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FlexRFID Middleware in the Supply Chain: Strategic Values and Challenges

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Abstract

Radio Frequency Identification (RFID) was used since the Second World War to identify "friend or foe" aircrafts. Recently, it is becoming an enabling wireless technology which is widely employed in a number of application areas such as ID badges and access control, equipment, personal, and patient tracking in hospitals, highway tolls collection, tracking livestock movements and air freight, parking lot access and control, container and pallet tracking, product tracking through manufacturing and assembly, inventory control, and in supply chain management (SCM). RFID tags were used for tracking pallets and cases by both Wal-Mart and the Department of Defense (DoD) of USA in 2003. By 2006, Wal-Mart has extended the requirements to use RFID to all its suppliers. The use of RFID in supply chain networks has allowed Wal-Mart to create value through greater visibility in its networks, higher product velocity, reduced human error and labor cost, and more efficient inventory management. This eventually led to the achievement of Quick Response (QR) and improved Customer Relationship Management (CRM) in the supply chain. However, some RFID system challenges (e.g. system design, tags and readers cost), and uncertain Return-On-Investment (ROI) still need to be overcome to fully achieve these objectives. This paper introduces RFID technology and its key components and concepts, and presents our RFID middleware solution called FlexRFID which was developed with an aim of achieving the maximum benefits of RFID technology independently of the interested backend applications. We illustrate how RFID technology can be used to solve the main problems in SCM, the advantages and key issues when implementing RFID in SCM networks, and the relationship between RFID and the main SCM processes. Finally we give a suggestion of how FlexRFID middleware can be integrated with an SCM application for inventory control.

Keywords-- RFID, middleware, FlexRFID, SCM, CRM, ROI, supply chain, policy, inventory control

INTRODUCTION

Radio Frequency Identification (RFID) is one of the Automatic Identification and Data Capture (AIDC) techniques (Ishikawa et al., 2003). RFID uses low-power, and radio waves to automatically identify people or objects, and to provide radically enhanced data handling capabilities (Tektronix, 2004). It is convenient, easy to use, and well suited for automatic operations (ADC Technologies Group, 2002). RFID technology can be used to track objects in a manner similar to using barcode based systems (Ishikawa et al., 2003) and Optical Character Recognition (OCR) systems (Phoenix Software International, 2006), but RFID also combines additional advantages not available in these technologies. RFID does not require line of sight readings, can function under a variety of environmental conditions, can read multiple tags simultaneously, store large amounts of data in addition to the ID of the object tracked, and provide a high level of data integrity (ADC Technologies Group, 2002; Ajana et al., 2009).

While existing for decades as an enabling technology, RFID does not provide much value on its own, however the creation of RFID based applications is the key that creates value for the companies. Although RFID can be a complicated and costly business technology, it appears that RFID will overcome the implementation obstacles and become a breakthrough technology throughout the supply chain for manufacturing, packaging, logistics, distributions, and retailing (Chuang & Shaw, 2007).

A *supply chain* is “a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers”. The complexity of supply chain varies greatly from industry to industry (Ganeshan & Harrison, n. d.). The supply chain starts and ends with the customer, and is made up of several elements that are linked by the movement of products along it. The supply chain consists of the following elements: customer, planning, purchasing, inventory, production, and transportation (Murray, 2010).

Supply Chain Management is the “management and control of all materials and information in the logistics process from acquisition of raw materials to delivery to the end user” (Michael & McCathie, 2005). Companies have adopted SCM processes and associated technology in order to ensure that the supply chain is operating as efficient as possible and generating the highest level of customer satisfaction at the lowest possible price (Murray, 2010).

RFID technology has the potential of helping retailers provide the right product at the right place at the right time, thus maximizing sales and profits. The integration of RFID technology in the SCM systems has helped in optimizing inventory management, reducing losses, increasing ROI and information accuracy, and improving visibility in various stages of SCM (Sheng et al., 2008). RFID offers item-level data visibility; a revolutionary advance that can improve product availability and reduce losses associated with shrinkage and product obsolescence (IBM Global Business Services, 2005).

Mandating RFID, Wal-Mart and other companies believe that it benefits their own supply chains as well as their suppliers. However, not all these possible benefits are fully achieved. Uncertainty exists about how RFID will affect supply chains and what benefits and risks it will bring, and evidence suggests that companies will not be able to see RFID ROI for the first two or three years (Chuang & Shaw, 2007). RFID integration in the SCM happens in stages; therefore its benefits accrue in phases throughout the supply chaining activities.

The paper is organized as follows. We talk briefly about RFID system components, and then we present FlexRFID middleware architecture. We show how RFID technology is used for supply chain management networks, its benefits and risks, and its integration stages in SCM. Then we showcase the relationship between RFID and SCM processes. Finally we describe how an SCM application for inventory control can be developed based on the FlexRFID middleware architecture, followed by conclusions and future work in the last section.

RFID SYSTEM COMPONENTS

RFID systems consist basically of three main components: a tag/transponder, a reader, and a middleware running at a host computer. *RFID Tags* are the data carrier part of the RFID system; they store information about the object being tracked. Specific object data is stored in the memory of the tag and is accessed via the radio signal of the reader (Knowledgeleader, 2006). Data stored in RFID tags can consist of serial numbers, security codes, product codes and other object specific data. Various types of tags exist and are classified with respect to different parameters. For example with respect to powering, tags may be passive, semi-passive, and active (Sheng et al., 2008; United States Government Accountability Office, 2005). *Passive tags* present the simplest version of RFID tags which do not contain a battery as their own power source, and cannot initiate communication with the reader. The passive tag derives its power from the energy waves transmitted by the reader and responds to the reader's radio frequency emissions. *Semi-passive tags*, called also semi-active tags, also do not initiate communication with the reader but contain batteries that allow the tag to perform other functions, such as monitoring environmental conditions and powering the tag's internal electronics. *Active tags,* unlike passive tags, they contain a power source and a transmitter in addition to the antenna and chip, and send a continuous signal. These tags typically have read/write capabilities (United States Government Accountability Office, 2005). In terms of access to memory, the tags may be read-only, read-write, Electrically Erasable Programmable Read-Only Memory, Static Random Access Memory, and Write-once Read-many (Al-Mousawi, 2004;United States Government Accountability Office,2005). Tags may also be classified with respect to geometrical parameters such as size and shape, or serve different environmental conditions e.g. tags suited to cardboard cases containing plastic items may not be ideal for wooden pallets, metal containers or glass (Intermec, 2007).

The *RFID reader* is a device that transmits and receives data through radio waves using the connected antennas. RFID reader can read multiple tags simultaneously without line-of-sight requirement. The reading happens even when tagged objects are embedded inside packaging, or even when the tag is embedded inside an object itself (e.g. RFID implants). There exist different types of RFID readers; fixed and handheld/portable, and they can be equipped with tag collision and reader collision prevention techniques, and also tag-reader authentication algorithms (Glasser et al., 2007). RFID deployment is becoming more attractive due to the decreasing prices of RFID tags and readers over the years. The first operation to happen is that the reader sends energy through its antennas and forms an interrogation zone. When a tag enters this zone, it gets activated to exchange data with the reader. The reader then decodes this data and sends it to a software system known as RFID middleware for processing (Al-Mousawi, 2004).

The *RFID middleware* refers to the software layer which resides between the physical layer components (RFID tags, and RFID readers), and the upper layer standalone or distributed enterprise applications. Hence it is a key component for managing the flow of information between tag readers and enterprise applications (Burnell, 2008). In the traditional applications of RFID such as access control, there was a little need for RFID middleware because networking among RFID readers was not a concern. In contrast to the novel application areas such as SCM, a number of RFID readers are networked to capture data which is disseminated to a variety of backend applications. There is no longer a one-to-one relationship between RFID reader and application, and therefore there is a strong need for RFID middleware to give better device control, and enable users to infer intelligent decisions from the raw RFID data coming from the readers. A successful middleware design solution depends on how well the different components of the middleware in different layers fit together and work to provide valuable processed data to the enterprise applications (Ajana et al., 2009).

FLEXRFID MIDDLEWARE

We developed FlexRFID, which is a multi-layered middleware that has a simple and robust design, satisfies applications' needs, and allows for an easy management of devices as described in (Ajana et al., 2009). Herewith we provide a summary of the FlexRFID middleware architecture focusing on each of its layers separately.

As shown in Figure 1, FlexRFID is part of a three-tier architecture consisting of: the backend applications layer, FlexRFID middleware layer, and hardware layer. We will proceed below through a bottom-up description of these layers.

The hardware layer contains *Diverse Types of Sensors and Devices* such as RFID readers, barcode scanners, sensors, and other industrial automation devices. This approach allows creating an intelligent sensor network by offering incredible flexibility in the selection of devices, and enables companies to build their enterprise solutions without handling low-level programming. This diversity in makes and models of sensing devices requires a middleware layer for device management, monitoring and coordination. Our approach consists of using Device Abstraction Layer (DAL) that abstracts the interaction with the physical network of devices. The FlexRFID middleware incorporates three other layers which are: Business Event and Data Processing Layer (BEDPL), Business Rules Layer (BRL), and Application Abstraction Layer (AAL).

Figure 1. FlexRFID middleware architecture. (©2009, Ajana, M. E. Used with permission.).

The *Device Abstraction Layer* (DAL) uses the *Data Source Abstraction Module* (DSAM) and the *Device Abstraction Module* (DAM) to handle various data sources and devices independently of their characteristics. The *Device Management and Monitoring Module* (DMMM) of the DAL is responsible for dynamic loading and unloading of the driver libraries and device adaptors, as well as configuration, monitoring and status reporting of the devices.

The *Business Event and Data Processing Layer* (BEDPL) acts as a mediator between the DAL and the AAL, and provides the following services: data dissemination, data aggregation, data transformation, data filtering, duplicate removal, data replacement, data writing and privacy management. The BEDPL acts in parallel with the *Business Rules Layer* (BRL) when performing the services cited above. When an application requests a service from the FlexRFID middleware, its specific rules loaded in the BRL are given as input to the service, which then applies these rules to issue commands to the DAL to access raw data and process it accordingly. Similarly raw data is carried from the DAL, processed by the BEDPL, and passed on to the AAL.

The BRL is a policy-based management engine that hosts the rules applied to the services of the FlexRFID middleware. This is achieved by determining the policies to apply when an application requests access to a service in the BEDPL. Policies are operating rules used to maintain order, security, consistency, or other ways of successfully achieving a service.

As shown in Figure 1 the BRL has four main components. The *Middleware Policy Editor* (MPE) allows storing, retrieving, and removing policies from the *Middleware Policy Repository* database. If an application needs to access a service that is protected by the Business Rules Layer, the request goes through the *Middleware Policy Enforcement Point* (MPEP) which asks the *Middleware Policy Decision Point* (MPDP) whether to permit or deny access to the service. The MPEP gives the MPDP the authority of decision making whether or not to grant the application access to the service based on the description of the application attributes. The MPDP makes its decision based on the applicable policies stored in the system. The returned decision is Permit, Deny, Indeterminate or Not Applicable. Indeterminate is returned if there is an error in processing the request and Not Applicable if no policy that applies to the request could be found.

Examples of policies included in the BRL are: data filtering policy, location transformation policy, and data aggregation policy. The *data filtering policy* filters data according to predefined policies by the applications. For example to filter the duplicate reading reported by different readers in the network, the filtering policy will scan data within a sliding window to find if there are duplicate RFID tag readings, and delete the duplicate if it exists. An example of *duplicate removal policy* could state that if readings from readers R_x and R_y have the same tag ID value within time T, then one of them is dropped according to the application's needs. The *location transformation policy* transforms RFID readers' observations into location changes. For example, Reader R is mounted at a warehouse departure zone and will scan objects before their departure. A policy for this transformation could specify that any observation generated from reader R will change the object's location to a value different from its current location. The *data aggregation policy* is used to detect a sequence of ordered events and generate an aggregation relationship from them. For instance when pallets are loaded into a truck to depart, a sequence of readings on the pallets is done, followed by a separate reading of the truck's tag. This sequence of events will aggregate as a containment relationship between the pallets and the truck.

The *Application Abstraction Layer* (AAL) provides various applications with an interface to the hardware devices, through which the applications request the set of services provided by the FlexRFID middleware with hidden complexity. This layer provides a high level of software abstraction that allows for communication among the enterprise applications and the FlexRFID middleware.

To sum up FlexRFID middleware provides the following distinguishing aspects: a device and data source neutral interface for the applications to communicate simultaneously with different hardware creating an intelligent RFID network, a hardware management and monitoring interface, and data processing capabilities enforced by a policy based management layer. The modular and layered design of FlexRFID allows integrating new services and policies with little effort, and enables seamless integration of many enterprise applications.

RFID TECHNOLOGY FOR SUPPLY CHAIN NETWORKS

RFID technology has gained greater prominence and a higher level of adoption due to its recent advancements and decreasing costs across the years. The applications of RFID in the SCM have vast potential in improving effectiveness and efficiencies in solving supply chain problems. In the very near future, by adding RFID to every product, tool, resource, and item, manufacturers will be able to get better demand signals from customers (AME Info, 2005). All products in motion are traced throughout the supply chain from manufacturer's shop floor, to warehouses, to retail stores. Such a visibility of accurate data brings opportunities for improvement and transformation in various processes of the supply chain, and allows a wide range of organizations to realize significant productivity gains and efficiencies (Sabbaghi & Vaidyanathan, 2008).

In the next sections we try to answer the following questions: (1) what would be the benefits of RFID integration in supply chain? (2) What are the risks, challenges, and recommendations in adopting and implementing RFID in supply chain? (3) What processes in supply chain will be affected by RFID, and where this technology has the potential of creating the most business value?

The Benefits of RFID

RFID promises to revolutionize supply chains and usher in a new era of cost savings, efficiency and business intelligence. As follows is a description of the main benefits of integrating RFID in SCM.

Automatic non-line-of-sight scanning; this means that items do not require particular orientation for scanning, unlike barcodes. Also RFID readers can communicate to tags in milliseconds and have the ability to scan multiple items simultaneously. This attractive offering significantly aids the automation of many SCM tasks that have been labor intensive, gives an accurate data about stock levels for organizations which in turn leads to lower inventory costs and less out-of-stock occurrences (Michael & McCathie, 2005).

RFID leads to *labor reduction* throughout the supply chain process. RFID could yield labor savings of up to 36% in order picking and 90% reduction in verification costs for shipping processes. Labor is the major cost component of typical distribution centers accounting for around 50-80% of total distribution costs. Therefore, these reductions in labor by using RFID can deliver considerable financial savings (Michael & McCathie, 2005).

Enhanced visibility; RFID technology offers greater visibility to all stakeholders in the supply chain. This offered visibility could provide real-time and accurate information about products, allowing organizations to use this information to increase efficiency. Inventory visibility can also be used to make faster response to customer demands and market trends. Smart shelves including inbuilt RFID tag readers are used for real-time reporting of information, and help retailers track the exact number of products they hold (Michael & McCathie, 2005; RFID4U, 2006).

Asset tracking and returnable items; RFID is ideal for improving asset utilization by tracking asset's movement, use, and placement. RFID can also log an asset history and ensure that government requirements and regulations are adhered to. RFID tags enable greater visibility of the asset pool which impacts six main areas: operating costs, shrinkage, lead times, inventory visibility and accuracy, customer service and integration among parents (Michael & McCathie, 2005; RFID4U, 2006).

Item level tracking using RFID, opens the door to a whole range of potential benefits, for example theft detection or customized manufacturing. It is a necessity for smart shelves to achieve their maximum potential, and will allow identifying and storing individual product properties such as expiry date. This level of tracking will be fully introduced for around 10 years. Currently, most organizations have decided to focus on pallet and case level tracking (Michael & McCathie, 2005).

Traceable warranties and product recalls. Faulty instances of a product often lead to destruction of a perfectly good brand. Using RFID to track affected products will allow manufacturers to issue targeted recalls of these products only. Plus, tagged items that require repair and are covered by a warranty can be authenticated, ensuring that the warranty period of the product has not expired. The item can also be monitored as the product moves back up the supply chain to the manufacturer or authorized repairer, allowing customers to receive detailed information on where their item is in the process (Michael & McCathie, 2005).

Quality control and regulation; RFID permits to monitor the quality of products not only internally in an organization, but also when products move along the supply chain. This allows lowering the chance of customers receiving poor quality products as well as reducing the time spent monitoring and reworking orders. Some RFID tags can monitor things like temperature, and bacteria levels, which is an important capability where many products are shipped around the world, and exposed to countless environmental forces which could affect the quality of the finished good (Michael & McCathie, 2005).

Ability to withstand harsh environments; RFID can continue to work perfectly in harsh conditions, such as high or low temperature degrees, and in acids, dirty, oily, or wet industrial and commercial environments (Michael & McCathie, 2005).

The Risks of RFID

Despite the enticing benefits of RFID, some thoughts about its implementation issues in the global supply chain must be taken, including sizes of the chips because they cannot be placed on all products, environment limitations, and personal privacy (Lin et al., 2006). These issues are well known to the industry, and solutions are under development. Here we examine a list of the most prominent problems facing RFID implementation today that are important strategy considerations.

One of the major issues that inhibited RFID growth has been the *cost of RFID* and uncertain Return on Investment. The costs of a fully functional RFID system include tags, readers, printers, middleware, infrastructure, consulting, and a changed system. Today, tag prices have dropped and are projected to drop much further. A cost driver that should be considered in supply chain is whether the tags will be reused or disposed of. This driver is influenced by the level of partnering achieved by downstream partners who would return, reuse or discard the tags. In addition to tag cost, there are other significant RFID system incurring costs such as software including middleware, integration, and process redesign (Chuang & Shaw, 2005; United Parcel Service of America, 2005).

Whether *tag readability* is an issue depends on many factors such as tag range and frequencies, reader capabilities and locations, interference from other devices, operating environment variations (temperature, humidity, vibration, and shock), and the type of assets being tagged; for e.g. metal objects and liquid containers tend to create reading problems for some types of tags. Readability issues will become manageable for most applications, given the incremental improvement of RFID technology (United Parcel Service of America, 2005).

Due to *RFID data volume and its unique characteristics*, new structures for RFID data management should be considered, because most ERP and WMS systems are not designed for RFID capture (United Parcel Service of America, 2005).

The implementation of RFID in SCM may suffer from the issue of *data ownership and sharing*. The benefits of sharing item specific data as it progresses throughout the supply chain between multiple trading partners can be significant; however the willingness of the partners to do so has historically been a challenge (United Parcel Service of America, 2005).

There are significant efforts undertaken by standard bodies to converge on common requirements for RFID data, but there will be differences based upon applications and other factors. The standardization issue concerning how RFID data is structured, communicated and managed among trading partners should not be a major stumbling block to determine the business value of RFID (United Parcel Service of America, 2005).

RFID implementation involves significant *business process changes*. Therefore the design of any RFID strategy should consider organizational changes as new processes for automating tasks and decision making will be made (United Parcel Service of America, 2005).

Individual privacy concern is an issue in RFID. Consumers do not want themselves or the products they take to be tracked once they own them. In order to counter the privacy concerns, the industry has developed a "*kill tag*" feature that will disable the RFID tags in the checkout point at retail. Also some fears of compromised privacy can be alleviated by the fact that RFID tags could not be read from long distances (United Parcel Service of America, 2005).

Competing *standards* have been one of the most difficult issues for RFID. The problem is that there exists no universally accepted standard, and therefore most RFID applications have been closed systems. Standards can include an agreement about the format and content of the codes placed on the tags, the protocols and frequencies used by the tags and readers to exchange data, the security issues involved on placing tags on packaging and freight containers, and applications use (Modrak et al., 2010).

RFID Integration stages in SCM

A key success factor when implementing RFID is to start from a pilot RFID infrastructure and make it scalable while taking time to analyze and plan. Chuang & Shaw (2007) suggested a model for RFID integration in SCM that contains three different RFID implementation stages. Stage 1: Functional RFID Integration, Stage II: Business Unit RFID Integration, and Stage III: Inter-Company RFID Integration. This model takes into consideration the involvement of business partners and addresses the benefits and risks as more supply chain partners are part of the integration.

Functional RFID Integration addresses companies that apply RFID to a single process or internal activity, such as distribution center processes, Just-In-Time manufacturing processes, and asset tracking activity. By starting a RFID project in this category, the organization addresses several key questions. What process does the company want to change? What results does the company want to see by implementing RFID in this process? What are the expectations from this implementation? The benefits at this stage are improved functional process efficiency and effectiveness, and reduction of labor cost and human errors. The risks and complexity are relatively low at this level since this stage specializes on a single process or activity (Chuang & Shaw, 2007).

Business Unit RFID Integration is extended to different business units within an organization such as distribution centers, warehouses, or headquarters. This integration requires a scalable RFID architecture designed to meet a number of intra-organization expectations. The benefits of Business Unit RFID implementation include reduced labor costs and human errors in logistics operations, and better inventory management between the manufacturing and distribution centers. The involvement of several entities at the same time in the integration process makes the risk level relatively high (Chuang & Shaw, 2007).

Inter-Company RFID Integration means that a company implements RFID in its supply chain networks in collaboration with its business partners. Examples of companies that fall into this category are Wal-Mart, Metro Group, and Target. This integration type consists of having a collaboration relationship between upstream suppliers and downstream customers. Downstream customers communicate their needs from RFID implementation with their supply chain partners. Suppliers in turn would implement RFID with downstream users in mind to ensure that their expectations are met. Since the majority of organizations are both suppliers and consumers of goods and services, this stage becomes complex and with great technical and business risks (Chuang & Shaw, 2007).

Organizations can experience the overlap between each stage of integration; they can therefore carry the implementation experience and benefits to the next level of integration. Upstream suppliers tend to consider that RFID requires a big investment and uncertain ROI because typically they do not have RFID infrastructure in their current business processes and external supply chains. As a start, upstream suppliers can integrate RFID into their production and distribution systems first and then gradually integrate with their downstream customers (Chuang & Shaw, 2007).

RELATIONSHIP BETWEEN RFID AND SCM PROCESSES

There are eight key processes that make up the SCM, and provide a framework for various aspects of strategic and tactical issues present in the management of the supply chain. As follows is a description of these processes and their functions (Sabbaghi & Vaidyanathan, 2008):

1. **Customer Relationship Management (CRM)**: A business philosophy which provides a vision for how a company wants to deal with its customers. A CRM strategy is needed to deliver that vision, and helps giving shape to many activities such as sales, marketing, customer service, and data analysis. Therefore the aim of CRM strategy is to maximize profitable relationships between the company and its customers (Atos Origin, 2002). CRM provides processes that help identifying and targeting the best customers, generating quality sales leads, and implementing marketing campaigns with clear goals and objectives.
2. **Customer Service Management (CSM)**: offers benefits to both providers and customers by allowing the monitoring of service level agreement negotiated between the two parties. CSM offers a competitive advantage to providers, and enables customers to control up-to-date and adequate information about service specific QoS parameters (Langer, 1998). It can also provide real-time information to customers such as shipping dates, and product availability.
3. **Demand Management**: Demand Management is a highly iterative process that uses prioritization of customers, channels, products, and the demand stimulation programs

in order to achieve revenue. Demand Management relies on highly sophisticated quantitative analytics and advanced modeling techniques to preset tolerance levels, predict problem areas, adjust strategies dynamically, and achieve real-time visibility and synergy across all channels (IBM Business Consulting Services, 2005). This process helps to forecast demand and manage the demand in production, distribution and in all other outputs of the company. Therefore, it helps balancing the customers' requirements with the company's supply capabilities.

4. **Order Fulfillment Management**: concerns the management of the company's partnerships to meet the customer requirements. This would include the integration of the company's manufacturing, logistics and marketing plans.
5. **Manufacturing Flow Management**: helps to manage product flow and establish the manufacturing flexibility required to service target markets. This process includes all activities necessary to obtain, implement, and manage manufacturing flexibility in the supply chain and to move products through it.
6. **Supplier Relationship Management**: defines how companies interact and manage partnership with their core suppliers providing a competitive advantage. This process helps improving the selection and management of global suppliers, and therefore streamlining the other processes by making sure that the company is working with the most capable and economical suppliers.
7. **Product Development and Commercialization**: provides structure for developing new products and reducing time to market by jointly integrating customers and suppliers. This process enables management to coordinate the efficient flow of new products across the supply chain, and also assists supply chain members with the logistics, marketing and other related activities to support the commercialization of the product. It is one of the most important keys to firm's success.
8. **Returns Management**: concerns the management of all logistic operations related to returns of products from their original user to their supplier. When the product is returned, it incurs inventory carrying costs, and takes up warehouse space. Returns management allows encountering these problems by allowing a company to monitor productivity improvements and identify valuable ideas related to its products and services.

Out of these eight processes, RFID may be used in demand management, order fulfillment, manufacturing flow management, and returns management. The relationship between RFID and these four supply chain management processes is described in detail as following (Sabbaghi & Vaidyanathan, 2008).

Demand Management and RFID

The lack of reliable data has been one of the major difficulties in Demand Management. Adopting RFID would enhance data accuracy related to inventory of finished goods, work in-progress, and reliable due dates. RFID can eliminate inaccuracies in data due to human error or absence of data, and provide timely data both at the item-level and in aggregate about the market demand of a particular product. Therefore, the integration of RFID would help to develop more successful strategies in production, marketing, and distribution.

Order Fullfilment and RFID

Order fulfillment is a key process in meeting customer requirements and improving the effectiveness of the supply chain. RFID can reduce the cost of operations in order fulfillment. RFID enables suppliers to automatically and accurately determine the location of an item, to track its movement through the supply chain, and to make instantaneous business decisions.

This will free up labor-intensive work involved in the quantity check-in and receiving operations.

Manufacturing Flow Management and RFID

The use of RFID in manufacturing helps streamlining the assembly line operations, and therefore reducing cycle time, increasing production throughput, and improving the velocity and visibility of products in the supply chain. This will help manufacturers with their Just-in-Time (JIT) assembly lines by tracking where every item is in the manufacturing process and supply chain.

Returns Management and RFID

RFID can facilitate returns management by helping retailers track the history of the item being returned. Through the Electronic Security Marker (ESM) (Pearson, 2006), RFID can tie the relationship of a particular product to a given sale and then to the return. The tagging of products with electronic security markers enables them to have automated track-and-trace capabilities, and provides real-time visibility of the products through the supply chain.

FLEXRFID BASED SCM APPLICATION

Among the most important aspects that SCM applications target is inventory control. Inventory control aims at minimizing the total cost of inventory, and has three main factors in its decision making process: the cost of holding the stock, the cost of placing an order, and the cost of shortage; what is lost if the stock is insufficient to meet all demand.

We will focus herewith on the use of FlexRFID middleware to provide input to existing tools and applications for inventory control. FlexRFID middleware deals with RFID data streaming, reactivity, integration, and heterogeneity that represent a challenge for e-logistics and SCM systems.

Data Streaming

RFID devices are becoming cheaper and widely deployed and it is now increasingly important to perform continual intelligence analysis of data captured. To relieve the SCM applications from dealing with the streaming nature of data and the fact that the data might be redundant, even unreliable in certain cases, the FlexRFID middleware is able to process such unreliable real time sensing data before delivering it to the backend system.

Data Reactivity

RFID and other sensing technologies have promised real time global information visibility for SCM participants. To benefit from such visibility, the SCM participants have to be able to identify the interested situations and react to such situations when they happen. The events associated with the triggers have to be reported in a timely manner and notification has to be sent to interested SCM participants. The FlexRFID middleware handles this through its Business Event and Data Processing Layer, and policy based Business Rules Layer.

Data Integration

The design of FlexRFID middleware allows it to scale and support different devices and data sources that may be used at numerous points of inventory control such as Point of Sale (PoS), and smart Shelves.

The advantages of using FlexRFID for inventory control can therefore be summarized as follows:

- Report RFID data about location and inventory level in real time so that the inventory control application could place an automatic order whenever the total inventory at a warehouse or distribution center drops below a certain level.
- Report and aggregate accurate data at the PoS that will be used by the SCM application to monitor demand trends or to build a probabilistic pattern of demand that could be useful for products exhibiting high levels of dynamism in trends.
- Reduction of the *Bullwhip effect*, which means an exaggeration of demand in upward direction in a supply chain network. FlexRFID will provide accurate and real time information on actual sales of items that can be used for decision making and that will diminish the magnitude of the bullwhip effect. Reducing the bullwhip effect would benefit industries where instances of supply-demand imbalances have high costs attached to them.
- Capturing data that gives total visibility of product movement in the supply chain. This will help to make early decisions about inventory control in case there is any interruption in the supply. This results into reduction of total lead-time for arrival of an order. Pharmaceutical and perishable product industries could benefit from this to increase total useful shelf life of items.
- Reduced inventory shrinkage: FlexRFID can transform the capture of RFID data into inventory shrinkages events including thefts and misplacement of items.
- FlexRFID allows issuing policies by the inventory control applications for items as per the requirements. E. g.: first-in-first-out (FIFO) policy for items such as, vegetables, and bread.

CONCLUSION AND FUTURE WORK

Radio Frequency Identification is expected to become a critical and ubiquitous infrastructure technology for SCM related processes and services. It promises automatic data capturing and entering and makes it possible for real time information visibility for supply chain. In this paper we presented the benefits of using RFID in the supply chain networks, and its integration stages within the SCM processes. We developed the FlexRFID middleware and presented how it can be integrated with an SCM application especially for inventory control. Among the tasks that could be achieved while using FlexRFID with an inventory control application are: allowing inventory status to be determined in real time, shipping and receiving documents to be generated automatically, and triggering automatic orders for products that are low in inventory.

With respect to the future works, we intend to integrate the FlexRFID middleware with an open source system for inventory control (e.g. TechLogic Inventory Control System, Opentaps…), define the different scenarios and events that could be triggered by this system, and show how the different layers of FlexRFID middleware will work to deliver enhanced visibility of inventory in various stages of supply chaining.

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