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Abstract: Radio Frequency Identification (RFID) technology has received considerable attention from practitioners, driven by mandates from major retailers and the United States Department of Defense. RFID technology promises numerous benefits in the supply chain, such as increased visibility, security and efficiency. Despite such attentions and the anticipated benefits, RFID is not well-understood and many problems exist in the adoption and implementation of RFID. The purpose of this paper is to introduce RFID technology to practitioners and academicians by systematically reviewing the relevant literature, discussing how RFID systems work, their advantages, supply chain impacts, and the implementation challenges and the corresponding strategies, in the hope of providing guidance for practitioners in the implementation of RFID technology and offering a springboard for academicians to conduct future research in this area.

Key Words: Supply Chain Management, RFID, RFID Adoption and Implementation, E-Business

1 Introduction

Over the last two decades, manufacturers have improved supply chain efficiency through a number of initiatives from Kanban and ISO 9000 to Six Sigma, Lean Manufacturing and Flexible Manufacturing. With the advent of RFID technology, the supply chain is poised for a new and rapid transformation.

The origins of RFID technology can be traced back to laboratory research in the 1940s that focused on reflected power communication. Commercial use began in the

1980s, primarily in the transportation industries of railroad and trucking (Landt, 2001). These applications used battery powered *active* RFID tags and proprietary systems to track and manage capital assets, such as rail cars and cargo ship containers (Dinning & Schuster, 2003).

Recently, efforts have been made to reduce the cost of RFID technology through the use of non-battery powered "passive" tags. Passive tags can be used to replace barcodes as a means of gathering information within the supply chain. The adoption of passive RFID technology promises numerous benefits: improved speed, accuracy, efficiency and security of information sharing across the supply chain (Jones et al., 2004), reduced storage, handling and distribution expenses, increased sales through reduced stock outs, and improved cash flow through increased inventory turns and improved utilization of assets (Käkkäinen, 2003).

Due to the possible benefits of RFID systems, Wal-Mart has requested its top 100 suppliers to tag pallets and cases they ship to Wal-Mart distribution centers by January 2005 (Handfield, 2004) and for its next top 200 suppliers by January 2006 (RFID Journal, 2004a). Their objective is to replace bar coding and scanners with RFID tags and readers in order to increase speed and efficiency in the supply chain (Weil, 2004), and to reduce inventory, out of stock merchandise and labor cost in stores and warehouses (Seideman, 2003). Procter & Gamble and Gillette are using the technology to track products from the production line to the store shelves. Gillette estimates that its sales would be 15% higher if shelves were always stocked. Marks & Spencer announced in May that they were replacing barcodes with RFID tags throughout its refrigerated food supply chain. Tesco is testing RFDI technology to track trays and cases moving from its distributors to

two of its UK (United Kingdom) stores (Jones et al., 2004). The tags are being tested by the United States Navy to monitor the temperature, humidity and air pressure in aircraft parts containers (Roberti, 2004b). Some other early adopters of RFID technology include The Gap, Woolworth's, Allied Domecq, Argos, Benetton, Prada (Wilding and Delgado, 2004b), and Target (Industrial Engineer, 2004). In addition, the United States (US) Department of Defense will require its 43,000 suppliers to put RFID tags on pallets, cases and on any single item with a cost of more than $5,000 beginning January 1, 2005 (Collins, 2004b). Also, enterprise software companies, such as SAP, Oracle, Microsoft Corp., Manugistics, and WebMethods Inc., have planned to add support for RFID to their products.

The major driver behind RFID is the mandate from the major retailers and the US government. A study by Accenture (Accenture Report, 2004) found that more than half of US companies surveyed were under mandates to implement RFID technology. This is consistent with the finding of another survey, that indicated mandates from government and major retailers are spurring RFID implementation among 46% of surveyed companies (Emery, 2004). Similarly, the survey of Cap Gemini Ernst & Young LLC reported that 51% of the surveyed organizations agree that either RFID would be a major business driver or they would start an RFID initiative (Ferguson, 2004).

In spite of increased pressure for its implementation, RFID technology is not well understood by both companies and consumers. An online survey of more than 350 information technology (IT) executives in April 2004, conducted jointly by BearingPoint Inc., the Software and Information Industry Association in Washington and International Data Group's CIO magazine, found that only 22 percent said they have a high

understanding of the technology, less than half said that they have a moderate level of understanding (Emery, 2004). On the other hand, a survey of 100 North American consumers conducted by Cap Gemini Ernst and Young in 2004 reported that only 23% of consumers have heard of RFID technology (usingRFID.com, 2004).

Moreover, there exists doubt in practitioners about the potential benefits of RFID. According to a survey of US and European executives carried out by Deloitte Touche, the EPC Group and the Retail System Alert Group, more than half of the manufacturers had "very low" expectations that their RFID deployment would boost revenues within the next five years (Collins, 2004a). The same result is supported by the survey of Accenture (Accenture Report, 2004), which revealed that two-thirds of surveyed companies are "unconvinced" as to the benefits of the RFID technology.

The increased popularity and the lack of understanding of RFID technology create a dilemma that calls for immediate research to explore RFID technology and guide its implementation in practice. However, there is a very limited and fragmented research in this area. To fill this gap, this study aims to introduce RFID technology to practitioners and academicians by systematically discussing how RFID systems work, their advantages, supply chain impacts, and the implementation challenges and the corresponding strategies. This research will offer useful guidance for companies who wish to implement RFID and offer a springboard for future research in this area.

The paper is organized as follows. We first present a review of relevant research. We then provide definitions of RFID terms and discuss how RFID systems work. Next, we discuss the advantages of RFID and its impacts on the supply chain, followed by a discussion of the challenges and corresponding strategies of implementing RFID. We

end our paper with a glimpse of the near-term future of RFID and our concluding thoughts on RFID systems.

2 Research Review in RFID

Because of its newness, research on RFID is limited and fragmented, mainly focusing on a single participant in a supply chain (such as retailers or manufacturers) (Jones et al., 2004; Småros and Holmström, 2000; Brewer and Sloan, 1999), a specific production process (packaging) (Jansen and Krabs, 1999), type of product (short shelf life products) (Kärkkäinen, 2003), the benefits of RFID in a certain functional area (forecasting) (Lapide, 2004) or on logistics operations in the supply chain (McFarlane and Sheffi, 2003).

For example, Jones et al. (2004) discuss the opportunities and implementation challenges of RFID technology for retailers in UK. Småros and Holmström (2000) consider RFID as a data capture method in consumers' refrigerators to develop a new type of e-grocery related service, vendor managed inventory (VMI) in the household. Brewer and Sloan (1999) regard RFID as an intelligent tracking technology in manufacturing which provides real-time information throughout the supply chain to support logistics planning and execution. Jansen and Krabs (1999) consider RFID technology as an efficient way for companies to replace their one-way packaging systems with returnable systems (containers) in order to save energy and resources and to reduce waste in packaging. Kärkkäinen (2003) discusses the potential of RFID implementation for increasing supply chain efficiency of short shelf life products through a RFID trial conducted at UK retailer Sainsbury's. Lapide (2004) suggests the benefits of RFID for

forecasting, such as improved forecast accuracy, correct demand data for out-of-stock items, more accurate point of sale (POS) data from retailers, and better tracking of products sold with or without promotion. Moreover, Kärkkäinen and Holmström (2002) consider RFID as a wireless product identification technology to enable material handling efficiency, customization and information sharing in a supply chain and discuss some benefits of RFID in supply chain management. McFarlane and Sheffi (2003) use a ship/receive (S/R) pair structure to examine four basic logistics processes (shipping, transportation, receiving and in-facility operations) and discuss how low cost RFID can be used to improve each process.

It can be seen that previous researchers mainly focus on the implementation of RFID technology by a certain participant without including all the partners in a supply chain. Those researchers considering all the supply chain participants have failed to discuss the implementation challenges of RFID and the corresponding strategies. This paper will address the above mentioned issues and will discuss specific strategies for each of the implementation challenges. By including all the members in a supply chain, the current research not only provides researchers and practitioners an integrated view of RFID technology, but also helps them better understand its opportunities and challenges.

3 The RFID System

All RFID systems are comprised of three main components: (1) the RFID tag, or transponder, which is located on the object to be identified and is the data carrier in the RFID system; (2) the RFID reader, or transceiver, which may be able to both read data

from and write data to a transponder; and (3) the back-end database which associates records with data collected by readers (Jones et al., 2004).

RFID tags can be placed in two primary categories: active and passive tags. Active tags contain a battery that provides power so the tag can transmit a signal, up to 100 feet, to a reader. Passive tags do not contain a battery and hence are much cheaper than active tags. Passive tags are read when they pass through the electromagnetic field of a reader (Dinning & Schuster, 2003). Tags can be chip-based or chipless. Chip-based tags consist of a microchip that stores data and a coupling element, such as a coiled antenna, used to communicate via radio frequency communication, while a chipless tag does not contain an integrated electronic chip. Chipless tags can be used in anti-counterfeiting and anti-theft applications. Tags can be read-only, write once/read many times or read-write. Data on a read only-tag cannot be changed unless the chip is electronically reprogrammed and they are often used to track assets that will have a unique ID over their lifetime. A read-write tag will allow changes to the stored data and they are used to track items through the supply chain (Wilding & Delgado, 2004a). This paper will focus on the passive, chip-based, read-write tags for the following reasons. Passive tags are significantly cheaper than active tags and therefore can be used to cost effectively track at the pallet, case and item levels. Read-write tags provide a living history of the item being tracked and therefore increase transparency in the supply chain.

RFID tags can be manufactured from a variety of chip and code formats. One code format that enjoys substantial support in the retail industry is the Electronic Product Code (EPC). The EPC uses a 96 bit scheme advocated by EPCglobal (previously known as the Auto-ID Center).

3.1 How RFID Systems Work

Figure 1 shows how a RFID system works. First, a unique identifier, such as an EPC, is embedded into the microchip in a tag. The microchip can also incorporate functionality beyond simple identification and include integrated sensors, read/write storage, encryption and access control. The tag is then attached to an item, case or pallet. As the item/case/pallet moves into the scanning range of the reader, the reader sends out electromagnetic waves that form a magnetic field when they "couple" with antenna on the RFID tag. The tag draws power from the magnetic field and uses it to power the microchips' circuits. The microchip then modulates the received signal in accordance with its identification or programmed code and transmits or reflects a radio frequency signal. The modulation is in turn picked up by the reader, which decodes the information contained in the transponder and depending upon the reader configuration, either stores the information, acts upon it, or transmits the information to the host computer via the communications port (Jones et al., 2004).

[***Insert Figure 1 about here***]

3.2 Performance Tradeoffs of RFID Systems

The cost and performance of RFID tags are a function of the level of radio frequency waves produced by the reader. Low frequency tags require a larger antenna which increases the tag size and cost. High frequency tags can be smaller and cheaper, but require a more expensive reader. Reader range and speed of data transfer increase as frequency increases, but so does the health risk to workers due to radiation. Higher frequencies also have reflection problems and are negatively impacted by metal, liquid,

glass and moist environments. Low frequencies are not impacted by the presence of metal and can even read through some non-ferrous metals (Wilding and Delgado, 2004a).

Reader antenna shape and tag antenna design also affect RFID system performance. A circular polarized reader antenna should be used if the tag orientation within the radio frequency field is unknown, while a linear polarized reader antenna provides greater radio frequency penetration and longer read ranges. On a passive tag, the most important design characteristic is the antenna. A multi-directional antenna is less orientation specific and hence performs better than a single-directional antenna, but at a higher cost (Weil, 2004).

Another performance consideration in the current RFID systems is the read rate. Wal-Mart suppliers testing the RFID system have had mixed results. For example, Kimberly-Clark has achieved reads ranging from 85 to 94 percent for cases on a pallet (Kimberly-Clark produces paper based products which are RFID friendly) while Unilever (makers of shampoo and other personal hygiene products) has reported low readability rates for cases stacked on pallets and less than 100% readability for cases moving on a conveyor. Simon Ellis, supply chain futurist at Unilever stated, "We're nowhere near 100 percent on the pallet. We may need to do some packaging redesigns." (Roberti, 2004a, p.1).

3.3 Comparison of RFID with EAS Systems and Bar Codes

Traditionally in the supply chain, electronic article surveillance (EAS) systems are used as security devices and bar-codes are used to track the movement of goods. RFID tags

promise many advantages over EAS systems and bar codes, and have the potential to replace both in the supply chain.

In the retail environment an EAS tag is attached to the merchandise and is removed from the item at the time of sale. If an active EAS tag passes through the magnetic field (typically at the store entrance/exit) it sets off an alarm (Wilding & Delgado, 2004a). RFID tags will have this same security capability, and at the time of the sale the tag can simultaneously record the transaction and be deactivated.

Bar codes are used from the container level to the individual item level and though currently in widespread use, bar codes have limitations. Bar codes are the same for all instances of a unique stockkeeping unit (SKU) and hence do not differentiate between items. For example, ten cases of shampoo will all have the same bar code and each bottle of shampoo in all ten cases will have the same bar code. This same bar code for all SKUs makes it difficult to track and trace items that may need to be recalled due to quality or safety concerns. In contrast, RFID can be used to identify products at item level, can be read with no requirement for line of sight and can operate in harsh environments, where dirt, dust and moisture conditions can affect other types of Automatic Data Capture Systems, such as bar codes. Moreover, multiple tags can be read simultaneously and tags can also be programmed easily. Tags are capable of carrying more than 64 bits of information compared with 19 bits for bar-code technology, thus enabling RFID to store information such as location, move history, destination, expiration date and environmental conditions (temperature, moisture, etc.). Table 1 shows the advantages of RFID tags over bar codes.

[***Insert Table 1 about here***]

4 Impact of RFID on the Supply Chain

RFID implementation brings about many potential impacts on a supply chain and companies in various supply chain positions may reap different benefits from RFID applications. This section will discuss the impact of RFID on the supply chain as a whole, followed by a discussion of specific impacts of RFID technology on the major participants in a supply chain, including retailers, logistics providers, distributors, manufactures, and suppliers. To facilitate the discussion, logistics providers and distributors are combined into one group and manufacturers and suppliers into another group since they receive very similar benefits from the implementation of RFID. We summarize our findings in Table 2 at the end of this section.

4.1 The Impact on the Supply Chain as a Whole

The greatest benefits from RFID would come when RFID technology is implemented across multiple organizations in the supply chain (Accenture Report, 2004). RFID can be used to track the movement of products through the supply chain from production to the retail point of sale in real-time which will provide higher visibility for inventory and assets in the supply chain (Seideman, 2003) and facilitate better management of inventory and logistics (Jones et al., 2004). RFID technology can also be used across the supply chain to improve reverse logistics for reusable assets and for the recycling of products. RFID improves the safety and security of the supply chain through improved track and trace, more efficient recall management, better expiration date management and reductions in shrinkage. The implementation of RFID will facilitate better planning in the supply chain through reductions in inventory, working capital, stockouts and

expediting costs (Accenture Report, 2004), and lead to improved information sharing and tighter connection with business partners which can lead to more efficient business processes (Emery, 2004). Moreover, RFID provides both more information and more timely information on supply chain performance, thus a higher level of detailed analysis can be done to guide the management and synchronization of the supply chain. Increased synchronization would enable collaborative planning, forecasting, and replenishment (CFPR) activities beyond the typical buyer-seller relationship. Early adopters of RFID have experienced significant benefits- anywhere from a 3% to 5% reduction in supply chain costs, and 2% to 7% increases in revenue as a result of greater inventory visibility (Kay, 2003).

4.2 The Impacts of RFID on Supply Chain Partners

To simplify the discussion, we focus on the impact of RFID on three areas: cost, sales, and customer service and satisfaction, which are the major benefits of RFID discussed so far in the literature. This section will show how RFID will benefit retailers, distributors/logistics providers, and manufacturers/suppliers in each area.

Retailers Impacts

Some argue that the major beneficiaries of RFID will be retailers since tag cost and the burden of tagging is being placed mainly on manufacturers (Kevan, 2004). The cost benefits of retailers may come from reduced inventory of goods (estimated at least 7.5%) (Kevan, 2004), store labor reduction (estimated at least 7.5%) through automating the check-out process and reducing the amount of labor required to count inventory, and

improved theft prevention with shelves that report if large amount of goods are removed (Käkkäinen, 2003, Jones et al., 2004). Marks & Spencer estimates that the capital cost of an RFID system will be less than 10 percent of the annual cost of using bar-codes (Jones et al., 2004). In addition, retailers can increase sales by the reduction of out of stocks (Kevan, 2004). Customer (consumer) service and satisfaction can be improved by the reduction of stock-outs (Roberti, 2004c) and the retailers' ability to offer better product selection and lower prices. Retailers can target customers and track their purchasing behavior through the use of RFID technology (Jones et al., 2004). Consumer confidence should also increase since product recalls can be conducted quickly and efficiently, and at a lower cost to supply chain partners.

Distributors/Logistics Providers Impacts

Benefits to distributors/logistics providers are that they will be able to know what has been loaded, what has been shipped and when the goods arrive at their destination (O'Neill and Newton, 2004). Having better visibility on the items entering the warehouse means cost saving and higher profitability, since 60% to 80% of a warehouse's labor is spent on dealing with receiving goods (Seideman, 2003). Since multiple items can be scanned at the same time, both the logistics provider and the distributor benefit from faster unloading and loading. In addition, the cost can be reduced through improved use of warehouse and distribution center space in that goods will not need to be stored according to product type for manual operation, but they can be stored in the most efficient manner based on size and shape. Also, knowing accurate departure

and arrival times of goods will increase lead time accuracy and hence improve decision making and customer satisfaction.

Manufacturers/Suppliers Impacts

Cost benefits for manufacturers and suppliers come from enhanced inventory visibility, greater labor efficiency (Käkkäinen, 2003), reduced data latency and errors associated with product handling, reduced fixed assets through better utilization of space and equipment, the elimination of the need for manual inventory management, and the labor and downtime that is associated with closing distribution centers for annual inventory taking (Kay, 2003). Shrinkage can also be reduced through tag use. Custom motorcycle manufacturer Viper Motorcycle installed RFID tags on all parts that have a value of greater than $75. After conducting a random inventory audit, management located a missing $2400 transmission in an employees van (Sullivan, 2004a). In addition, manufacturers can increase sales by reducing out of stock rate of products on retail store. Customer service and satisfaction can be improved through improved fulfillment rates (Käkkäinen, 2003). RFID tags can also be used in manufacturing to ensure that products on mixed-model production lines contain the correct parts. For example, a RFID tag can be used to indicate to the worker which part to install on the product as it moves down the line. A scanner can be installed at the end of the production line to scan the finished good and verify the correct parts have been used to make the item. Viper Motorcycle uses RFID tags in the production process to track subassemblies as they move through the facility in order to determine where motorcycles are in the production process (Sullivan, 2004a). Seagate tracks media discs through a complex manufacturing system

containing a combination of 20 production and test processes. The tags ensure that the proper steps have been taken not only to make the product but also to quickly identify sources of production problems for quality improvement. The data is collected by the company's ERP system and provided to production facilities around the world in near real-time. Ford Motor Company uses RFID to track inventory, manage the assembly process and identify causes of quality problems (Ferguson, 2002).

According to Kevan (2004), the evaluation of the benefits of RFID for manufacturers can be divided into three stages: the first stage focuses on compliance with customers' requirements; the second involves the internal supply chain; and the last stage deals with the inter-enterprise, or extended supply chain. The compliance with the customers' requirement is just a cost reduction since saving from reduced labor costs (scanning and reading) are offset by the cost of the tags, readers and integration services. In the second stage, companies start to make internal supply chain improvements and can begin to leverage RFID information to make their processes more efficient. At the third stage, the company begins to analyze the complete flow of goods and information across the whole supply chain, thus reducing inventory and cutting overall logistics expenditures. Suppliers' benefits will be similar to those of manufacturers.

We summarize our findings of the impacts of RFID on the supply chain in Table 2. We present the impact of RFID on the supply chain as a whole and how RFID benefits each participating organization in the supply chain in terms of cost, sales and customer service and satisfaction.

[***Insert Table 2 about here***]

5 RFID Implementation Challenges and the Corresponding Strategies

The literature on RFID has consistently reported cost and the lack of standards as the major barriers for RFID adoption. A survey of manufacturing executives across consumer goods and pharmaceutical companies conducted by Accenture (Accenture Report, 2004) reported cost, the instability of the RFID market and the lack of standards as the leading barriers to implementing RFID. An online survey of more than 350 IT executives in April, 2004 revealed that the top three business risks of using RFID are that technical standards are not final, business benefits or return on investment are unclear, and a lack of industry-wide adoption (Emery, 2004). According to a survey conducted by the Institute of Management and Administration in 2004 (IOMA, 2004), the hurdles to RFID adoption are a lack of global standards, multiple frequencies and specifications for tags, optical reader compatibility with supply chain partners and security issues. The following sections will discuss RFID implementation challenges, including cost, standards, integration, security and privacy risks, and environmental issues. Furthermore, the corresponding strategies are also discussed.

5.1 RFID Cost

Cost is a major factor in determining the speed at which RFID tags are adopted (Jones, 2004) and some worry that investment in RFID technology will not pay off (Käkkäinen, 2003). RFID systems require expenditures for tags, readers, hardware, software and system maintenance (Logistics& Transport Focus, 2004). Consulting firm A.T. Kearney estimates that major retailers will have to invest $400,000 at each distribution center, $100,000 at each store to read and manage the data, and $35 to $40 million to integrate

the RFID system into existing information systems (Feder, 2003). AMR Research estimates that large suppliers to Wal-Mart will spend an average of $13 million to $23 million to implement RFID systems (Gilbert, 2003a). Figleaves.com, an online lingerie company, used RFID technology to track its inventory but dropped it later because of cost concerns (McGinity, 2004). However, the cost of passive tags has fallen from about $1 per tag in 2000 to about 25 cents in 2003. The cost of readers and allied equipment has also fallen significantly (Jones et al., 2004).

Associated with tag cost is tag reliability. A defective label cannot be read and therefore a system must be in place to signal if a tag is not read. Don Mowery, director of e-business and supply chain at Nestle Purina Petcare states "Even if we achieve a failure rate of 1 percent, that means there are 1000 pallets a day that I can't scan" (Roberti, 2004a). Poka-yoke systems can be designed to ensure a tag has been read. Pacific Cycle uses a signal light located on the reader that illuminates when a tag has been successfully read (Swedberg, 2004). A signal light system can also be used for multiple item reads to reconcile information on a pallet tag with the number of cases read on the pallet. For example, if the pallet tag transmits ten cases to the reader and only nine case tags are read, then a light could indicate a shortage.

It should be noted that cost concerns may overshadow more important issues in RFID implementation. Without proper commitment, planning and partnering, an inexpensive RFID system will not be sufficient to maintain a sustainable long-term competitive advantage (IOMA, 2004).

5.2 Standards

The unproven level of the technology and the lack of standards prevent suppliers from investing in RFID technology (Käkkäinen, 2003). There are many proposals for standards waiting to be ratified, but it is difficult for companies to know which technology will prevail. To gain maximum benefit from RFID in the supply chain, various business partners worldwide need to use common tags, readers and frequencies so that they can be used beyond the confines of a company's walls. Kay (2003) points out that the lack of technology uniformity and standards keep costs high, and that standards are the key to the proliferation of RFID technology. The establishment of a standard will force cost to drop since RFID product suppliers can all produce compatible chips, readers, associated hardware and software.

Within the RFID market, a number of standards have been developed. For example, several ISO standards are now established, including ISO 11785 for 125 KHz (low frequency), ISO 15693 for 13.56MHz (mid frequency), and ISO 18000-6 for 860-930MHz (ultra high frequency) (RFID Journal, 2003). The Electronic Product Code (EPC) is in the process of being established by EPCglobal, a non-profit joint venture of the standards organization EAN International and the Uniform Code Council (UCC). The UCC is the organization that developed the Universal Product Code (UPC). EPCglobal has developed a standard for the 13.56MHz frequency (Class one) and for the ultra high frequency (UHF) (2 standards: Class 0 and Class 1). Recently, a new standard (Generation 2) has been developed and approved by EPCglobal in December 2004, which will replace class 0 and class 1 (Sullivan, 2004b). Generation 2 protocols will allow tags to contain more data and ease the ability to program tags (Proctor, 2004). It is

expected that RFID technology will evolve in a similar way as did bar code technology, but at a much faster rate (Weil, 2004).

5.3 Integration

A survey of 275 respondents working in the packaging industry by Cap Gemini Ernst & Young LLC revealed that 46% of the respondents consider integration as the single biggest concern with RFID (Ferguson, 2004). The challenge of RFID implementation comes from integrating RFID systems and the data they generate with other functional databases and applications (Jones et al., 2004). Currently, companies need to build the RFID system themselves from parts offered by technology providers and then integrate it with their internal database and ERP system (Käkkäinen, 2003), which increases the time and complexity of the implementation. To solve the problems, many software developers have focused on the integration issue of RFID technology. Major ERP providers Oracle (Westervelt, 2004) and SAP (RFID Journal, 2004b) currently offer applications that capture, manage and analyze data from RFID readers. And, Microsoft plans to enter the RFID market in the first half of 2005 by coding RFID specifications into the warehouse management module of the Axapta ERP suite (Foley and Sullivan, 2004).

The other implementation issues may be related to the effective use of the massive data captured by RFID systems and the incorporation of RFID technology throughout the whole supply chain. RFID systems generate large volumes of data. A field research conducted by Wal-Mart, the Auto-ID Center and key suppliers at Wal-Mart's pilot distribution center in Oklahoma for tagging of cases resulted in the generation of thirty

times more data as products were tracked through the supply chain (Wilding and Delgado, 2004b).

5.4 Security and Privacy Risks

RFID may pose security and privacy risks to both organizations and individuals. On one hand, unprotected tags may have vulnerabilities to eavesdropping, traffic analysis, spoofing (tampering) or denial of service (Weis et al., 2003), and data obtained from RFID tags can be misused or revealed illegally. Hackers could reduce the price of expensive items and use self checkout to avoid store clerks (Lemos, 2004). Corporate espionage is another risk. Retail inventory labels with unprotected tags could be monitored and tracked by a business' competitors and sales data may be gleaned by correcting changes over time (Weis et al., 2003). Programmable read-write tags can be encoded with security features that limit access, and to identify and record unauthorized reads.

On the other hand, RFID technology used at the item level can be used to obtain information about customers and to track their movement without their knowledge. Some steps have been suggested to reduce the privacy concerns of consumers. For example, RFID can be used only on pallets, cases, and shelves for streamlining the inventory and supply chain handling systems, but not at the item level. If tags are used at the item level, they should be deactivated after the point of sale. Or if a retailer is going to use the information obtained from the tags, they need to make that information and choices available to the consumers (Jonietz, 2004). Another idea may be to use a metal shopping bag or blocker tags because RFID cannot go through metal (Jonietz, 2004).

Next generation tags could incorporate blocking and encryption systems, designed to protect privacy and unauthorized reading (Jones et al., 2004). Senator Debra Bowen (D-Redondo Beach), a California State Senator, proposed the first-in-the-nation privacy standards for the use of RFID. The measure SB 1834 was introduced at the State Capitol and passed the California Senate in April, 2004. SB 1834 requires four conditions to be met before RFID tags and readers could be used to collect personal information: (1) information could be collected only to the extent permitted by law; (2) information would be provided by a customer only to complete a rental or purchase transaction at a store; (3) no information could be collected before a transaction or after it was completed; (4) information would only be collected on the person presenting the items for purchase or rental, and only in regard to those particular items (Kuchinskas, 2004).

5.5 Environmental Issues

One final concern of RFID tags is that they pose potential environmental problems since the tags are non-biodegradable and may contain poisonous metals (Wilding and Delgado, 2004a). Reverse supply chains will have to be set up in order to recycle or reuse tags, especially when the proliferation of tags spreads to low-cost individual items. It is well understood that the biggest benefits of RFID implementation come from solutions across the supply chain. But it is difficult to implement because of the disputes regarding sharing the cost and benefits between manufacturers and retailers. Moreover, successful RFID implementation will require culture, process, and technology change within and across organizations.

6 The Near-Term Future of RFID

The majority of current RFID implementations are for the tagging of pallets, cases, re-useable assets, capital assets and for high cost individual items. As RFID technology becomes more widespread, tag and system costs should decrease to the point where it becomes economically feasible to tag low cost individual items. Tagging at the individual item level will significantly increase the amount of data available for decision making and foster additional innovation in RFID systems. Also, item level tagging will tighten the linkages between operations and marketing, and open up significant sales and marketing opportunities. Two RFID systems currently being tested for tagging at the item level are smart carts and smart shelves.

Smart carts are being touted as a way to increase customer satisfaction of grocery store shopper's at the most undesirable point in the shopping experience - the checkout line. Smart carts have been tested by supermarket chains Stop & Shop (MSNBC.com, 2004) and Safeway (Gilbert, 2002). RFID technology will dramatically reduce the check-out time of customers in that customers will be able to push their shopping cart or basket past a reader and get a complete list of the items purchased and total price (Jones et al., 2004).

Smart shelves are specially designed shelves that can read RFID tags embedded in individual items placed on the shelf. The shelves can automatically monitor inventory levels and alert employees when stocks run low or when a theft has occurred. Consumer goods companies hope to benefit from increased sales due to reduced stockouts. But, smart shelves and individual item tagging raise concerns about consumer privacy (Gilbert, 2003b). Gillette tested smart shelves at a Tesco supermarket in the United

Kingdom and secretly photographed customers when they took the tagged razor blades off the shelf and when they left the store. Consumer privacy advocates cried foul and Gillette has backed away from individual item tagging (Wilding and Delgado, 2004b). Also, Wal-Mart canceled tests using smart shelves in order to focus on the installation of RFID systems in warehouses and distribution centers (Gilbert and Shim, 2004). Due to the cost and privacy concerns of tagging individual items, it may be ten or more years before these systems are implemented (Gilbert, 2003a).

7 Conclusion

The mandates from the government and the major retailers will continue to drive the adoption of RFID technology, and companies will have no choice but to implement RFID systems. In this paper, we discussed the supply chain impact and the implementation challenges of RFID in the hope of providing guidance for the adoption and implementation of RFID technology. It should be noted that the real benefit of RFID technology comes from going above and beyond compliance, and investigating other applications of RFID to improve marketing efforts, operational effectiveness and efficiency, and customer service.

The implementation of RFID systems has the potential to revolutionize supply chain dynamics by significantly increasing supply chain transparency through the dissemination of large amounts of accurate, real-time data. This data can be used to enhance decision making throughout the supply chain in order to increase supply chain efficiency by reducing lead times and inventory levels, while minimizing stockouts,

overstocks and shrinkage. These improvements should lead to higher levels of customer satisfaction, sales and profits, and sustainable competitive advantage.

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Table 1. RFID Tags and Bar Codes

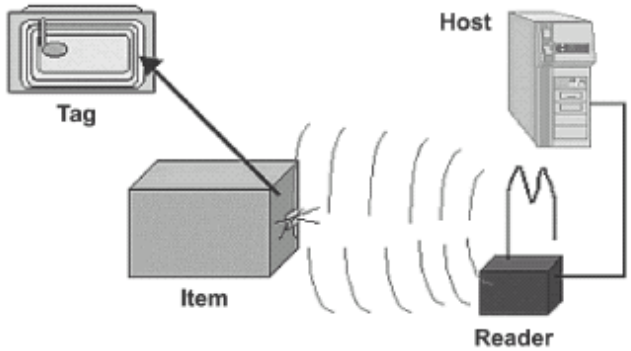
	RFID Tags	Bar Codes
Direct line of sight to reader	Not required	Required
Multiple item reads	Yes - multiple items can be read simultaneously	No - only one code can be read at a time
Human intervention	Not required, though for some products (metal, liquids) package must be oriented	Required in most cases to scan the bar code and to orient packages
Labor requirements	Lower - the tag is read as it passes through the reader	Higher - automated bar code scanners require proper package orientation
Communication	Two-way, through the use of a read-write tag	One-way
Information currency	Real-time - data is entered into the computer system as the item is read	Seldom real-time - data is entered into the computer system when the scanner is uploaded (typically for hand-held scanners)
Missed reads	No - a poka-yoke light system can be utilized to indicate an item has been read	Yes - items not scanned have no way to indicate a mis-read or a no-read (theft)
Multiple reads of an item	No - an item with an RFID tag can only be read once since the item has a unique code, its EPC	Yes - the same item can be read multiple times with no way of prevention or detection
Robustness	More robust since RFID tags can be embedded in the item	Bar code can be damaged (water, abrasion, tear) and be unscannable
Reader range	Higher	Lower
Security	Can be used as a security device	Cannot be used as a security device
Reading speed	Higher - due to automation and multiple item reads	Lower - limited by the ability of the human operator
Long-term system costs	Lower due to tag reuse, cheaper maintenance costs and lower labor requirements	Higher
Data Storage	Higher, ≥ 64 bits and growing	Lower, 19 bits

(Dinning and Schuster, 2003; Wilding and Delgado, 2004a)

Table 2. Benefits of RFID in the Supply Chain

Impact	Retailers	Distributor/Logistics Provider	Manufacturers/Suppliers
Reduced Cost	✓ Reduced inventory of goods through fewer overstocks ✓ Reduced store labor through multiple item reads and human intervention not required to orientate package ✓ Improved theft prevention ✓ Reduced operating expenses - an RFID system will be less than 10 percent of the annual cost of using bar-codes	✓ Improved use of warehouse and distribution center space ✓ Reduced labor due to fast loading and the fact that all the items in a pallet can be read simultaneously ✓ Improved visibility on what precisely is entering the warehouse ✓ Faster receiving and shipping since all the items in a pallet can be read simultaneously ✓ Reduction in 'unofficial supply chains'	✓ Enhanced inventory visibility ✓ Improved labor efficiency ✓ Elimination of the need for manual inventory management ✓ Reduced labor, data latency and errors associated with product handling ✓ Reduction of fixed assets through better utilization of space and equipment ✓ Reduced shrinkage ✓ Reduced inspection costs
Increased Sales	✓ Reduction of stockouts	✓ Reduction of stockouts at retail stores	✓ Reduction of stockouts at retail stores
Improved Customer Service and Satisfaction	✓ Automated checkout process ✓ Reduction of out of stock ✓ Better target and track the purchasing behaviors of consumers ✓ Better product selection and lower prices ✓ Product recalls can be conducted quickly and efficiently	✓ Improved accuracy for departure and arrival times of goods	✓ Improved fulfillment rates ✓ Increased control in mixed-model production, which allows for greater product variety for customers
	Supply Chain as a Whole		
Increased inventory and asset visibility	✓ Track the movement of products through the supply chain from production to the retail point of sale in real-time ✓ Improved reverse logistics for reusable assets and for the recycling of products		
Increased safety and security	✓ Improved recall management through tracking and tracing unique EPC ✓ Improved lot track and trace ✓ Better expiration date management ✓ Reduced shrinkage		
Better supply chain planning	✓ Reduction in inventory and working capital ✓ Reduction in out of stocks ✓ Reduction in expediting costs		
Improved information sharing and quality	✓ Information on the tags can be read and updated in real time as they move along the supply chain ✓ Tags can contain more information to supply chain partners		
Increased collaboration	✓ Increased synchronization through information sharing would enable collaborative planning, forecasting, and replenishment (CFPR) activities beyond the typical buyer-seller relationship		

Figure 1 A typical RFID system and tag



RFID Tag (not to scale)

Source: What is RFID? *http://www.e-centre.org.uk/products_rfid_whatis.htm*