Figure 13. Here, the fluctuation of DC inventory is even smaller than the previous case in Section 5.2; the range of inventory is between 19 and 84 for all four products. The average DC inventory is 41.80, which is a 23% reduction from the case in Section 5.1. There is no back order in this case either. Since the range of inventory is very small and the average DC inventory is relatively high, this presents an opportunity to reduce the DC inventory by lowering the target inventory at DC, which is discussed in the next section.

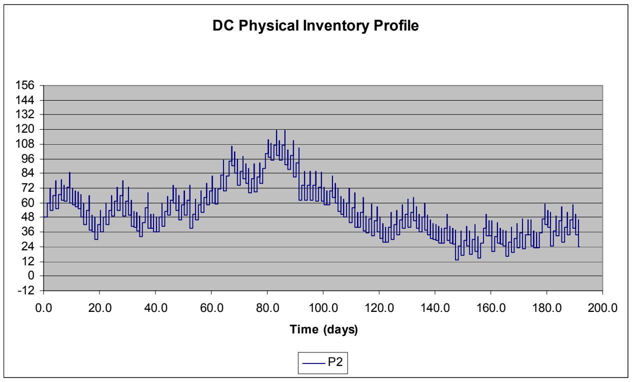

Figure 12. DC Inventory Profile When Daily Manufacturing Quantity is Fixed (Set to Average Daily Sales Quantity)

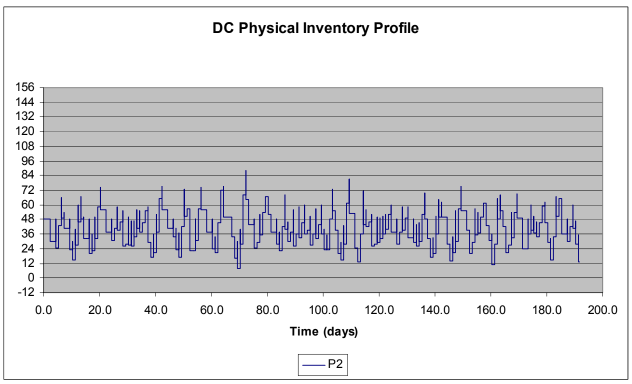

Figure 13. DC Inventory Profile When Daily Manufacturing Quantity is Based on DC Inventory

5.4 With RFID, Manufacturing Quantity = (Target Inv. – Current Inv.) at (Manufacturer + DC + Retailer) with Lower Inventory Target at DC

As explained in the previous section, there is unnecessarily high level of inventory at the DC in the scenario in Section 5.3. Therefore, in this scenario we lowered the target inventory of the DC while keeping other simulation parameters constant as that in Section 5.3. The simulation results are shown in Figure 14. The range of the DC inventory for all four products is similar to the case in 5.3, but the average inventory is 28.52, much smaller than the previous case. Back order still did not occur. Comparing the simulation results with the case in Section 5.1 (without RFID), this case (with RFID) identified an opportunity for a 47% reduction of DC inventory, while eliminating the back order completely. The simulation results for case study 3 are summarized in Table 3. This case serves as an example of process transformation taking advantage of new data offered by RFID technology.

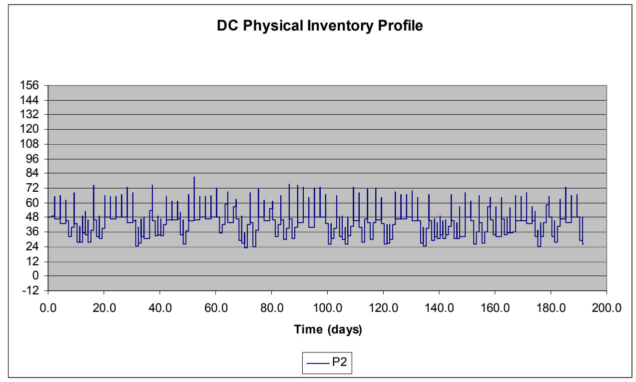

Figure 14. DC Inventory Profile When Daily Manufacturing Quantity is Based on Inventory in Manufacturer, DC, and Retailer

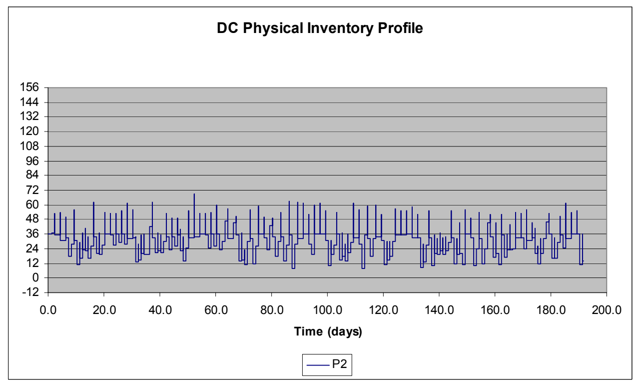

Figure 15. DC Inventory Profile When Daily Manufacturing Quantity is Based on Inventory in Manufacturer, DC, and Retailer and with a Lower Inventory Target at DC

Table 3. Simulation Case Study 3: Summary of Benefits

	Without RFID (case 5.1)	With RFID (case 5.1)	With RFID (case 5.3)	With RFID (case 5.4)
Manufacturing Quantity	Avg Daily Sales Qty at Retailer	(Target Inv-Inv) at DC	(Target Inv-Inv) at (Mfg+DC +Retailer)	Same as 5.3, Lower DC Inv Target
DC Inventory Range	-10 to 140	6 to 90	18 to 84	5 to 72
DC Avg. Inventory	54.14	40.18 (26% down)	41.80 (23% down)	28.52 (47% down)
DC Back Order	44	0 (100% down)	0 (100% down)	0 (100% down)

6 CONCLUSION AND FUTURE WORK

Through this simulation study, we demonstrated that there are opportunities for RFID technology to provide significant benefits in a supply chain, well beyond the automation oriented advantages such as labor savings. We have chosen to analyze simple scenarios that might be extreme and might not be completely realistic, so our numerical results should not be used directly. However, our results do show the potential of RFID in a supply chain that is not widely known in the literature or commonly explored in business practice. Such potential should increase the chance of RFID being deployed as a standard instrument in manufacturer-retailer supply chains.

It is true that some of the scenarios we studied are possible without RFID, for example, by integrating different sources of data available today in a real-time environment. RFID represents one of a number of possible solutions to obtain the required data. It is therefore important to do a cost-benefit analysis to evaluate each alternative solution. The approach discussed in this article is useful for the benefit estimation of such an analysis.

We are currently investigating more complex scenarios that are closer to practice. This includes the cases of an RFID read accuracy of less than 100%, other supply chain configurations such as multiple retail stores and the addition of retailer owned distribution centers. It would be interesting to find out whether complexity in the supply chain configuration would amplify or diminish the effect of the RFID benefits explored here.

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AUTHOR BIOGRAPHIES

Young M. Lee has been working in the mathematical science department of IBM's T.J. Watson Research Center since 2002 in the areas of supply chain simulation and optimization. Prior to joining IBM, he had worked for BASF Corporation for 14 years, where he had founded and managed the Mathematical Modeling Group, and led development of numerous optimization and simulation models for various logistics and manufacturing processes. He has a B.S., a M.S., and a Ph.D. degree in Chemical Engineering from Columbia University in the City of New York. His research interest includes simulation and optimization of supply chain and manufacturing processes. His email address is <ymlee@us.ibm.com>.

Feng Cheng is a Research Staff Member at the IBM T.J. Watson Research Center in Yorktown Heights, NY. He received a Ph.D. degree in Operations Management from the University of Toronto. His current research interests include modeling and analysis of stochastic systems with applications in manufacturing systems, supply chain management, and e-commerce. His e-mail address is <fcheng@us.ibm.com>.

Ying Tat Leung is a Research Staff Member at the IBM Thomas J. Watson Research Center in Yorktown Heights, New York. He is currently leading a research program in business value modeling. His recent work includes many aspects of supply chain management: demand planning, inventory replenishment, and product pricing. Prior to joining IBM, he was a Senior Member of Research Staff at Philips Laboratories, the North American research arm of Royal Philips Electronics of the Netherlands. Ying Tat holds a B.Sc. degree from the University of Hong Kong, M.S. and Ph.D. degrees in Industrial Engineering from the University of Wisconsin - Madison. His e-mail address is <ytl@us.ibm.com>.