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A COMPREHENSIVE SYSTEM DYNAMICS MODEL FOR RETAIL OPERATIONS: RFID ADOPTION IN THE RETAIL SECTOR

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ABSTRACT

This study develops a comprehensive system dynamics model for retail operations that includes the operations in marketing, merchandising, and store execution of supply chain (SC) management. The simulation is built based on a Delphi study and shows that benefits in marketing and merchandising operations are as significant as those in SC.

1. INTRODUCTION

The first wave of technology that changed retail operations management significantly was Point of Sale (POS) systems with barcode scanning. These systems provided information on customers' purchases which was useful in managing inventory, the supply chain, promotions, and advertising (Fraza, 2000). The next generation of technology for retailers, Radio Frequency Identification (RFID), can provide information to track customers as they enter the store, walk through the aisles, search for and select items, and finally purchase them. In RFID technology, radio waves automatically detect items, reading multiple items simultaneously and instantly. Items containing RFID tags do not need to be "in the line of sight" of the readers, but can be read from a few feet afar. Therefore, RFID is intended to replace or supplement barcodes in retail operations management (Karkkainen and Holmstrom, 2002; Prater et al., 2005).

Item-level RFID information technology in retailers is in its infancy, and organizations are seeking an extensive cost benefit analysis effort. Although innovative technologies with high risks can still bring strategic advantages for businesses, such ideas are not as available as they were in the 1990's and earlier. RFID is a new area to explore in retail and manufacturing operations, for example, and investing in such technology with uncertain returns has a high risk.

Many industries, such as healthcare, the military, and financial services, are working on implementing this technology. However, research shows that retailers will take up the largest part of the market; their RFID market value will form more than 40% of the RFID market by 2016 (Figure 1) and item level share will be more than 50% of the investment (Figure 2). RFID technology impacts all retail operations; however, before initiating any investment, managers have to understand the potential benefits of investing in this technology. Some major retailers and manufacturers, such as Wal-Mart and its suppliers, have already adopted RFID at the pallet level. However, item-level RFID deployment is in the early stages and has only been implemented in pilot level studies. Managers need to identify the advantages of implementing the technology before any investment.

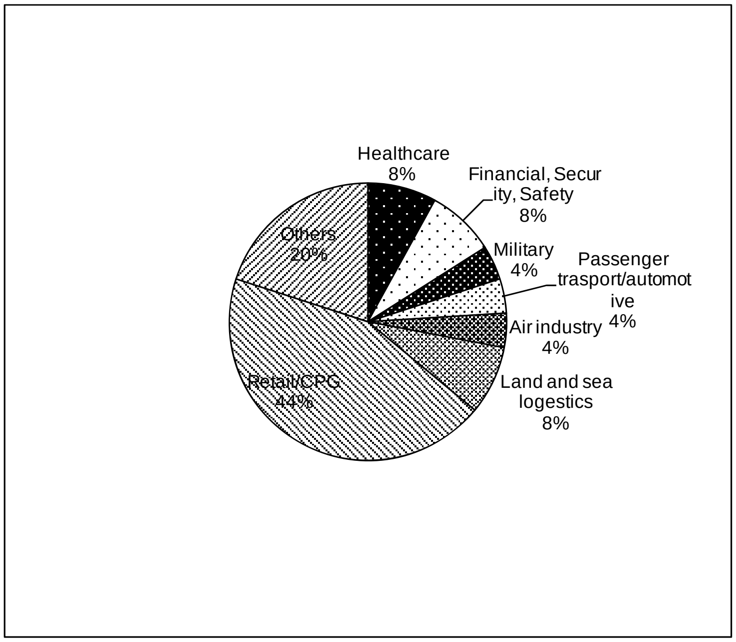

Figure 1 RFID market value perspective by 2016 (IDTechEx)

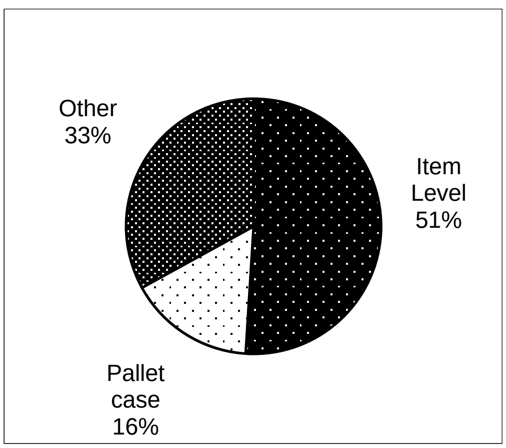

Figure 2 Item-level RFID market value (IDTechEx)

There are two types of RFID tags: active and passive. A passive tag is less expensive and does not contain a battery (Rawal, 2009). Power from the tag reader activates it and extracts information upon request. Passive tags must be within meters of the reader to be detected. Active tags, on the other hand, have a battery. They are more powerful and can be detected within a longer range from the reader but are also more expensive. For item-level RFID in retail situations, passive tags are probably more appropriate in terms of costs as well as functionality (Prater et al., 2005; Gaukler et al., 2007).

Retail operations management includes 5 major elements: store and service factors, merchandise management, pricing, supply chain management, and technology (Krafft and Mantrala, 2006). Implementation of this technology impacts all retail operations and benefits them in different ways. Following is a brief review of potential advantages of RFID to each element in retail management.

Store and Service factors are determined to help customers have a more pleasant and convenient shopping experience. In RFID equipped stores, for instance, a Personal Shopping Assistant (PSA) with a touch-screen equipped tablet PC is attached to each cart. These PSAs provide "decision convenience" by offering information about each item, "access convenience" by locating items needed, and "transaction convenience" by automating checkouts and returns. All of these factors enhance customer service in a retail store (Krafft and Mantrala, 2006).

Merchandise management intends to provide items for customers when customers need them. RFID helps to manage the availability of items on the shelves. Monitoring of items on the shelves gives better information visibility to store managers. In addition, reducing out-of-stock problems (OOS) and increasing inventory accuracy guarantee that items are available on time, meeting customer demand and enhancing the merchandise management process (Doerr and Gates, 2003).

Pricing can also be improved through RFID deployment. Price is one of the major factors in increasing retailers' profit. Among retailers, there has been a paradigm shift from price optimization to pricing process improvement. Pricing optimization models in microeconomics are intended to determine the optimal price of products to maximize the profit. A pricing process, on the other hand, is the decision-making process that involves one or more price components such as discounts, rebates, and bonuses to determine the final price of a product. With enhanced visibility provided by RFID, for example, retailers can observe customers' shopping behavior and use this information to help set the initial pricing and markdown prices. Moreover, promotion and marketing will also change with real-time data focused on customers' behavior (EPC Global , 2008; Krafft and Mantrala, 2006).

Supply chain management is improved significantly by fewer out-of-stock occurrences and less inventory inaccuracy (Atali et al., 2005; Heese, 2007; Gaukler and Seifert, 2007; Hardgrave et al., 2008). Information visibility provided by RFID decreases the uncertainty in the supply chain and consequently decreases high inventory costs and errors in forecasting the number of promotional items needed (Delen et al., 2007; Zhou, 2009). This area of retail operations has been studied more extensively than other areas in retail management.

RFID offers a wide range of benefits and is the technology that can give a competitive advantage to retailers in managing stores (IBM, 2004). How item-level RFID influences all components involved in retail management needs to be studied comprehensively in order to measure the benefits of this technology. The benefits from different applications are either tangible (direct), such as those in the supply chain, or intangible (indirect), such as those in improving customer service.

Based on the literature and the Delphi study, we found the applications by which item-level RFID can impact the operations when all products are tagged (Table 1). Automatic Perpetual Inventory (PI) is an application that is obtained if RFID readers are installed at the entrance/exit doors and checkout points, in addition to frequent manual checks using RFID handheld readers. Frequent manual checks decrease OOS events by reducing the inventory inaccuracies caused by misplacement, theft, and transaction errors. In addition, it decreases forecasting demand errors which result in OOS decrease. Real time visibility is provided by storewide implementation of RFID that includes smart shelves as well. Another application is implementing product locating tools such as smart carts or smart dressing rooms that help more customers find the products they desire.

Table 1 Implementation Options

Application	Implementation	Benefits
Automatic PI	All products tagged Readers at the entrance/exit doors and checkout points Using handheld reader for frequent cycle counting	Reducing OOS caused by misplacement/theft/transaction error/forecasting error/lighter or fewer markdowns
Real time visibility	All products tagged Readers at the entrance/exit doors and checkout points Using smart shelves	Reducing OOS caused by misplacement/theft/transaction error/forecasting error/lighter or fewer markdowns
Product locating	All products tagged Readers at the entrance/exit doors and checkout points Using customer shopping assistants such as smart carts and smart dressing room	Increasing the number of customers who can find their desire products

We use a system dynamics model to see how item-level RFID improves retail operations, and to identify and quantify the benefits of such an investment within an organization. In the next section we describe system dynamics simulation model that includes causal loops, stock and flow diagrams for various applications. At the end we conclude the paper by discussing the contributions, limitations, and future directions in the study.

2. SYSTEM DYNAMICS MODEL

System dynamics (SD) has been used extensively in the area of information technology applications, which usually change an organization's business processes and behavior. Using system dynamics, possible changes in organizations are projected and analyzed through conceptual models and simulations (Forrester, 1958; Sterman, 2000; Gregoriades and Karakostas, 2004; Céline et al., 2005; Marquez and Blanchar, 2006). Marquez and Blanchar (2006) developed a system dynamics model to analyze a variety of investment strategies in a high tech company. They analyzed strategies and trade-offs that are hard to investigate in real cases. SD has also been used in operations management such as in supply chain management. Angerhofer and Angelides (2000) present a taxonomy of research studies on SD modeling in supply chain management. These studies look at the effect of various factors such as lead time, demand amplification, ordering policies, etc. on the performance of supply chains from manufacturers to retailers (Barlas and Aksogan, 1996; Anderson et al., 1999; Akkermans et al., 2003; Angerhofer and Angelides, 2006). For example, Barlas and Aksogan (1996) in a case study with an SD simulation show how product diversification increases sales by better meeting customer expectations and at the same time increases lost sales as a result of lower stock levels held for each product. Most SD models in the literature look into the effects of various parameters along the supply chain, i.e., the coordination of operations from manufacturer, distribution center, retailer, and final customers (Barlas and Aksogan , 1996; Hafeez, et al., 1996;

Liu et al., 2011). Liu et al. (2011) proposes a system dynamics model to analyze how out-of-stock behaves in retail operations. De Marco et al. (2012) conduct a case study that looks into how RFID impacts an apparel store inventory control and management operations. They develop an SD simulation model to show the changes in inventory control, inventory turnover, and staff time when item-level RFID is implemented in a store. There are also simulation studies that look into pallet and case level RFID and its impacts in manufacturing and supply chains (Swamy and Sarma, 2003; Sarac et al., 2008).

Our model measures the benefits of integrating RFID throughout the value chain in retailer operations, from supply chain management to pricing and customer service management (Curtin et al., 2007). A system dynamics approach as a predictive model can map complex relationships among the retail operations processes into a model by which one can dynamically measure the effect of any changes such as RFID in the parameters over time.

2.1 Casual Loops

In system dynamics modeling, validation of the structure is the most important part of the study (Barlas, 1994). Causal loop diagrams as the conceptual model of the operations representing the relationships between variables in a system, should be validated. Delphi study is a well-known method that helps researchers to form insights about causal relationships in operations processes (Scavarda et al., 2006). Our casual loops are validated based on opinions of retail experts who participated in a Delphi study that was conducted in 2009 (Kasiri et al., 2011). Kasiri et al. develop a balanced score card model based on interviewing 10 retail managers from various types of retail establishments who were expert in RFID to provide some insight on how item-level RFID can be integrated into retail operations. A balanced score card model enables us to look into operations performance measures in each dimension. Then, by employing system dynamics concepts, we can present cause-and-effect relationships between performance measures in different categories (Bianchi and Montemaggiore, 2008). Following are the description of three causal loops for three areas of retail operations, i.e., supply chain, marketing, and merchandising.

2.1.1 Supply chain management causal loop

The store execution of the supply chain, i.e., every operation involved in inventory and shelf control and management from receiving items from distributors to delivering them to customers, was examined. Retailers can take advantage of item-level RFID to track their individual products on shelves and in the backstore (Kambil and Brooks, 2002). Item-level RFID provides different levels of information visibility, depending on various deployment levels. Most available studies on item-level RFID examine its impact on improving supply chain operations in order to avoid OOS situations and inventory inaccuracy (e.g., Gaukler et al., 2007; Bai et al., 2009; Rekik et al., 2008 and 2009; Zhou, 2009). This study looks at two levels of enhanced information visibility: automatic PI and real time visibility. These visibility levels lead to the same type of benefits but to different extents (Figure 3). There is a positive loop between shelf management and inventory management. Enhanced visibility provided by RFID leads to, for example, more frequent shelf replenishments and reduces transaction errors in shelf management. This produces a lower OOS on shelves and more accurate shelf records, which generates a lower OOS in inventory management (since inventory ordering is based on more accurate forecast of demand.) Conversely, a more accurate ordering in inventory leads to a lower OOS in inventory and subsequently a lower OOS on shelves. These benefits result in more number of customers who can purchase their desired products and consequently increase revenue.

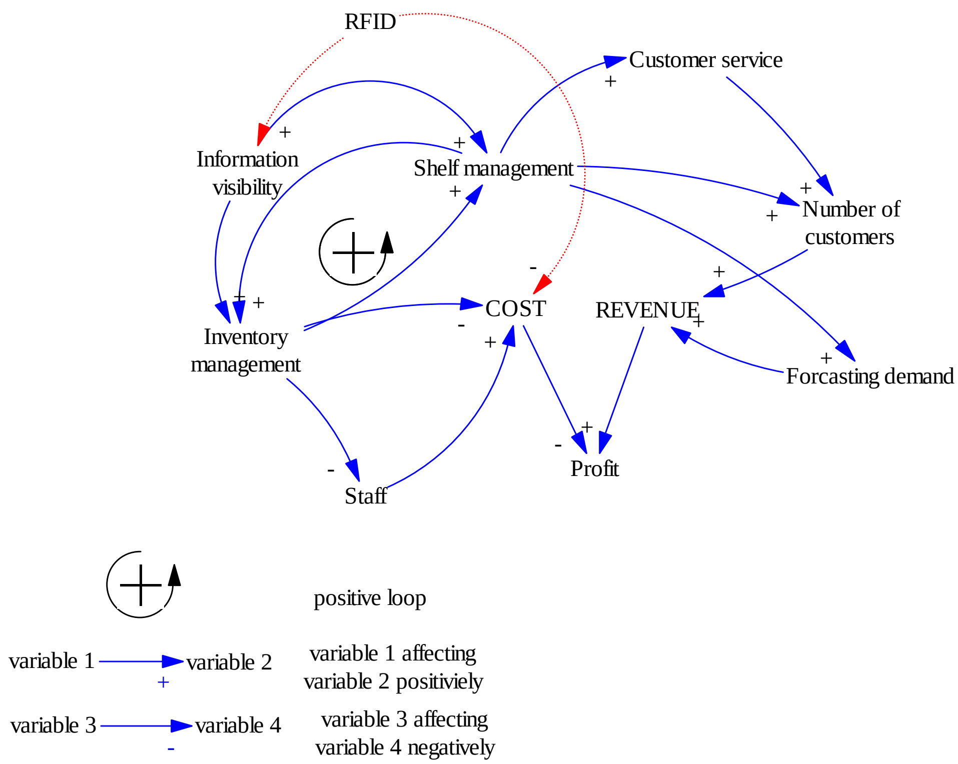

Figure 3 Supply chain management causal loop

Automatic PI

In the lowest level of enhanced visibility, the backstore inventory management process is improved by providing readers in the backstore and at Point of Sale (POS). Inventory records are updated at the backstore entrance/exit doors and at POS when an item is purchased. Cycle counting and PI are performed automatically through the use of RFID handheld readers, which work much faster than manual operations. The visibility of items in inventory improves inventory accuracy, and the record of items on the shelves is more accurate. Shrinkage, including theft and misplacement, is detected easily and more often through automatic PI. This level of deployment seems to have the lowest cost and fewest technical restrictions among the three levels. Case studies of Dillard's (Hardgrave, 2009a), American Apparel (2009), and Bloomington's (Hardgrave, 2009b) have measured the benefits of item-level RFID on inventory management in retail stores when handheld readers are used in PI and cycle counting, in addition to readers at the POS and backstore exit/entrance doors.

Real time visibility

The second level of enhanced visibility occurs when smart shelves are added to the previous level. This level provides real-time shelf visibility on the store floor as well as at the back of the store and, compared to the first level, further improves inventory accuracy, shelf replenishment, and loss detection (Doerr and Gates, 2003). The visibility of items on shelves leads to real-time detection of misplacement and theft and thus adjustment of the inventory level. Shelf visibility also allows retailers to monitor customer shopping behavior to some extent. A case study conducted at Tesco in the UK, which implemented smart shelves to track DVDs and software games, discusses how this tool can boost customer satisfaction (Berthiaume, 2004). However, the cost of deploying smart shelves is significant. In addition, some practical issues with smart shelf mobility have delayed their use even at the pilot levels.

The Delphi study experts confirmed the results of analytical research that shows RFID adoption at the shelf level can release shelf space and reduce inventory holdings (Kasiri et al., 2011; Szmerekovsky, Tilson, and Zhang, 2009) because shelf replenishment can be done more frequently. In addition, inventory inaccuracy is reduced because misplacement and theft are detected faster and execution errors are lowered. In particular, when demand uncertainty increases, enhanced item-level visibility on the shelves enables retailers to improve performance compared to retailers without such visibility.

2.1.2 Marketing management causal loop

The purpose of marketing operations is to promote goods and services within the store. Customer shopping experience, pricing management, and customized promotions are among the processes that are influenced by item-level RFID as shown in Figure 4. In the following we look into RFID enabled changes in customer shopping experience and pricing management. The interactions described here are important in realizing item-level benefits, even though there is no explicit feedback loop in the diagram. The processes described in the diagram influence the behavior of the loops in the supply chain and merchandising causal loop diagrams. For example, automatic check-out reduces transaction errors which leads to less inventory inaccuracy and consequently a lower OOS.

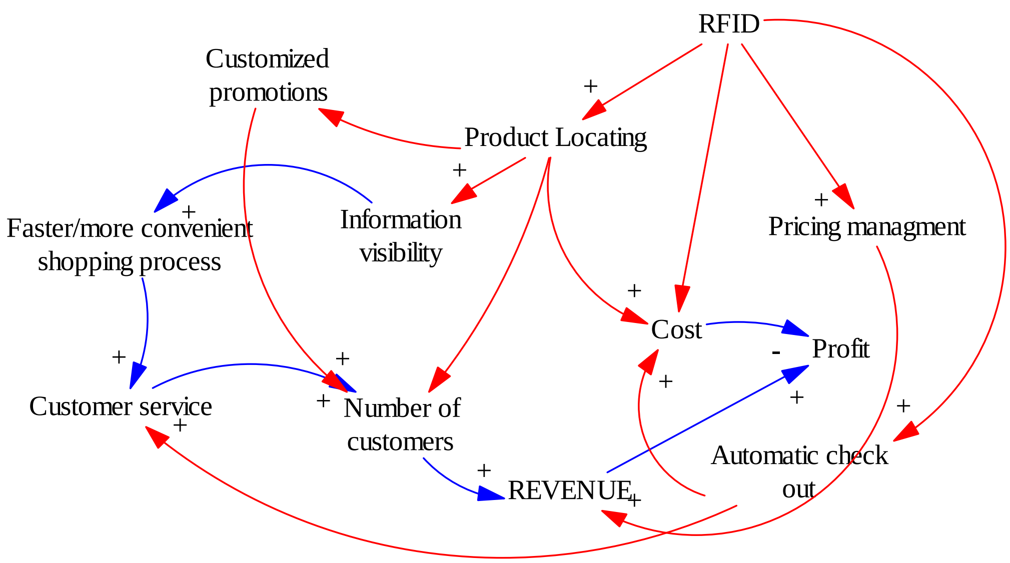

Figure 4 Marketing management causal loop

Customer shopping experience

Various applications of enhanced visibility in stores can transform the customer shopping experience. For example, shopping carts and dressing rooms can be equipped with RFID readers and touch-screen monitors that allow customers to search for information on products and locate items throughout the stores.

There are also some case studies (by the Metro group) on how RFID tools such as smart carts or smart dressing rooms can make customers' shopping experiences faster and more convenient (Krafft and Mantrala, 2006; Frédéric et al., 2009). Assuming that inventory management has deployed item-level RFID in its operations, smart carts, smart dressing rooms, and automatic checkout all contribute to speeding up shopping and providing a more convenient shopping environment. These tools also free up staff time. For example, in automatic checkout, the time previously spent in manually checking out customers can be spent providing better customer service.

The impact of RFID on customers' shopping experience is primarily related to the customers' response, either positive or negative, to RFID tools. Automatic check-out, smart carts, or smart dressing rooms/kiosks are all changing the way customers behave in stores. Our study is based on the assumption that the customers' responses to the deployment of these RFID tools are positive.

Automatic check-out

Automatic check-out charges customers' accounts automatically when customers pass through the check-out lines so customers spend less time in check-out lines and feel more efficient. In addition to saving time for customers, automatic check-out saves labor that can be spent providing customer service. It also reduces check-out (transaction) errors by removing manual operations.

Product-locating tools

One application of RFID at the item level is helping customers locate the products they need. Product-locating tools such as smart carts, smart dressing rooms, or kiosks enable customers to locate products more easily and obtain information on any individual item faster. Customers can find answers to most of their questions regarding product availability and location. A faster and more convenient shopping experience improves the store image and, in the long term, increases the number of customers.

Pricing management

The Delphi study experts believed that enhanced information visibility does not change the original price of items. However, enhanced information visibility on shelves and in backstores leads to fewer and lighter markdown prices. About 30% of items are not placed on shelves in a timely manner and thus stay in the backroom so long that they come to the floor at already marked-down prices (Aberdeen Group, 2008). On-time and fast shelf replenishment increases the number of items sold at full price and decreases the number of markdowns. This benefit results in a higher average price for each product and directly increases the revenue.

2.1.3 Merchandise management causal loop

Merchandise management intends to provide items for customers when customers need them, and RFID helps to manage that effort (Doerr and Gates, 2003). Enhanced visibility of items on the shelves helps store managers increase the availability of the products to customers with more frequent shelf replenishments. As mentioned by Szmerekovsky et al. (2009), enhanced visibility of shelf information reduces the shelf space needed for an item and releases capital by reducing the inventory holdings. Therefore, retailers using the extra capital and space can offer a wider variety of products (Figure 5).

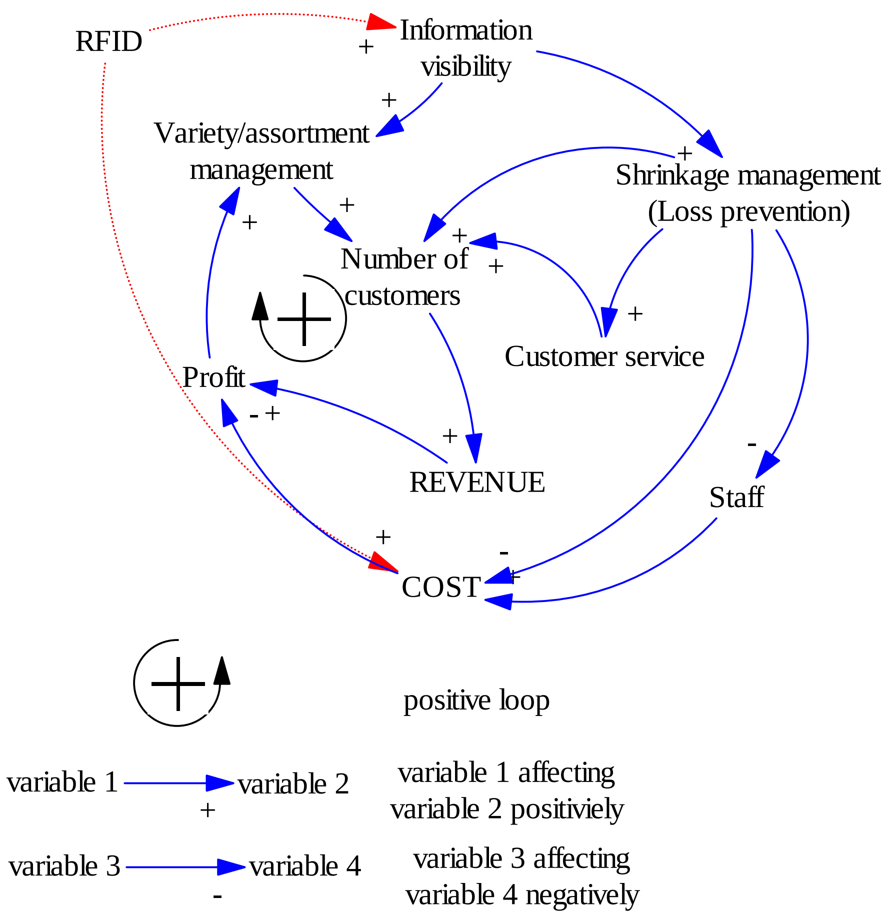

Figure 5 Merchandise management causal loop

Enhanced information visibility and applications such as smart carts and smart dressing rooms also help managers to determine what products are complementary. For example, loyalty cards provided by RFID enable retailers to monitor customers' behavior as they enter a store and look at different products. This monitoring helps managers select a more appealing variety and assortment of products. The feedback loop represents that more customers produce more information leading retailers to identify customers' desired variety. In addition, it releases capital that allows retailers to enlarge their assortment of wares in stores. On the other hand, more assortments lead to having an increased number of customers finding their desired items.

2.2 Stock-and flow Diagram

Given the validated causal loop diagrams from the Delphi study, we need to build stock-and-flow diagrams (SFD) in order to derive the equations in the simulation model. SFDs represent the relationships in more detail than does a causal loop diagram. Stocks are fundamental elements that generate behavior in systems, and flows or rates are what make stocks change. For example, inventory in the backroom in which we keep items is a stock (Figure 6). The diagram shows two stock levels for inventory. "Inventory Record" stock represents the inventory record that stores keep based on PI inventory systems and frequent cycle counting. "Real Items in Inventory" stock shows how many items really exist in the backstore. In this diagram, receiving orders is an inflow and shelf-replenishment is an outflow. The inflow is triggered if the level of the inventory reaches the reorder point. An order for a new shipment is placed, and new items arrive after the lead time has passed. The outflow is triggered by a request for shelf replenishment with a certain amount.

Inventory inaccuracy is the discrepancy between the inventory level on the records and the actual number of items in the backstore. The discrepancy can be caused, for example, by theft or misplacement. Theft and misplacement are outflows from the actual inventory but they do not appear on the inventory record. RFID visibility rate (0-1) is a percentage that shows how close these two stocks are. For example, a perfect RFID visibility (= 1) means that all theft and misplacement is detected so there is no discrepancy and no inventory inaccuracy. As RFID visibility decreases, discrepancy and inventory inaccuracy increases. OOS occurs when the inventory on record is higher than the real number of items in the inventory and the system does not trigger a reorder event. In such a situation, when the store needs items for shelf replenishment, no items are in the inventory. This is considered OOS and leads to a loss in sales. The inventory record is updated if a manual check is performed or if there are not enough items to replenish the shelves. The latter case results in OOS if the level of the inventory does not meet the level of customers, and an out of stock event leads to updating inventory records.

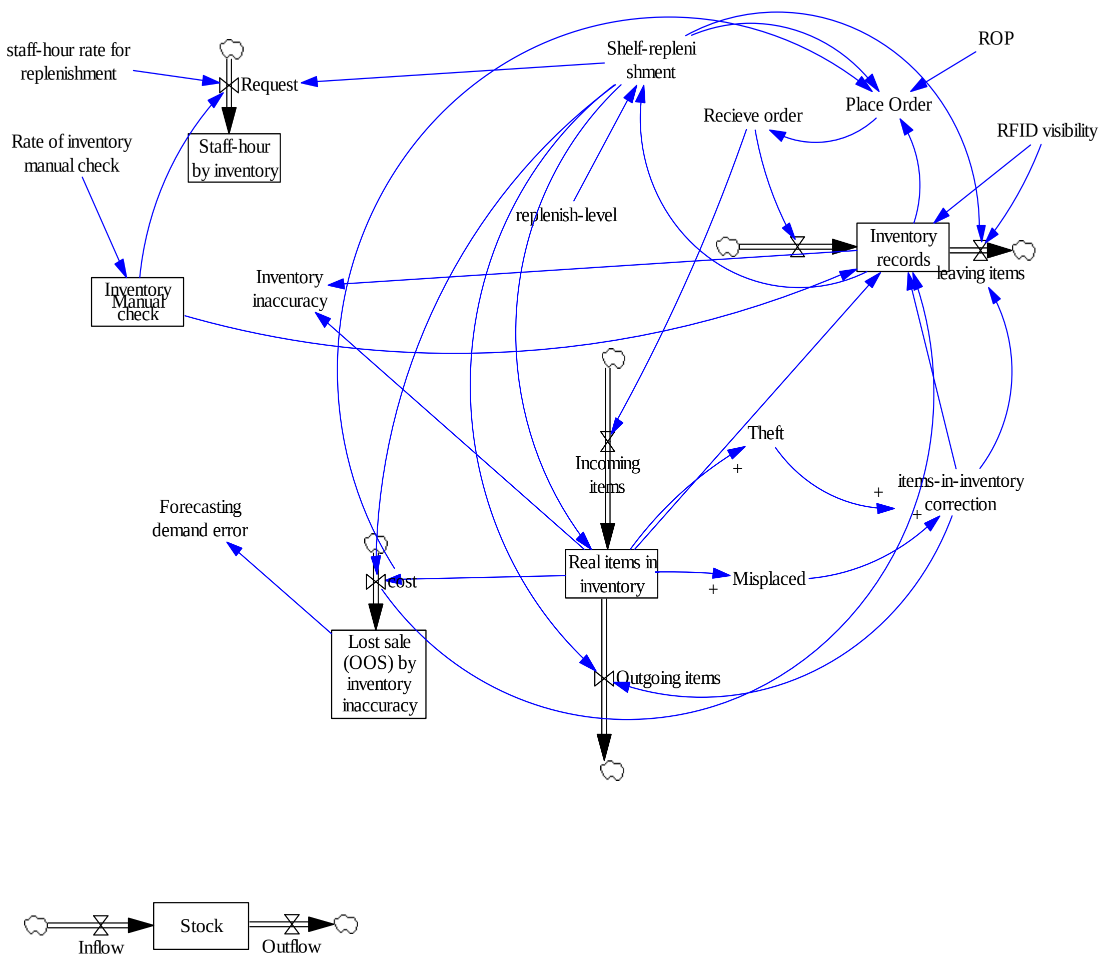

Figure 6 Stock-and-flow diagram for inventory management

SFDs are built for three processes: to model backstore operations management, to map shelf operations management, and to present marketing and merchandising operations management. We implemented backstore operations and shelves operations SFDs to be able to measure shelf OOS and shelves OOS separately. While these two processes are interrelated, improvements in backstore OOS improves the forecasting errors and improving shelf OOS increases product availability (Gruen and Corsten, 2008). Because these three SFDs are interrelated, the comprehensive retail operations model integrates the SFDs into one model (Figure 7).

The relationships described in the causal loops diagrams change the levels of these stocks and are implemented through the flows in SFDs. For example, a theft event decreases either inventory level or shelf level while it also decreases sales. Integrating these SFDs produces a comprehensive SFD for retail operations that are influenced by item-level RFID (Figure 7). The purchasing process starts when a customer goes to a shelf and takes an available item. A shelf replenishment request with the number of items needed is sent to the inventory management process. The shelf record then is updated when replenishment units are received from the inventory. If product locating tools in the merchandising and marketing process are used, customer satisfaction improves and the number of customers shopping in the store increases with associated additional positive results as outlined earlier. Theft, misplacement, and transactions errors make record inaccuracies in both shelf and backstore inventory levels that are equal to the difference between record and real item. Record levels will be the same as real items on the shelves if a manual count with (either RFID or barcode) handheld reader happens.

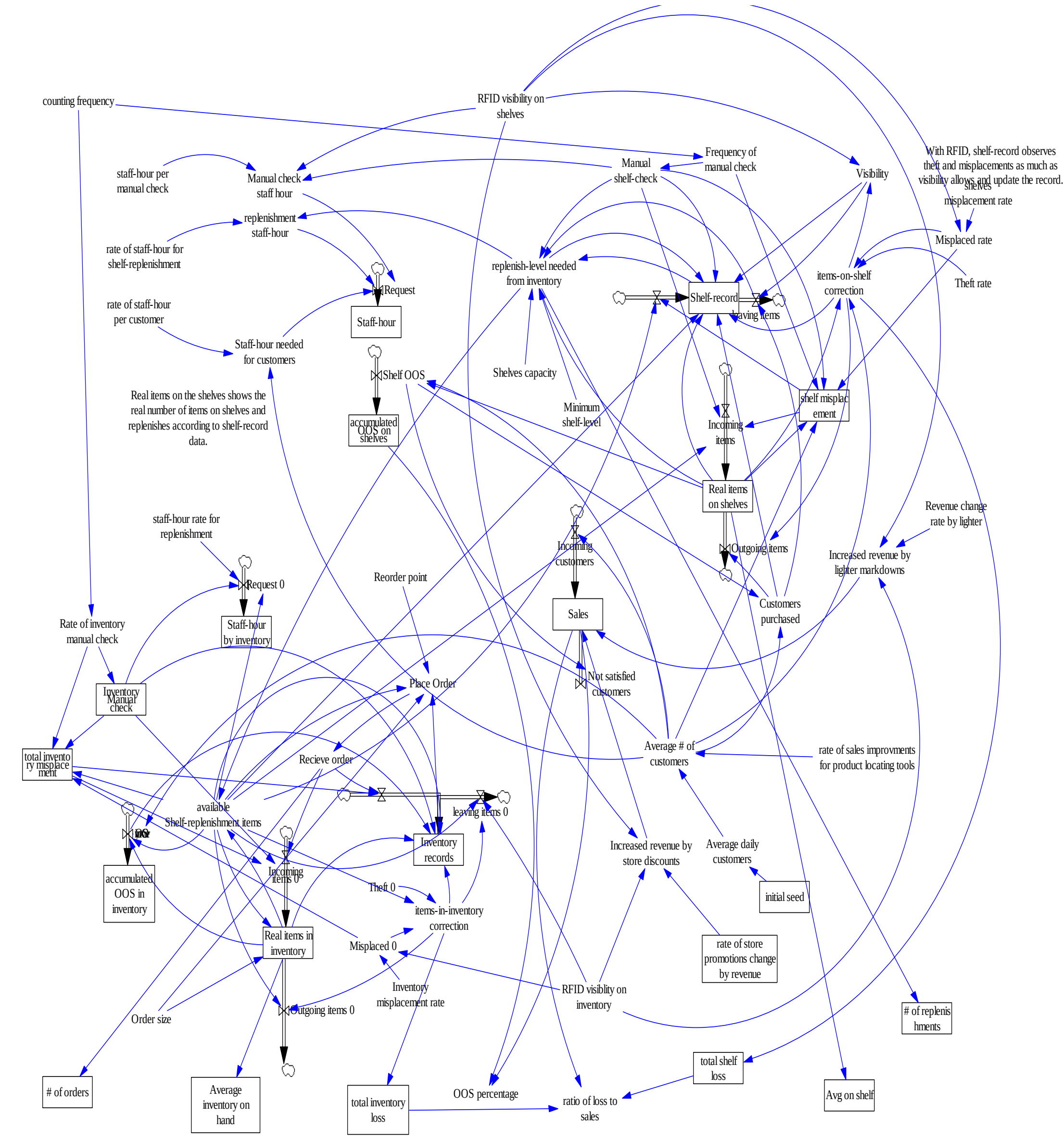

Figure 7 Comprehensive retail operations Stock-and-Flow diagram

2.3 Simulation Parameters

Simulation parameters such as theft and misplacement rates come from the literature. The misplacement, theft, and transaction error rates are stochastic parameters of the model. Previous studies show that the rate of misplacement and theft can vary from 1% to 5% in retail stores. Raman et al. (2001) report that a median of 3.4% of items are not found on the sales floor because of misplacement and theft. Fleisch and Telkamp (2005) looked at a range of 1-5% to analyze different scenarios in their simulation model. These studies also show that misplacement and theft follow a uniform distribution. Some inventory and shelf parameters such as the size of shelves, inventory, and orders for a given product depend on the number of daily customers.

Assuming that we look into the behavior of a sample product in stores, the daily number of customers for the product is set to a certain number (e.g., average of 30 customers) in the first phase and a perfect store in which there are no thefts, misplacements, or transaction errors is set up (Figure 8). Starting with large numbers for parameters such as the size of shelf, inventory, and reorder points, we decrease them as much as possible as long as OOS is zero. Next, shrinkage and transaction problems are introduced in order to observe how those problems lead to OOS. We adjust the inventory and shelf parameters so that with a monthly manual counting of items the OOS is up to 4%. Thus, the simulation shows if the inventory size is 230, the shelf capacity is 150, and the store conducts a monthly manual counting of this product, they experience a 3.4% out of stock caused by theft, misplacement, and transaction errors (Gruen and Corsten, 2008). Finally in the third phase, various item-level RFID applications are introduced in order to demonstrate how performance measures such as OOS and sales change.

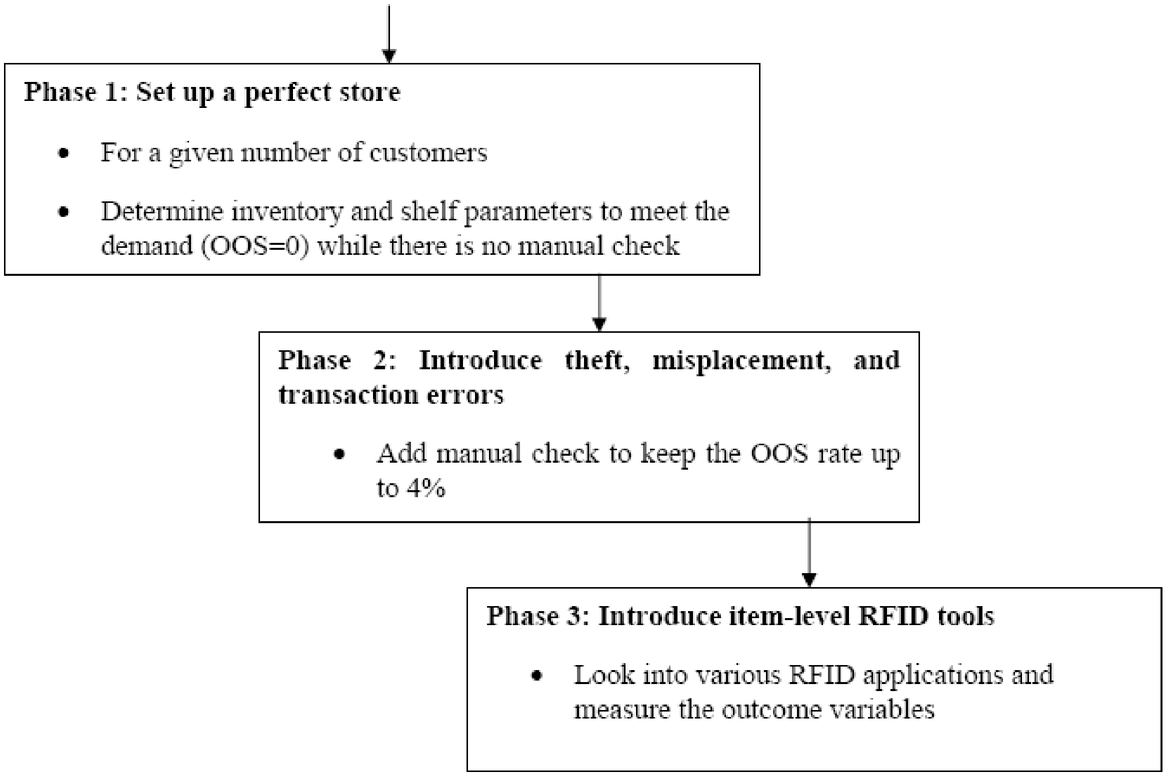

Figure 8 Setting up simulation parameters

Next, a Monte Carlo simulation is run across multiple stores to see how variations in the parameters lead to variation in outcome performance measures. The next section reports the results of a Monte Carlo simulation.

2.4 Various Scenarios in the Monte Carlo Simulation

We perform a Monte Carlo simulation for different applications, including automatic PI and product locating tools. The simulation of each application runs across 200 stores. Stochastic parameters such as theft, misplacement, transaction errors, and number of incoming customers change from store to store. Theft rate follows a uniform distribution that changes from .01 to .03 (Fleisch & Telkamp, 2005). Misplacement rate also has a uniform distribution and changes from .01 to .02 (Raman et al., 2001; Fleisch & Telkamp, 2005). Transaction errors follow a uniform distribution as well, within a range of 0 to .01 (Lee & Ozer, 2007). In addition, the daily number of customers changes across stores and follows a normal distribution with an average of 30 and standard deviation equal to 9. Our simulation runs over a season that is 100 days.

2.4.1 No RFID in stores

This is the base run scenario that looks at average OOS and average number of items sold when there is no RFID in the store. Manual checking is done once a month. The average number of items sold in the Mont Carlo simulation is 2910 and average OOS is 3.4%.

2.4.2 Automatic PI

With Automatic PI, RFID readers are installed at the entrance and exit doors. RFID handheld readers facilitate quicker and more frequent manual checks. This decreases inventory inaccuracy and subsequently OOS caused by theft/misplacement/transaction errors. The result shows that OOS is zero when there are daily manual checks using RFID handheld readers. Figure 9 shows how accumulated OOS in one store is changed from 121 with No RFID to zero with RFID.

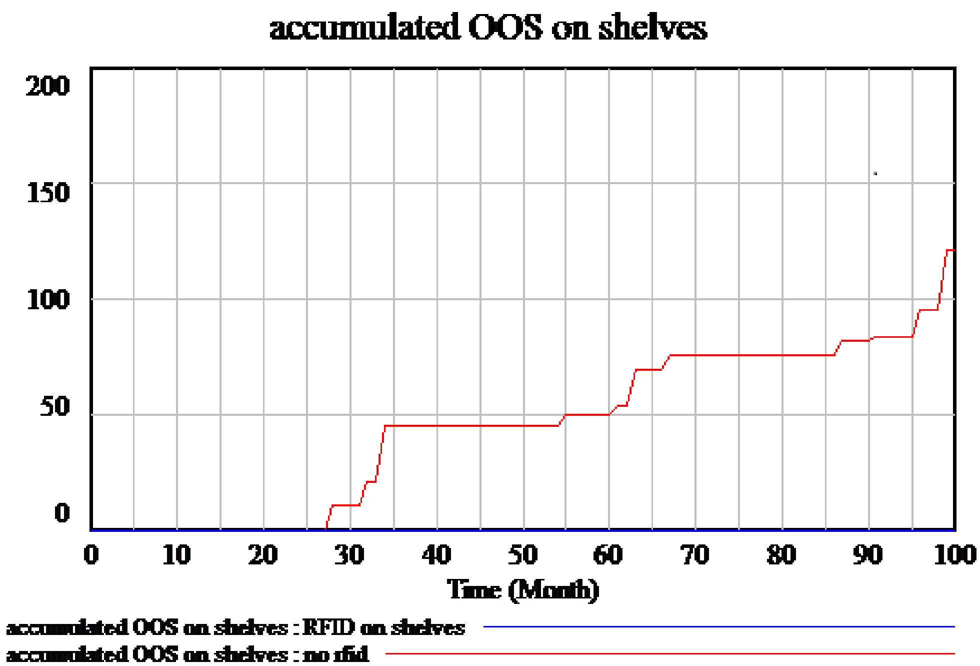

Figure 9 OOS in RFID vs. No RFID

In the Monte Carlo simulation, the average number of items sold increases from 2,910 in No RFID case to 3,026 in automatic PI. Enhanced visibility provided by daily manual checks brings the impact of transaction errors and misplacement/theft to zero.

Lighter and lower markdown prices

Enhanced information visibility on shelves and in backstores provided by automatic PI leads to fewer and lighter markdown prices. In fact, on-time and fast shelf replenishment increases the number of items sold at full price and decreases the number of markdowns. A case study by Kurt Salmon Associates shows that revenue increases up to 5% (Kay, 2008). An additional stochastic parameter, the rate of increase in revenue with lighter/fewer markdowns, is considered in order to see the effect of enhanced visibility on the markdown process. This parameter follows a uniform distribution and changes from .03 to .05 across 200 stores. The number of items sold is not changed compared to the previous cases, however, because the average price of the product in stores increases by 3% to 5% with a uniform distribution; the revenue increases by 3.8 percent on average.

Forecasting errors

Demand forecasting errors are also a source of OOS in the store. The actual demand is not captured in stores because a shopper may not buy or may shift her buying pattern due to an OOS. This may cause differences between the actual demand history and the sales history, and the store cannot capture the true demand (Gruen and Corsten, 2008; Bai et al., 2009). If OOS is reduced through enhanced visibility, then the demand forecasting error is reduced as well. For example, in our store, if there is 10% OOS, the true demand is 33, that is, 10% more than the effective demand (an average of 30). The store inventory and shelf parameters were set up with an average demand of 30. In such a situation, even with perfect visibility, there should be some out of stock due to demand forecasting errors. The average number of sold items is increases by .3% to 3037.

2.4.3 Product locating tools

With Automatic PI application in place, product locating tools such as smart carts (shopping carts equipped with a small monitor and an RFID reader) and smart dressing rooms (equipped with a small monitor and an RFID reader) help customers find their desired items faster and more conveniently. In addition, they free up staff time that can be spent on improving customer service and increasing customer satisfaction. A case study by Kurt Salmon Associates shows an increase of 3% in the number of customers who were able to find and buy their desired items (Kay, 2008). We use a stochastic parameter to represent the increase rate of customers with a uniform distribution that changes within a range of 1.5% to 3.5% across 200 stores.

Results show that the average number of items sold increases by 2.5% to 2986 from 2910 in No RFID case.

Figure 10 shows the increase in sales numbers in one store if product locating tools are added to already implement RFID application. Sales are increased to 3130 with RFID and product locating tools in place.

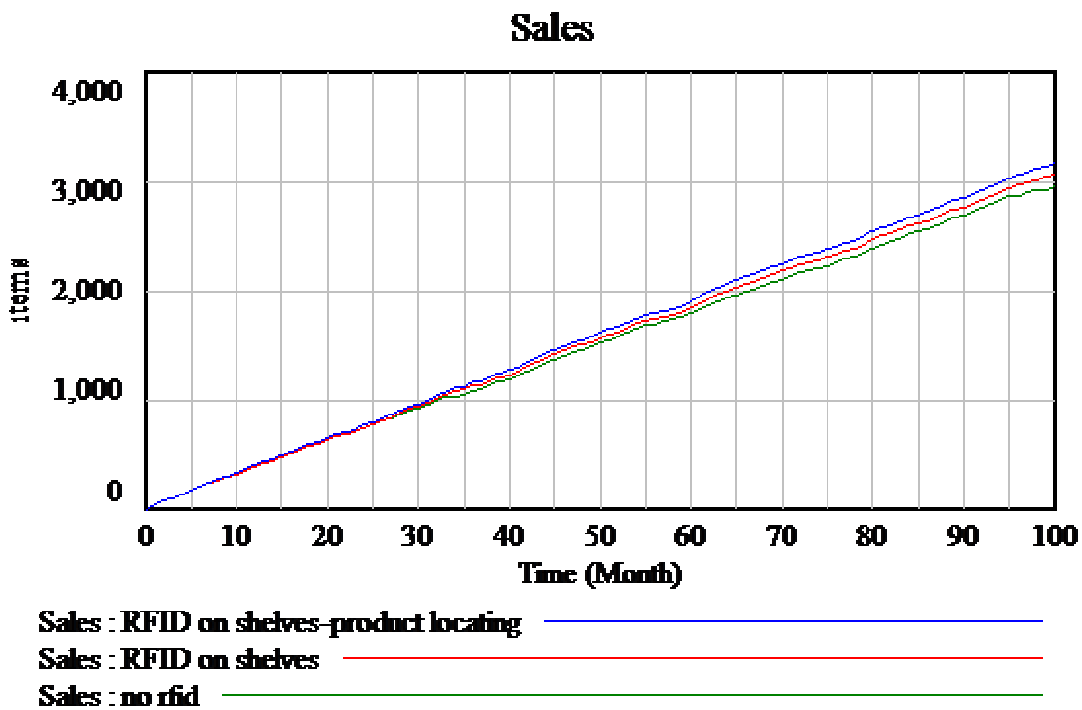

Figure 10 Sales increase with Product Locating Tools

2.4.4 Comparing various applications

Table 2 lists the number of items sold under various applications. Automatic PI and real time visibility provide the highest number of items sold that is an increase of 127 items (improvements in areas of theft, misplacement, transaction errors, and forecasting errors increase the sales numbers). The product locating application, on the other hand, helps customers find their desired product and increases the number of items sold by 76.

Table 2 Performance comparison across applications

Applications	Average sales(μ)	Increase over no RFID application
No RFID	2910	0
Automatic PI (OOS, forecasting errors)	3037	127
real time visibility	3037	127
Product locating	2986	76

3. DISCUSSION, LIMITATION AND FUTURE DIRECTION#

The robust simulation model allows us to estimate the item-level RFID benefits in terms of increased sales numbers for any given store of any size when the parameters are set. This information is crucial for performing an economic analysis of such an investment. Increased sales numbers can be translated to profits and considering the cost of applications, one can use various investment evaluation models such as real options to conduct a thorough analysis of investing in this technology. For example, managers have timing flexibility for investing in this technology and can postpone their decision. Real options analysis is the technique that fits the best to measure managerial flexibility on investment timing. The real options model calculates the options return values for given parameters. Some parameters of the real options model such as the expected payoffs and volatility of the expected payoff can come from our developed simulation model (Kambil et al., 1993; Benaroch and Kauffman, 1999; Whitaker et al., 2007).

The results of this study are limited to the various scenarios and assumptions made in the simulation model. Using simulation is valid when real data are not available. Conducting more case studies and using results from real implementations will significantly improve the credibility of these results.

The system dynamics simulation is a macro-level simulation that looks into the operations at an aggregate level. An extension of this research is to use some micro-level simulations, such as an agent-based simulation, to track products on an individual basis and study the behavior of the system in more detail (Borshchev and Filippov, 2004).

On the practical side, this study looked at the operations that can be managed on a retail floor. Some of the item-level RFID benefits such as those in designing the promotions are achieved across stores and at a higher level of management than operations. However, those types of benefits have to be considered in order to determine the total benefits of investment applications for retail stores

This study looks into the impact of RFID on current retail operations. A major area of future research is to explore areas of retail operations in which RFID can significantly change the way operations are performed. In other words, how can item-level RFID and the information collected from it be used in reengineering store processes in order to make operations more efficient and effective?

4. CONCLUSION#

Item-level RFID technology in retail management is in its infancy and will be the focus of investments for the next few years. This study uses system dynamics to capture benefits in retailers' operations management from customer service and pricing to the supply chain. The results of the simulation demonstrate how item-level RFID applications influence retail operations and generate sales. This information can be used for developing rigorous return on investment models to help managers in the process of making their investment decisions. In addition, our model developed a practical framework to help retail managers learn what applications are available and how they can analyze the benefits of the applications. Interesting results show that the benefits of RFID go beyond the supply chain operations. The supply chain, marketing and merchandising operations are all potential areas to investigate.

REFERENCES

Aberdeen Group (2008). *Know what's in store with RFID*. White Paper, Boston, MA.

Akkermans, H., A., Bogerd, P.,Yücesan, E., and Wassenhove, L. N. V. (2003). The impact of ERP on supply chain management: Exploratory findings from a European Delphi Study. *European Journal of Operational Research,* 146(2), 284-301.

American Apparel RFID Project- Case Study (2009).*RFID Monthly,* June.

Anderson, E.G. Jr. and Fine, C.H. (1999). Business cycles and productivity in capital equipment supply chains. In: Tayur, S., Ganeshan, R., Magazine, M. (eds*) Quantitative models for supply chain management*. Boston: Kluwer.

Angerhofer, B. J., and Angelides, M. C. (2000).System dynamics modeling in supply chain management: Research review. *Proceedings of the 2000 Winter Simulation Conference,* 342-351.

Angerhofer, B. J., and Angelides, M.C. (2006). *A model and a performance measurement system for collaborative supply chains*. *Decision Support Systems* archive, 42(1), 283-301.

Atali, A., Lee, H., and ÖlpOzer, O. (2005). If the inventory manager knew: Value of RFID under imperfect inventory information. White paper, Stanford University.

Bai, L., Szmerekovsky, J., and Zhang, J. (2009). Modeling inventory inaccuracy and demand deviation to assess the value of RFID. *International Journal of Operations and Quantitative Management, 15(3),* 157-172.

Barlas, Y. (1994). Model Validation in System Dynamics. Proceedings of the International System Dynamics Conference, Methodological Issues Vol., 1-10, Stifling, Scotland.

Barlas Y. ,and Aksogan, A. (1996). Product diversification and quick response order strategies in supply chain management. International System Dynamics Conference, Cambridge, MA, USA.

Benaroch, M., and Kauffman, R. J., (1999). A case for using real option pricing analysis to evaluate information technology project investments, *Information Systems Research,* 10(1), 70-86.

Berthiaume, D. (2004). RFID boosts customer satisfaction at Tesco - smart shelves show potential to improve visibility. *Chain Store Age,* January, 24A - 25A.

Borshchev, A., and Filippov A. (2004). From system dynamics and discrete event to practical agent based modeling: Reasons, techniques, tools. The 22nd International Conference of the System Dynamics Society. Oxford, England.

Bianchi, C. and Montemaggiore, G.B. (2008) Enhancing strategy design and planning in public utilities through “dynamic” balanced scorecards: insights from a project in a city water company. *System Dynamics Review* 24(2), 175–213.

Céline, B., Cloutier, M., and Cassivi, L. (2005). Performance evaluation of management information systems in clinical trials: A system dynamics approach. International System Dynamics Conference, Boston, MA.

Curtin, J., Kauffman, R. J., et al. (2007). Making the 'MOST' out of RFID technology: Are search agenda for the study of the adoption, usage and impact of RFID. *Information Technology and Management*, 8, 87-110.

DeHoratius, N., and Raman, A. (2008). Inventory record inaccuracy: An empirical analysis. *Management Science* 54 (4), 627-641.

Delen, D., Hardgrave, B. C., and Sharda, R. (2007). RFID for better supply-chain management through enhanced information visibility, *Productions and Operations Management Journal*, 16(5), 316-324.

De Marco, A. , Cagliano A.C., Nervo M. L., Rafele C. (2012). Using System Dynamics to assess the impact of RFID technology on retail operations. *International Journal of Production Economics* , 135(1), 333-344.

Doerr, K., Gates, W. (2003). An integrated multi-criteria and simulation approach to cost benefit analysis of inventory tracking. *INFORMS annual meeting*. Atlanta, Georgia.

EPC Global (2008). Improving retail promotional execution, March15, 2010, available at http://www.epcglobalus.org/KnowledgeBase/Browse/tabid/277/DMXModule/706/Default.aspx?EntryId=1171.

Fleisch, E., and Tellkamp, C. (2005). Inventory inaccuracy and supply chain performance: A simulation study of a retail supply chain. *International Journal of Production Economics*, 95, 373-385.

Forrester, J. W. (1958). Industrial dynamics: A major breakthrough for decision makers. *Harvard Business Review*, 36(4), 37-66.

Fraza, V. (2000). Ending inventory errors in 60 days. *Modern Materials Handling*, 55(3), A11.

Frédéric, T., Jasser, A., and Elgar, F. (2009). Understanding the value of integrated RFID systems: A case study from apparel retail. *European Journal of Information Systems*, 18(6), 592-614.

Gaukler, G. M., Seifert, R. W., and Hausman, W. H. (2007). Item-level RFID in the retail supply chain. *Production and Operations management Journal*, 16(1), 57-65.

Gaukler, G. M., and Seifert, R. W. (2007). *Applications of RFID in supply chains*. In H. Jung, F.F. Chen, and B. Jeong (Eds.), *Trends in supply chain design and management: Technologies and methodologies*. London: Springer-Verlag.

Gregoriades, A., and Karakostas, B. , (2004). Unifying business objects and system dynamics as a paradigm for developing decision support systems. *Decision Support Systems*, 37(2), 307-311.

Gruen, T. W. and Corsten, D. (2008). A comprehensive guide to retail out-of-stock reduction in the fast-moving consumer goods industry, *Grocery Manufacturers of America*, Washington, D.C.

Hafeez, K., M. , Griffiths, J., et al. (1996). Systems design of a two-echelon steel industry supply chain. *International Journal of Production Economics*, 45, 121-130.

Hardgrave, B. C. (2009a). *Item-level RFID for apparel: The Dillard's RFID initiative*. White Paper, Information Technology Research Institute, University of Arkansas, Fayetteville, AR.

Hardgrave, B. C. (2009b). *Item-Level RFID for apparel: The Bloomingdale's RFID initiative*. White Paper, Information Technology Research Institute, University of Arkansas, Fayetteville, AR.

Hardgrave, B. C., Langford, S., Waller, M., and Miller, R. (2008). Measuring the impact of RFID on out of stocks at Wal-Mart. *MISQE*, 7(4), 181-192.

Heese, H. S. (2007). Inventory record inaccuracy, double marginalization and RFID adoption. *Production and Operations Management* 16(5), 542-553.

IBM (2004). Item-level RFID technology redefines retail operations with real-time, collaborative capabilities. New York: IBM Corporation.

Kasiri, N**.,** Sharda, R., Hardgrave B. (2011), A Balanced Scorecard for Item-Level RFID in the Retail Sector: A Delphi Study, to be published in *European Journal of Information Systems*.

Kambil, A., and Brooks, J. (2002). Auto-ID across the value chain: From dramatic potential to greater efficiency and profit. White paper. MIT Auto-ID Center, Cambride, MA.

Kambil, A., Henderson, J., and Mohsenzadeh, H. (1993). Strategic management of IT investments: An options perspective. In *Strategic IT Management: Perspectives on Organizational Growth and Competitive Advantage,* Banker, R., D., Kauffman, R. J. and Mahmood, M.,A. , Harrisburg, PA: Idea Group Publishing, 161-178.

Karkkainen, M., and Holmstrom, J. (2002). Wireless product identification: Enabler for handling efficiency, customization and information sharing. *Supply Chain Management: An International Journal*, 7(4), 242-252.

Kay, M. (2008). An apparel research study and analysis, RFID well within reach. Apparel Magazine, June issue.

Krafft, M., Mantrala, M. K. (2006). *Retailing in the 21st Century: Current and future Trends*. New York:Springer.

Lee, H., and Ozer, O. (2007). Unlocking the value of RFID. *Production and Operations Management* 16(1), 40-64.

Liu, S., White J. C., Sholtes, R. (2011). *Addressing Retail Out-of-Stock Issues Using System Dynamics,* Proceedings of the International System Dynamics Conference, Washington DC.

Marquez,A.C., Blanchar, C. (2006). A decision support system for evaluating operations investments in high-technology business, *Decision Support Systems*, 41(2), 472-48.

Prater, E., Frazier, G. V., and Reyes, P. M. (2005).Future impacts of RFID on e-supply chains in grocery retailing. *Supply Chain Management: An International Journal,*10(2), 134-142.

Rawal, A. (2009). RFID: The next generation auto-ID technology. *Microwave Journal*, 52(3), 58-60.

Rekik, Y., Sahin, E., and Dallery, Y. (2008). Analysis of the impact of the RFID technology on reducing product misplacement errors at retail stores. *International Journal of Production Economics*, 112(1), 264-278.

Rekik, Y., E. Sahin, E., and Dallery, Y. (2009). Inventory inaccuracy in retail stores due to theft: An analysis of the benefits of RFID. *International Journal of Production Economics,* 118(1),189-198.

Sarac, A. ,Absi, N., and Dauzère-Pérès, S. (2008). A simulation approach to evaluate the impact of introducing RFID technologies in a three-level supply chain. Winter Simulation Conference, 2741-2749, Miami, FL.

Scavarda, A. J., Bouzdine-Chameeva, T., et al. (2006).A Methodology for Constructing Collective Causal Maps, *Decision Sciences*, 37, 263-284.

Sterman, J., (2000). Business dynamics: Systems thinking for a complex world, New York: McGraw-Hill, Irwin.

Swamy, G., and Sarma S. (2003). Manufacturing cost simulations for low cost RFID systems. MIT Auto ID. Whitepaper. Cambridge, MA.

Szmerekovsky, J., Tilson, V., and Zhang, J. (2009). Pricing and allocation of retail space with one RFID enabled supplier and one non-RFID enabled supplier. *International Journal of Revenue Management, 3(1)*, 37-55.

Raman, A., DeHoratius, N., and Ton, Z.(2001). Execution: The missing link in retail operations. *California Management Review,* 43, 136–152.

Rodkin, H.H., and Yanahan, P. (2005). *RFID adoption in the retail industry*. A research paper prepared by USA Strategies Inc.

Whitaker, J., Mithas, S., et al. (2007). A field study of RFID deployment and return expectations. *Production and Operations Management Society,* 16(5).599-612.

Zhou, W. (2009). RFID and item-level information visibility. *European Journal of Operational Research,* 198(1), 252-258.