2

Applications of RFID in Supply Chains

Gary M. Gaukler and Ralf W. Seifert

Abstract: In this chapter, we first give an introduction to radio-frequency identification (RFID) technology. We discuss capabilities and limitations of this technology in a supply chain setting. We then present several current applications of this technology to supply chains to demonstrate best practices and important implementation considerations. Subsequently, we discuss several issues that may hinder widespread RFID implementation in supply chains. We close by deriving several consequences for successful implementation of RFID, and we give guidance on how a company might best benefit from this technology.

2.1 An Overview of RFID Technology

At its core, RFID is a contactless interrogation method for identification of objects. Besides the applications in supply chain operations on which this chapter is going to focus, some of the everyday uses of this technology are in ID cards, sports equipment, windshield-mounted toll tags, and gasoline quick-purchase tokens. RFID has also begun to be used in keychain auto antitheft devices and toys (most notably, Hasbro Star Wars figures), and even on paper tickets for the 2006 Soccer World Cup in Germany (Odland 2004; Want 2004).

2.1.1 RFID Hardware

An RFID system consists of three parts: the RFID tag itself, the RFID reader device, and a backend IT system. The RFID tag typically consists of a silicon chip that can hold a certain amount of data (such as a unique identification number) and an antenna that is used to communicate with the remote reader device. There are chipless RFID tags as well, which exploit certain RF-reflecting properties of materials. In the case of chipless RFID, the tag's unique serial number is given by the properties of the material, e.g., the configuration of RF fibers embedded in paper.

The reader device communicates with the RFID tag by sending and receiving radio-frequency waves. The way this communication happens differs between so-called passive and active RFID tags. Passive RFID tags do not have a power supply; the energy stored in the reader device's radio-frequency interrogation scan is enough to wake up the RFID tag and to enable it to send a response (that is, the RFID tag's data) to the reader device by reflection. Active tags contain a battery that allows them to respond to the reader's interrogation with a stronger signal, thus increasing the distance from which the tag can be read. The backend IT system is responsible for cross-referencing the RFID tag's ID number with a database record that describes the object to which the tag is attached.

The method of communication by reflection of power that is the basis of passive RFID was described as early as 1948 (Stockman 1948). Related transponder technology was also used by the military as a friend-or-foe means of detection in Great Britain by the Royal Air force in World War II.

Regardless of the choice of active vs. passive RFID, the radio-frequency communication between tag and reader may happen on several frequency bands. Low frequency (LF) RFID uses the 125–134 kHz and 140–148.5 kHz channels, high frequency (HF) RFID is located at 13.56 MHz, and ultra high frequency (UHF) RFID uses 868–928 MHz. These frequencies are the ones that are used in the United States of America, European and Asian frequency bands differ slightly. The different frequencies have different characteristics with respect to the speed and the range of the communication. In general, the higher the frequency, the longer the communication range, and the faster the communication, which means that more data can be transmitted. Each of the different frequencies typically requires different tags and reader devices, although for some applications, combination devices that work in multiple frequency bands are available.

2.1.2 RFID and Bar coding

In some ways, RFID is similar to bar coding: Both technologies use labels and scanners to read the labels, and they both rely on an IT system that cross-references the ID on the label and relates it to an object or a class of objects using a database system. However, from an application standpoint, there are three major advantages of RFID over bar coding (see, e.g., Clampitt 2006; Sweeney 2005):

- No line of sight required
- Multiple parallel reads possible
- Individual items instead of an item class can be identified
- Read/write capability.

To illustrate the first two of these advantages, consider a typical receiving operation in a warehouse. A mixed pallet of goods is received. If all individual products on the pallet need to be entered into a computer system to acknowledge receipt, then in the bar coding scenario, a worker needs to break the pallet, open the cases, and scan each product. (If there were bar code labels on each case, these bar codes were linked to the contents of each case, and the recipients were to trust that the cases had not been tampered with, then the number of bar code scans could be much lower.)

This is both time-consuming and error-prone, and it means that the flow of goods into the warehouse needs to be interrupted to recognize what was received. In a scenario in which each product has an RFID tag attached to it, the pallet would simply be pulled through an RFID reader portal, and all products on the pallet would be identified almost instantaneously.

The third advantage is that an RFID tag can give more information than today's bar code labels. (Advanced bar codes have been devised that can store more information, e.g., 2D-bar codes. However, the size of the bar code limits how much information can be encoded.) Consider, for example, a can of Coca Cola. The bar code on each can of Coke is the same–The bar code describes the class of the product. In an RFID scenario, each can of Coke will have its own unique identifier. This means that complete tracing of the origin of an individual product is possible for the first time. This enables new possibilities, for example, for handling product recalls, warranties, and demonstrating the authenticity of a product based on information about its origin.

The read/write capability of RFID tags may have additional benefits when a computer link to a network database cannot always be guaranteed. In this case, data about the item that is tagged with the read/write tag can be stored and changed on the tag itself, without requiring a change in the database record that corresponds to the tag's serial number. Military applications of RFID make heavy use of read/write tags.

2.1.3 Levels of RFID Tagging

RFID tagging can take place at essentially three levels of granularity. In pallet-level tagging, a tag is affixed to a pallet. When the pallet is ready for shipment, a tag ID is programmed into the tag. This tag ID is typically cross-referenced to a purchase order and a list of the inventory on the pallet. At the shipment destination, the tag ID can be cross-referenced again to the database record that contains the pallet information.

In case-level tagging, tags are placed on cases. As in pallet-level tagging, the tag typically cross-references the purchase order and inventory information. The primary advantage of case-level tagging over pallet-level tagging is that it allows more detailed tracking. If inventory is moved in case quantities (as opposed to in eaches), then full inventory visibility can be achieved with case-level tagging. Case tagging also saves labor time by automatically reporting case counts and thus making manual counting of cases unnecessary.

Item-level tags are usually part of the item packaging. They are placed either inside the product's box or attached to the item itself. Item-level tagging gives the highest possible granularity of visibility. It is useful if individual products are handled in the supply chain, such as in a retail environment. In virtually all existing item-level RFID implementations, the manufacturer places the RFID tag on the finished good. Item-level tagging seems to hold the most potential for the retailer but is the costliest solution for the manufacturer (Gaukler et al. 2006). Despite some widely publicized trials, the business case for item-level tagging on low-value/low-margin items remains unproven; the cost of RFID tags is a drawback for an application of this technology to low-value, low-margin items.

2.1.4 RFID Standards

The need for standards arises automatically when considering RFID for a supply chain implementation. Tags and readers in different geographic locations (e.g., countries) and from different manufacturers need to communicate. Moreover, care must be taken that the serial numbers on RFID tags are unique – if there were two items with the same identification number in a supply chain, how would one determine which item is which?

Hence, the main types of standards that we consider for the purposes of this chapter on supply chain application are data standards and technology standards.

Data standards specify what is contained in the memory portion of the RFID tag, as well as the format in which this data is stored. For supply chain applications, the most important data standard is the EPC (electronic product code). This standard was developed by EPC global and UCC/EAN (now GS1), based on data format proposed by the MIT Auto ID Center. The EPC is simply a number, usually 64-256 bits long, that is being given out by EPCglobal. Each company that licenses and subscribes to this standard is given its own “address space” (or number range) for its items, so that no EPC will ever be duplicated worldwide.

Technology standards specify the protocols that are used for communication between tag and reader. Important variables here are the frequency and the power at which this communication occurs. For supply chain applications, the most important technology standard is the ISO (International Standards Organization) 18000 standards family. This standards family covers frequency bands from low frequency to HF, UHF, and microwave. In supply chain implementations, typically standards 18000-3 (HF), 18000-4 (microwave), and 18000-6 A/B (UHF) are most widely used. The ISO 18000 standards also specify data structure requirements which are compatible with the EPC. Unfortunately, different “flavors” exist, for example, of the 18000-6 standard (A and B), that make interoperability between tags from different manufacturers challenging.

The new EPCGlobal Gen2 standard (passive UHF), also known as ISO 18000-6 C, promises to be the first truly international and interoperable standard. In addition to interoperability, tags conforming to the Gen2 standard also promise higher and faster read rates, smaller size chips, and encryption capabilities (York 2005).

2.1.5 Limitations of RFID

Naturally, RFID has limitations. Some limitations are due to the laws of physics. Metals and liquids, for example, effectively block radio waves. This is particularly true for UHF and microwave frequencies. Thus, it is generally not possible to read RFID tags enclosed in metal or surrounded by liquids. There are some advances in tag and antenna design that allow placing RFID tags on metal objects, as long as the tag is not fully enclosed. But in general, RFID does not work very well in environments where the product is surrounded by metals or liquids.

A potential work-around to the problem of fluids and metals blocking RF is to use multiple readers, trying to read a tag from different angles. This will improve read rates in the presence of metals and liquids, and also in the general case. A similar method is employed by some companies to boost read rates of item- or case-level tags on a pallet. In this method, only one stationary reader is used, but the pallet with the cases and items on it is rotated so that the reader "sees" tags in different orientations. This can, for example, be combined with an existing workstation where the pallet is wrapped with protective tape.

Other limitations of RFID are due to the fact that the application of the technology in logistics operations is still relatively new. RFID tags can be defective (just like bar code labels that may be unreadable because they are torn, dirty, etc.), and to some extent interference issues between readers may exist that prevent tags from being read. It is expected that some of these limitations will find technological solutions as RFID technology becomes more mature in this application.

2.2 Current RFID Applications

In this section, we review some of the more interesting existing RFID applications. RFID implementations discussed here are in diverse sectors such as retail, logistics, etc. The discussion here focuses on implementations in industry, not on RFID research in the operations management community. Related discussions on implementation issues are given, for example, in Angeles (2005) and Jones et al. (2004). Sheffi and McFarlane (2003) discuss the value of RFID in supply chain operations. For an excellent overview of current theoretical research connecting RFID and operations management, see Lee and Ozer (2005). In the following, we will cover applications such as product tracking and identification, preventing misplaced items, enabling counterfeit protection, and connecting RFID tags with environment sensors.

2.2.1 RFID in Retail

An interesting application of RFID in the retail sector is the use of smart shelves and item-level tagging. Smart shelves are retail shelves that have RFID readers built-in. The main purpose of smart shelves is to prevent out-of-stock situations (OOS) from occurring at the shelf. An out-of-stock situation occurs at the shelf if a customer wants to buy a certain product, but the shelf is empty. Studies by Accenture and IBM Consulting (Alexander et al. 2002; Kambil and Brooks 2002) suggest that in approximately 30% of cases where the shelf is out of stock, there is actually product available in the backroom stocking location, but it just has not been put on the shelf yet. A timely alert to store personnel from a smart shelf could prevent this out-of-stock situation and thus prevent a sale from being lost.

Metro AG, a supermarket chain in Germany, has one of the most advanced RFID implementations in the retail sector to date (Metro AG 2006). When this was writen, it was the only RFID implementation that has been the subject of a Harvard Business School case (Ton et al. 2005). Metro has introduced RFID on the pallet-level (and increasingly on a case-level as well) throughout its supply chain. Around 100 of Metro's suppliers, 8 Metro distribution centers, and 250 Metro stores use an RFID-enabled logistics unit to document transportation routes, simplify warehouse picking and receiving, and to check inventories automatically. Metro's partners in this effort include Procter & Gamble, Henkel, Johnson & Johnson, and Esprit. Metro estimates that at the goods receiving stage in their warehouses and at their stores, manual labor times can be reduced as much as 80%. At the same time, backroom out-of-stock situations have become less common because employees are kept aware of backroom inventory levels continually. This in turn enables them to reorder products in a more timely fashion.

In addition to the widespread implementation of pallet- and case-level RFID, Metro is experimenting with item-level RFID at one of its supermarkets in Rheinberg, Germany. This supermarket is known as the Metro Future Store. This Future Store is a fully operational supermarket that serves 2,800 customers per day with a sales area of 4,000 square meters. The store is a working showcase for several technologies that are intended to improve the shopping experience. At this store, item-level RFID is used on four products (Procter & Gamble Pantene shampoo, Kraft Philadelphia cream cheese, Gillette Mach3 razors, and DVDs). These products are displayed on smart shelves (Figure 2.1).

Figure 2.1. Smart shelf with Gillette products (photo courtesy of Metro AG)

Shelf replenishment from the backroom is initiated by notification from the shelf to the store personnel. In addition, there are RFID reader gates at the checkout lanes (for future automated self-checkout purposes), between the inbound loading dock and the store backroom, as well as between the store backroom and the sales floor.

By using these RFID gates, it is possible to keep track of all RFID-tagged merchandise within the store. Figure 2.2 shows an RFID gate.

Figure 2.2. RFID gate at the Metro Future Store (photo courtesy of Metro AG)

Apart from the inventory control and efficiency aspects of this RFID implementation, Metro also attempts to add value to the shopping experience for its customers. This is done through RFID information kiosks. Customers can, for example, take DVDs to such a kiosk. The kiosk will read the RFID tag on the DVD and play a preview clip of the movie or display other additional information. In response to privacy concerns, there is also an RFID tag deactivation station, where customers can deactivate the RFID tags on their products after they have purchased them. Further ideas for such one-to-one marketing are developed in Klabjan 2005.

2.2.2 RFID in Logistics, Transportation, and Warehousing

The benefits of RFID in logistics, transportation, and warehousing can be broadly categorized into (1) labor and timesaving and (2) benefits from increased visibility. The first benefits category has also been described using the notion of "the uninterrupted supply chain" (TUSC) (Supply Chain Digest 2005). This is the idea that too large a percentage of a product's traversal time through a supply chain or a logistics system is spent waiting for identification or the completion of some manual process such as counting cases related to identification and documentation. Hence, the flow of goods is interrupted by stopping points. A system that uses automated identification through RFID can potentially remove many of these stopping points, enabling the product to move through the system faster and at less cost. These purely operational cost savings will tend to be especially large if the product in the supply chain is a serialized product, i.e., a product where each case needs to be identified instead of bulk identification per pallet. Serialized products include computers, computer printers, electronics equipment, etc. These are serialized products because, for example, each computer may have a different configuration. This is different from dealing with a generic, noncustomizable product such as dishwasher detergent, for example.

Another area where RFID can be a useful tool is in improving inventory accuracy. Inventory accuracy refers to the difference between logical and physical inventory. Logical inventory is the amount of inventory on record in the computer system – WMS, ERP, etc. Physical inventory is what is really in stock. Ideally, the logical and physical inventory quantities are equal, but for a variety of reasons (shrinkage, input errors, loss of goods, misplacement, etc.), these quantities may be quite different. Typically, logical inventory shown in computer systems is larger than physical inventory. RFID can help improve the logical inventory records due to automation of the scanning process. See, for example, Atali et al. (2005) for academic work on this subject.

These relatively simple efficiency and accuracy improvements may be large enough to justify an RFID implementation, out the lion's share of benefits are typically expected to be realized from increased visibility (MIT CTL 2004). Exact knowledge of the amount of inventory at each location in the supply chain in real-time is going to enable supply chain decision-makers to run a much more efficient supply chain. Knowing what is in the replenishment pipeline and when it is expected to arrive, potentially allows safety stocks to be reduced, while maintaining or increasing customer service levels. Essentially, this RFID visibility puts a supply chain on a new inventory/service-level exchange curve (see Figure 2.3).

In addition, new and more flexible inventory control policies can be devised that use the added visibility. Gaukler et al. (2005), for example, describe an inventory control policy that uses of knowledge about the location and timing of replenishment orders in the resupply channel to make decisions on placing additional orders from a different supplier if the existing orders are held up for some reason. It is expected that with the spread of RFID installations, many more sophisticated policies will emerge to control supply chain activities in an automated way based on RFID visibility.

2.2.3 RFID in Assembly, Manufacturing, and Configuration Management

Assembly and manufacturing of configurable products are supply chain activities that offer much potential for the use of RFID. RFID tags can be used in manufacturing to identify the product that is being assembled, as well as the constituent parts that are to be installed into the product. At the time of assembly, it is then possible to do an instant check to ascertain which parts need to be installed in the product and whether the parts that are installed are the correct parts. Thus, RFID has a role in assuring the quality of the end product. This benefit is particularly valuable if the product is highly customizable. The benefit from an introduction of RFID in this scenario is twofold: On the one hand, there are the labor savings from automating the scanning/identification of chassis and parts, and on the other hand, there are the savings in rework cost due to fewer assembly errors.

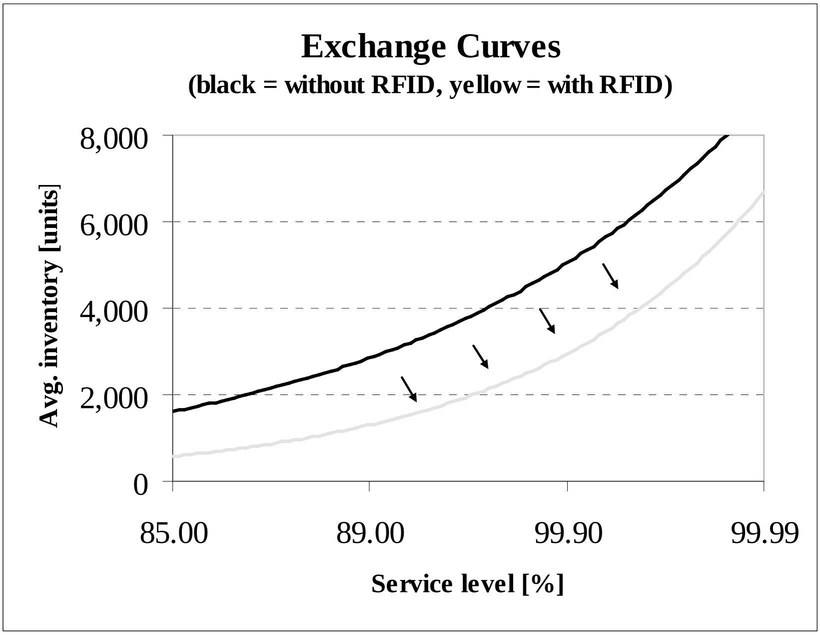

Figure 2.3. Sample exchange curves with and without RFID visibility

Ford Motor Co. has been using RFID tags for this purpose in their facility in Cuautitlan in Mexico as well as in U.S. facilities for a number of years (Johnson 2002). In Ford's implementation, an RFID tag is attached to each car's chassis skid. The tag indicates via its serial number, which parts and options are to be installed on that particular chassis. As the chassis moves from one assembly station to the next, RFID readers read the chassis' assembly requirements automatically so that the correct parts can be installed without the need for error-prone manual bar code scanning. "Error-prone" here refers, for example, to the case of a worker scanning the wrong tag, or a worker scanning the tag on one part, but then erroneously installing a different part. Gaukler and Hausman (2005) study a similar RFID scenario based on an implementation at a European car manufacturer. They present several net present value evaluations of a move from bar coding technology to an RFID implementation in such an assembly environment and provide an algorithm to determine an optimal RFID rollout schedule. Further analysis of RFID opportunities in the automotive sector is given, for example, in Strassner and Fleisch (2003).

It is expected that similar benefits can be realized in other, nonautomotive, complex assembly processes that consist of a large amount of manual labor with a high probability of assembling incorrect parts. Examples of this are the assembly of medical devices and aircraft.

2.2.4 RFID in Asset Tracking and Locating Objects

RFID can be used to prevent misplacement of items or to facilitate locating items. One way this can be done is to keep track of item movements in a database. For example, RFID readers can be installed at doors between rooms in a building. Evaluating the records of the RFID readers would then allow one to deduce in which room the item is located. It is worthwhile to note that this is typically not a good theft prevention method, because RFID readers can easily be inhibited by placing the item in a metal-lined bag for instance. However, this system can work well in an environment where one is more concerned about accidental misplacement of an item than about theft.

An example of such tracking is given at Bon Secours Richmond, which has implemented an RFID-based asset-tracking program at four hospitals (Baker 2005). Bon Secours tracks 20,000 pieces of medical equipment in this implementation, ranging from infusion pumps to ventilators and wheelchairs. This asset tracking implementation saves costs at several levels: First, the cost for purchase or rental of new equipment has gone down because utilization of existing equipment has gone from 40% to 70%; second, preventive maintenance costs for the equipment have decreased significantly since, with the tracking program, maintenance personnel do not have to search for the equipment anymore. Moreover, the handling of equipment recalls has become more efficient: Potentially hazardous equipment can be located fast and retired from active duty, thus increasing patient safety.

Another way of locating items is to use a mobile handheld RFID reader and RFID tags as a homing device. A variant of this method is to use information stored on RFID tags on a container to find out the contents of that container. The U.S. Army uses this extensively during overseas deployments. Cargo containers that are shipped to U.S. deployment sites contain an active RFID tag that lists the contents of that container. Containers are also tracked during shipment by GPS. During operation Desert Storm, more than 50% of the containers that were shipped to the Gulf region had to be opened to find out what was stored inside. Since logistics officers did not know what materials were already on site, many redundant replenishment orders were released, contributing to a high level of inefficiency. RFID and supporting technologies have drastically increased inventory visibility both on the ground and in transit. Due to this visibility alone, the U.S. Army has managed to decrease on-hand inventory for some pieces of equipment to one-tenth of the level necessary during Desert Storm (Trebilcock 2006).

2.2.5 RFID in Authentication, Counterfeit Protection, and Security

There are three ways in which RFID can aid in authentication and counterfeit protection of products: (1) by virtue of the presence of an RFID tag, (2) by proprietary encodings on the RFID chip, and (3) by establishing a chain of custody, also known as an e-pedigree of a product. (1) and (2) are a step up from no counterfeit protection at all, as it makes it harder (and more costly) for counterfeiters to copy the product. However, there is no absolute security because with sufficient expense, any RFID tag can be duplicated.

Much better security from counterfeiting is afforded by the e-pedigree approach. In this method, an item's authenticity is established by looking at the source of the item. As the item traverses the supply chain, its tag is read at multiple locations, including the manufacturer, logistics carrier, distribution centers, and retailer. Thus, an authentic item will have a record of tag reads (which is not saved on its tag, but rather on a supply chain computer system) that proves its progress from the manufacturer down the chain. A nonauthentic item, which is inserted into the supply chain at some other point, will not have this "correct" trace of tag reads. Hence, by looking at an item's e-pedigree, it is possible to distinguish counterfeit from original items. This scheme is harder to defeat, since defeating it would necessitate changing tag read records in the supply chain's computer system. One needs to keep in mind, however, that even when using an e-pedigree approach, an RFID tag can be duplicated. In this case, once the item with the duplicated tag is introduced into the supply chain, the system would see two distinct items that point to the identical history record. Although the system cannot decide which item is counterfeit based on this information alone, it can flag both items as suspect and would also be able to pinpoint the supply chain location where the counterfeit item was introduced.

Not surprisingly, a major target of counterfeiters is pharmaceuticals. Pharmaceuticals are typically high-value items and are relatively easy to fake. Pfizer is one of the pharmaceuticals companies that have turned to RFID to make its supply chain more secure. In Pfizer's RFID implementation, item-level RFID tags are put on drug bottles (in this case, Viagra and Lipitor). Pharmacists can check the authenticity of a particular bottle by scanning its RFID serial number and validating its authenticity with Pfizer directly, using their personal authentication account on Pfizer's Web site. This is an example of authentication through proprietary encoding. In the future, Pfizer plans to move toward an e-pedigree approach (Pfizer 2006).

Another area where authentication is required for security reasons is in inbound overseas container shipments. The goal there is twofold: To enable containers from trusted sources (countries) to be routed through customs faster and to prevent containers that have been tampered with from entering the country. Several of the largest seaport operators (Hutchison, PSA, P&O, China Merchants, and SSA) have formed a coalition to explore the use of automated tracking and RFID for containers shipped to the U.S. The idea behind this Smart and Secure Tradelanes Initiative (Savi 2006) is to apply an electronic seal using an RFID tag to the container at the outbound port and track the container through RFID readers and GPS on route to the destination port. At the destination port, the e-pedigree of the container would be checked, along with the integrity of the electronic seal. The result of this is ideally not only a higher level of security, but because of the e-pedigree, manual inspections may become largely unnecessary, speeding up the port operations considerably. Preliminary studies (Lee and Whang 2003) on the effectiveness of this method reveal large cost savings – for one pilot program, savings were estimated at $1,000 per container (Johnson 2004).

2.2.6 RFID with Environment Sensors

Apart from integrating RFID tags with GPS sensors as in the port security example, there are other applications where data from environmental sensors is integrated with and stored on RFID tags.

The U.S. Army, for example, uses RFID tags with temperature and shock sensors on cases of munitions. Shock sensors are important because the shelf life of munitions becomes drastically shorter once they have been dropped. The shock sensor records the g-shocks to which the case has been subjected to and writes the data to the RFID tag. When the case is opened, the data can be read out and used to determine the expected shelf life of the content of the case. A similar approach is used for temperature-sensitive material (DeLong 2003; Aitoro 2005).

A similar opportunity for individually setting expected shelf lives for product lots exists in perishable products that require a cold chain for transportation and processing. Such products include many food items, some pharmaceuticals, as well as blood bags and donor organs. Karkkainen (2003) discusses the value of RFID for short shelf-life products in detail, including perishable items. The Kroger supermarket chain is running a pilot project to explore the use of RFID and temperature sensors in distributing case-ready meat. Meat temperature will be tracked from packaging the meat to arrival at the retail store. It is envisioned that RFID temperature history of each case of meat will be used by the retailer as a guide to decide on discounts and on optimizing the sequence of restocking the sales floor. Since different cases of meat may have experienced different ranges of temperature during transportation and thus have different remaining shelf lives, it is no longer optimal to replenish the sales floor using a "first-in/first-out" rule. Rather, the replenishment rule would likely be of the type "lowest shelf life first." OATSystems, Inc, which is supplying middleware and integration to this pilot project, estimates that Kroger can potentially cut its losses from spoilage in half (O’Connor 2005).

2.3 Proliferation and Adoption Issues

Even with the clear advantages of RFID technology over bar coding and other identification methods, these factors impede the pervasive, large-scale adoption of RFID in many applications: The cost of RFID, the technological maturity of RFID, privacy issues, and the difficulty in allocating the cost of RFID to supply chain partners.

2.3.1 Cost of RFID

At first glance, the cost of RFID seems high. The cost of RFID includes the cost of tags, readers, and IT infrastructure. In 2006, several years after the commercialization of RFID, the costs of tags and readers have come down significantly, but they are still high compared to that of the major competitor, bar coding. Tag costs run anywhere between 25 ¢ for short-range passive tags to well over $10 for specialized long-range active tags. Tag prices tend to increase with the amount of information that can be stored on the tag. Reader costs hover between $500–$5000 per device, depending on technology and features. Faced with these cost figures, it is obvious that companies need to look for a significant return on this investment.

Typically, one can view reader and infrastructure costs as fixed costs because they tend not to vary significantly with the amount of product that passes through the supply chain. Tag costs, however, are variable costs in that every pallet, box, or item needs a tag. Thus, in popular literature, the cost of tags is usually seen as the most important determinant of RFID profitability.

Our view of the cost issue of RFID is that in most cases, the cost of RFID (and the cost of RFID tags) is overemphasized. In all RFID implementations that we have observed and in all the studies that we have conducted, it turned out that the RFID cost could easily be amortized over a few years. This held true even when only the most basic RFID benefits were realized. By basic RFID benefits, we mean "low-hanging fruit" such as labor savings from not having to bar code scan boxes or pallets in a warehouse, etc. It is important to understand that the economies of RFID are fundamentally different from bar coding: With bar codes, the label cost is low, but the incremental cost of each scan is high; because it typically involves human labor and a break in the material flow. With RFID, the tag cost is higher, but the incremental cost of each scan is very low because scans can be performed automatically by stationary readers as goods flow by. Thus, potential benefits from RFID tend to be highest when each tagged good is scanned repeatedly.

These RFID “economies of scan” notwithstanding, one needs to be realistic about which items can be RFID tagged and where RFID tagging simply does not make sense economically. RFID-tagging very inexpensive and low-margin items is not going to make sense – the 50-¢ candy bar with a 20-¢ RFID tag is not going to happen outside of pilot studies. This explains why mass-market consumer retail businesses that operate on very thin margins are reluctant to adopt item-level RFID tagging.

2.3.2 Technological Maturity of RFID

RFID itself is not a very new technology, but its commercial use is very recent. Thus, companies must deal with a number of issues when implementing RFID.

First, it is important to realize that there are several physical limitations of RFID technology, and any radio-frequency-based technology, for that matter. RFID does not work through metal or through liquids. Because metals and liquids inhibit the propagation of electromagnetic waves, which is the medium of communication that RFID uses. This does not necessarily mean that it is impossible to read RFID tags on bottles of orange juice. In fact, if there is line-of-sight between the reader and the tag, the tag will still be read.

Matters become more complicated, of course, when trying to read an RFID tag on a bottle of orange juice that is stacked in the middle of a pallet. But even in this case, the tag can be read, provided that there are sufficient air gaps between the bottles on that pallet.

A technique that is often applied to alleviate this shortcoming of RFID is to rotate the pallet while reading tags. That way, the reader will "see" tags at different angles and the tag read rate would increase. Product design and the location of the tag on the product also affect how easy it is to read the tag.

Second, several companies using RFID have reported issues with RFID tags that could not be programmed. In 2004, commonly reported RFID tag failures ranged from 10–12% – that is, 10–12% of tags purchased from a tag vendor could not be written and/or read (Brandel 2004). Of course, this is not a fundamental issue with RFID technology itself, but rather a quality control problem of the tag supplier(s). However, it shows that parts of the technology are fairly immature in the sense that, for example, manufacturing yields of RFID tags are low, which poses a potential problem for companies relying on 100% working tags.

Third, the reader-and-tag interaction in real-world environments outside of a lab setting is often not very well understood. Other radio-emitting devices such as machines using electromotors, microwaves, or radios and TVs create an environment that is prone to interference with RFID tag reads. Reader and tag orientation are key to extracting high read rates in an RFID setup. In many ways, the hardware of an RFID implementation (for example, placing readers and antennas correctly) is more of an art than a science. Detailed theoretical scientific research on how to select readers and antennas exists (see e.g., Keskilammi et al. 2003), but outside of a laboratory, trial and error prevail. During one consulting project for an electronics manufacturer, we observed the following: A conveyor belt system was set up with an RFID reader such that the reader would scan all incoming boxes. Read rates were low for no apparent reason. Then one engineer moved the stationary reader a couple of inches higher and read rates suddenly increased significantly. Such trial-and-error optimizations are common in first rollouts of RFID.

2.3.3 Privacy Issues

Consumer privacy concerns have been linked with RFID since the first commercial implementations of item-level RFID. Kelly and Erickson (2005) discuss privacy concerns related to commercial application of RFID in detail. The concerns have to do mostly with RFID tags on individual products, as opposed to RFID tags on boxes or pallets, simply because RFID tags on boxes or pallets do not typically get to the end consumer.

The supermarket chain Tesco in the U.K. was among the first to be targeted by privacy advocates. Tesco and Gillette had set up a theft-prevention system that used RFID-tagged razor blades, a smart shelf, and digital cameras. When razor blades were removed from the shelf, a digital camera would automatically take a picture of the customer. Then, at the cashier, another picture would be taken of the customer as s/he paid for the razor blades. At the end of the day, store detectives would compare both sets of images and conclude that potentially a theft occurred if a customer showed up on the picture at the shelf, but not on the picture at the cashier. The efficacy of such a system is doubtful at best, and privacy advocates claimed that customers were not sufficiently informed about this surveillance practice. The ensuing PR proved disastrous for the image of RFID.

However, apart from this scenario, most item-level RFID implementations do not save more data about customers than a regular supermarket loyalty card or a credit card would. Thus, we do not view privacy concerns as a significantly limiting factor to RFID adoption in the long run.

2.3.4 Allocating the Cost of RFID to Supply Chain Partners

From a supply chain perspective, it makes sense to introduce RFID upstream in the supply chain to achieve the most benefits. This means that in the case of item-level tagging, it makes sense to apply tags for the finished product at the packaging stage of the manufacturing process. Thus, the manufacturer should place the tag on the finished good.

However, experience indicates that manufacturers, logistics providers, and retailers typically see different benefits from RFID (e.g., see Alexander et al. 2002; Kambil and Brooks 2002). Manufacturers are generally most interested in tracking cases or pallets of their product via the transportation channel up to the retail outlets, whereas retailers typically gain most benefit from individual-product tracking on their shelves.

Thus looking at the supply chain as a whole, the dilemma becomes clear: Item-level tagging seems to hold the most potential for the retailer but is the costliest solution for the manufacturer who needs to put on the tags. Hence, in theory in a competitive environment, the manufacturer will generally need some kind of contractual incentive to incur the tag cost, and downstream supply chain partners will need to share in the cost of the tag (for more discussion of contractual incentives, see Pasternack 1985 and Gaukler 2004).

Exactly how this is to be done in practice, however, is not clear. But the question "who pays, and who benefits?" remain the subject of much contention. In the retail sector, Wal-Mart has taken the lead and announced a clear mandate: Any supplier to Wal-Mart must put RFID tags on cases and pallets from January 2005 on. The choice for Wal-Mart's suppliers hence has been to make the investment, or to stop being a supplier to Wal-Mart. In the military/government sector, the U.S. Department of Defense (DoD) has given a similar mandate for case- and pallet-level tagging to DoD suppliers. In both the Wal-Mart and the DoD cases, the market power of the mandating entities is such that suppliers overwhelmingly complied with the mandates.

In supply chains where the power structure is such that there is no mandating entity, however, things are not so clear-cut. Manufacturers may hold back on tagging their products, because for their operation – viewed in isolation – there is no positive return on investment that would justify item-level tagging. For the supply chain as a whole – including the downstream stages and the logistics providers – it may well be that item-level RFID can have a positive ROI. Such a supply chain would thus not operate optimally because the investment decision in item-level tagging is based on only one supply chain partner's (in this case, the manufacturer's) cost and benefit structure. In a recent paper, Gaukler et al. (2006) show that in the absence of mandating entities, there exists a unique optimal way of sharing the cost of RFID tags between a manufacturer and a retailer. Sharing the RFID tag cost is optimal in the sense that the total supply chain profits are maximized. Gaukler et al. compute the optimal way of splitting the cost of item-level tags and note that when tag costs are split that way, supply chain coordination can be achieved through a lump-sum payment.

2.4 The Strategic Dimension of RFID

RFID is a technology that is positioned to influence drastically the way supply chains are managed. The technology itself is rather simple – after all, it is just another way of identifying things – but the implications are vast. For the first time, there exists a low cost way of identifying anything completely automatically.

Limitations of RFID technology exist. Some of these limitations are physical, e.g., the difficulty in penetrating metal or liquids with RF. Some approaches to help alleviate this problem, such as varying the angle and position between reader and tag, have been discussed in this chapter. Another (financial) limitation is usually the cost of RFID. It is projected that part of this problem goes away as time goes by and tag and reader prices fall to more acceptable levels. In the meantime, smart use of, for example, reusable tags instead of one-time-use tags as discussed earlier, can dramatically improve the return on investment.

The beauty and the value of RFID lies in automating the identification process: No more does one need to rely on workers to scan items. The economies of RFID are fundamentally different from the economies of bar coding: With bar codes, the label cost is low, but the incremental cost of each scan is high because it typically involves human labor and a break in the material flow. With RFID, the label cost is higher, but the incremental cost of each scan is very low because scans can be performed automatically by stationary readers as goods flow by. Thus, potential benefits from RFID tend to be highest when each tagged good is scanned repeatedly, presumably at different stages of the supply chain. We call this the RFID "economies of scan."

Benefits from RFID can be roughly categorized as evolutionary vs.revolutionary. Evolutionary benefits from RFID are those where business processes are essentially unchanged from the pre-RFID status. The difference and the benefits from RFID in this category stem from cost savings due to faster and potentially more accurate scans under RFID compared to bar coding. Examples of such improvements are labor cost savings, increased throughput, and more accuracy in inventory control. These improvements tend to be fairly easy to attain, but the overall impact is usually limited in magnitude. Revolutionary benefits from RFID, on the other hand, can accrue when RFID data are used to drive new automated processes. An example of this is new enterprise event management software that can drive a supply chain much more efficiently by reacting in real-time to events in a supply chain in an automated fashion. In essence, RFID is positioned to be the key enabler of a new wave of supply chain competition based on information flows.

The decision to implement RFID, therefore, needs to be made by considering more than just the single company: Upstream suppliers and downstream customers as well as logistics providers, and their needs and requirements for an RFID implementation – all these elements need to be part of the decision process. Hence, when used to its full extent, RFID is not merely an operational tool that can be used in isolation; rather, it is a strategic technology. The successful supply chains in the future will be those that understand this strategic dimension and embrace it.

2.5 Guidelines for Practitioners

Out of the discussion in the previous sections, it becomes clear that for companies that are new to RFID, it is prudent to start small and gain first-hand experience with the technology within the four walls of the company. This will enable the company to learn about the technology without interfering with outside business relations. In this phase, the company will evaluate the hardware as well as the software side of an implementation. Some of the questions that need to be answered at this stage are:

- What type of tags and readers will be used?
- How many read points will be needed, and where?
- How does the RFID system interface with existing MRP, ERP, and warehouse management software?
- What level of worker training is necessary?

There also exist several RFID testing sites that companies can use, for example, Sun's RFID Test Center (Sun 2006). At this site, Sun has set up a full-fledged warehouse in which customers can pilot RFID equipment and Sun software to simulate an actual RFID rollout.

When following this "start small, expand later" approach, it is crucial not to neglect the strategic side of an RFID implementation. Typically, the majority of benefits from RFID are not achieved within the four walls of the company but rather from implementation across the complete supply chain.

Part of the strategic side of an RFID implementation is to identify the interfaces with suppliers, logistics providers, and customers. RFID is a cross-cutting technology in that it is used across the stages of the supply chain. As such, a successful implementation of RFID always needs to be viewed as an implementation that takes into account the whole supply chain. Insular implementation at individual companies without regard for what functionality is necessary or beneficial upstream and downstream in the supply chain, cannot extract the maximal benefits from RFID.

Taking into account the whole supply chain also means that a company needs to be aware of how its particular RFID hardware (tags and readers) is or is not able to interface with the hardware used by its supply chain partners. As we have highlighted previously in this chapter’s section on RFID standards, this is unfortunately not a trivial problem. In our view, considerable care should be taken to implement RFID hardware solutions that are compatible with today’s international standards.

The worst scenario a company can find itself in is to do what has been aptly named "slap and ship": Put the RFID tag on the product, and then forget about it. This is the ultimate insular implementation. "Slap and ship" only incurs cost (the RFID tag and the cost of tag placement), but there is no benefit to the company.

Going one step further and using RFID internally will provide some benefits to the company. These benefits will be mainly in the form of labor savings from not having to bar code scan items, savings from increased assembly quality and less rework, or general process improvements due to the fact that material flows can be visualized and improved.

For many companies that are starting to think about implementing RFID, the most intimidating factor is the cost of RFID tags. In many cases, this is a variable cost that cannot be amortized the way a one-time fixed hardware purchase cost or a one-time system installation cost can. It can help tremendously if some serious thought is given to potential ways of using reusable tags instead of one-time-use tags. This applies mostly to RFID implementations within the four walls of one company, but may in some instances also be applicable to supply chain implementations. In one example taken from one of our recent consulting activities, a semiconductor manufacturer wanted to employ RFID to track cans of chemicals on its production-lines. The initial idea was to tag each can with a passive RFID tag once it was received from the supplier. Unfortunately, the usage rate of these cans (and hence the rate at which tags would be needed) appeared to be too high to achieve a positive ROI. The financial side started to look markedly improved when we suggested using reusable (reprogrammable) tags instead. These reusable tags would be attached like key fobs to the cans. Even though these tags are more expensive, fewer of them are needed; essentially the tag cost in this example had been transformed into a fixed cost. A similar case is the Volkswagen example that was briefly mentioned in this chapter's section on RFID in Assembly, Manufacturing, and Configuration (Gaukler and Hausman 2005). Here, to identify a car chassis on the assembly line, a tag is not embedded in the chassis directly, but rather the tag is embedded in the assembly line conveyance that carries the chassis. The chassis tag can be reprogrammed depending on which car chassis the conveyance carries. Hence, again a variable tag cost is converted into a fixed cost that can easily be amortized.

Implementing RFID within the four walls of a company can yield substantial benefits. However, the greatest impact typically occurs when one goes beyond these low hanging fruit: RFID promises highest benefits from integrating the RFID data across a supply chain. RFID gives vast amounts of data that need to be processed to filter out information that can be used to develop insights that can then be used to drive operational actions. The true value of RFID is making data (and hence information) available in an automated fashion at low cost. New software systems can be built using this information to drive a supply chain much more efficiently by reacting to supply chain exceptions (e.g., a late order, a stock-out situation, etc.) in real-time in an automated way. A first example of such use of information from RFID is given in Gaukler et al. (2005).

As competition among supply chains becomes more intense, RFID is positioned to be a key technology. RFID allows successful supply chains to differentiate themselves from others by the extent to which they manage to use information. This competition on information flows, pre-RFID, is exemplified by the retail practices of Seven-11 Japan, the dominant convenience store chain in Japan (Whang 2003). Seven-11 Japan managed to gather detailed information on the types of customers and their shopping preferences based on the time of day.

From this customer demographic information, they derived insights that helped them restock and reconfigure the entire store with different products targeted at different customer demographics three times a day, maintaining an unparalleled degree of freshness of their products and offering a maximum of convenience for their customers. The small size of the Seven-11 stores and the limited variety of products allows them to do this efficiently without RFID. Nevertheless, this pre-RFID scenario illustrates the impact that managing and using information can have on business operations. In our view, RFID technology is going to be the key enabler of a new wave of supply chain competition based on information flows.

2.6 References

Aitoro J, (February 2005) The Government and RFID: What You Need to Know, VARBusiness, http://www.varbusiness.com/sections/news/breakingnews.jhtml?articleId=60403591.

Alexander K, Birkhofer G, Gramling K, Kleinberger H, Leng S, Moogimane D, Woods M, (2002) Focus on Retail: Applying Auto-ID to Improve Product Availability at the Retail Shelf, White Paper, www.autoidcenter.com.

Angeles R, (2005) RFID Technologies: supply chain applications and implementation issues, Information Systems Management 22(1).

Atali A, Lee H, Ozer O, (2005) If the inventory manager knew: Value of RFID under imperfect inventory information, Working Paper, Stanford University, Stanford CA 94305.

Baker M, (October 2005) Hospitals Save Costs, Time with Wireless Tags, ExtremeNano, http://www.extremenano.com/article/Hospitals+Save+Costs+Time+with+Wireless+Tags/162772_2.aspx.

Brandel M, (December 2004) The Trouble With Tags, Computer World, http://www.computerworld.com/softwaretopics/erp/story/0,10801,98340,00.html.

Clampitt H, (2006) The RFID Handbook, http://rfidhandbook.blogspot.com/2004/11/preface.html.

DeLong B, (2003) How the US Military is Achieving Total Asset Visibility and More Using RFID and MEMS, Presentation, Smart Labels USA, Cambridge, MA.

Gaukler G, (2004) RFID in the Retail Supply Chain: Benefits, Roll-Out Strategies, and Cost Sharing Agreements, The Supply Chain Connection 10(2), Stanford Global Supply Chain Management Forum.

Gaukler G, Hausman W, (November 2005) RFID in Assembly Operations: Process and Quality Savings, Working Paper, Dept. of Management Science and Engineering, Stanford University, Stanford, CA.

Gaukler G, Ozer O, Hausman W, (November 2005) RFID and Product Progress Information: Improved Emergency Ordering Policies, Working Paper, Dept. of Management Science and Engineering, Stanford University, Stanford, CA.

Gaukler G, Seifert R, Hausman W, (2006) Item-level RFID in the Retail Supply Chain, Production and Operations Management (POM), forthcoming.

Johnson D, (November 2002) RFID Tags Improve Tracking, Quality on Ford Line in Mexico, Control Engineering, http://www.manufacturing.net/ctl/article/CA257232?pubdate=11%2F1%2F2002.

Johnson J, (July 2004) Safe Harbors, DC Velocity, http://www.dcvelocity.com/articles/july2004/equipmentapplications.cfm.

Jones P, Clarke-Hill C, Shears P, Comfort D, Hillier D, (2004) Radio frequency identification in the UK: Opportunities and challenges, International Journal of Retail and Distribution Management, 32(3).

Kambil A, Brooks J, (2002) Auto-ID Across the Value Chain: From Dramatic Potential to Greater Efficiency and Profit, White Paper, www.autoidcenter.com.

Karkkainen M, (2003) Increasing efficiency in the supply chain for short shelf life goods using RFID tagging, International Journal of Retail and Distribution Management, 31(10).

Kelly E, Erickson G, (2005) RFID tags: commercial applications vs.privacy rights, Marketing Intelligence and Planning, 23(4).

Keskilammi M, Sydanheimo L, Kivikoski M, (2003) Radio freuqncy technology for automated manufacturing and logistics control – Part 1, International Journal of Advanced Manufacturing Technologies, 21(10).

Klabjan D, (2005) One-to-One Marketing with RFID, Working Paper, University of Illinois, Urbana Champaign.

Lee H, Ozer O, (March 2005) Unlocking the Value of RFID, Working Paper, Stanford University, Stanford, CA.

Lee H, Whang S, (October 2003) Higher Supply Chain Security with Lower Cost: Lessons from Total Quality Management, Working Paper, Stanford University.

Metro AG, (February 2006) Press releases on www.futurestore.org.

MIT CTL, (November 2004) Reading RFID, http://ctl.mit.edu/index.pl?id=3612.

O'Connor M, (December 2005) Kroger Turning to RFID to Stay Fresh, RFIDJournal, http://www.rfidjournal.com/article/articleview/2055/1/1/.

Odland T, (February 2004) RFID and Leisure RFID, Card Technology Today.

Pasternack B, (1985) Optimal pricing and returns policies for perishable commodities, Marketing Science 4(2).

Pfizer, (February 2006) Press releases at www.pfizer.com.

Savi, (February 2006) Press releases at www.savi.com.

Sheffi Y, McFarlane D, (2003) The impact of Auto-ID on supply chain operations, International Journal of Logistics Management 14(1).

Stockman H, (October 1948) Communication by Means of Reflected Power, Proceedings of the IRE, 1196-1204.

Strassner M, Fleisch E, (2003) The promise of Auto-ID in the Automotive Industry, White Paper, www.autoidcenter.com.

Sun, (February 2006) Sun RFID Test Center Website, http://www.sun.com/software/solutions/rfid/testcenter/index.xml.

Supply Chain Digest, (September 2005) Gillette, HP, and Lockheed Martin Say They Are Finding the RFID ROI, http://www.scdigest.com/assets/newsviews/05-09-15-2.cfm.

Sweeney P, (2005) RFID for Dummies, Wiley.

Ton Z, Dessain V, Stachowiak-Joulain M, (2005) RFID at the Metro Group, Case Study, Harvard Business School.

Trebilcock B, (January 2006) RFID on the Front Lines, Modern Materials Handling, http://www.mmh.com/article/CA6299039.html.

Want R, (January 2004) RFID A key to automating everything, Scientific American.

Whang S, (2003) Seven Eleven Japan, Case Study, Stanford Graduate School of Business.

York C, (January 2005) RFID Strategy – What Does the Gen2 RFID Standard Mean to You?, Industry Week, http://www.industryweek.com/Columns/Asp/columns.asp?ColumnId=1070.

http://www.springer.com/978-1-84628-606-3

Trends in Supply Chain Design and Management
Technologies and Methodologies
Jung, H.; Chen, F.F.; Jeong, B. (Eds.)
2007, XIII, 451 p., Hardcover
ISBN: 978-1-84628-606-3