RFID TECHNOLOGIES: SUPPLY-CHAIN APPLICATIONS AND IMPLEMENTATION ISSUES

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RFID technologies hold the promise of closing some of the information gaps in the supply chain, especially in retailing and logistics. As a mobile technology, RFID can enable "process freedoms" and real-time visibility into supply chains. This article provides an introduction to the technology, several case examples, and implementation guidelines for managers based on published reports.

NEWLY EMERGING WIRELESS TECHnologies, one of which is radio frequency identification (RFID), hold the promise of closing the information gaps in the supply chain. The applications of RFID are wide-ranging and include the manufacturing and distribution of physical goods such as automobiles and transmission assembly (Mintchell, 2002), minting bank notes (Anonymous2, 2002), oil exploration (Anonymous1, 2002), shipping and port operations (D'Amico, 2002; Dornheim, 2002), and pharmaceutical packaging processes (Forcinio, 2002), among others.

Keen and Macintosh (2001) consider RFID technologies as part of the "universal infrastructure" that will support mobile commerce. These authors also foresee RFID as an example of technologies that introduce "process freedoms," that is, those with the ability to add value along the entire supply chain and related logistical operations and business relationships by enabling the mobility of critical elements — the business activities, people, information, documents, and communications — needed for a more effective business process design. Given the recent mandates for suppliers to use RFID technologies by Wal-Mart and others, it appears that an initial phase of widespread diffusion of RFID technologies is at hand.

An RFID is one type of auto-identification technology that uses radio waves to identify individual physical objects. In this article, however, the term "auto-ID" refers to a specific technology prototype developed by the Auto-ID Center at the Massachusetts Institute of Technology (MIT) and allied research universities, and now supported by EPCglobal, a new nonprofit organization.

This article focuses on the application of RFID in logistical operations. First we summarize the key elements of RFID applications and summarize five case examples to demonstrate the supply chain benefits being realized with RFID. Next we describe a specific RFID technology implementation that has been developed in collaboration with the Auto-ID Center at MIT. We then use a hypothetical Auto-ID example to demonstrate how RFID can realize the promise of "process freedoms" and supply chain visibility. The article concludes with a set

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of managerial guidelines for RFID deployment, based on published literature.

INTRODUCTION TO RFID TECHNOLOGY

RFID is a generic technology concept that refers to the use of radio waves to identify objects (Auto-ID Center, 2002). RFID tags have both a microchip and an antenna. The microchip is used to store object information such as a unique serial number. The antenna enables the microchip to transmit object information to a reader, which transforms the information on the RFID tag to a format understandable by computers.

RFID is part of a range of technologies (such as barcodes, biometrics, machine vision, magnetic stripe, optical card readers, voice recognition, smart cards, etc.) used for automated data collection to augment enterprise resource planning or ERP system activities (Gupta, 2000). The RFID is considered a significant improvement over the conventional barcode, which needs to be read by scanners in "line-of-sight" fashion and can be stripped away if the paper product labels get ripped or damaged. RFID can also facilitate inter-organizational E-commerce initiatives such as continuous replenishment or vendor-managed inventories (Smaros and Holmstrom, 2000).

RFID Tags

Current RFID tags can be active, passive, or semi-passive. Active RFID tags use a battery to power the microchip's circuitry and broadcast signals to the reader. Passive tags do not have batteries and are powered by the electromagnetic waves sent out by a reader to induce a current in the tag's antenna. Semi-passive tags use both the battery and the waves sent out by the reader. Active and semi-passive tags are typically used for higher-value goods that are scanned over longer distances. Some newer tags also have anticollision features, such as Texas Instruments' Tag-it system, so that many tags can be read even if they are located in the same small contiguous area.

The chip in the tag is either read-write or read-only. Information can be embedded in read-write chips, which are far more expensive and are used for higher-value product items. Read-only chips are more commonly used for tracking inexpensive items. A new technique being used on chips is the electrically erasable programmable read-only memory or EEPROM, which allows existing data on the chip to be overwritten using a special electronic process.

A major issue with the RFID tag is keeping costs down to encourage wider scale adoption. At this time, the most inexpensive tags cost 50 cents each in very large quantities. The goal is to bring down the cost to about 5 cents per tag or lower using different methods such as shrinking the size of the chip itself and cutting the costs of the antenna.

The Tag Reader

Through the method of inductive coupling, RFID readers communicate with tags. The coiled antenna of the reader creates a magnetic field with the tag's antenna, which subsequently draws energy from this field and uses this to send back waves to the reader. These waves are transformed into digital information representing the Electronic Product Code (EPC). The "read range" of the tag depends on both the reader's power and the frequency used to communicate. Higher-frequency tags can be read from longer distances but they require more energy output from the readers. Range could be an important issue when certain applications are concerned, for instance, identifying train cars as they move in transit. Knowing what is in inventory by having range, however, does not guarantee that readers will help you find where the goods are. Only agile readers can help pinpoint the precise location of a tag.

There are two major technical issues with readers. The first one concerns two types of collisions. The first type of collision involves signals from one reader that can interfere with signals from another reader when their physical coverage overlaps. The Auto-ID Center at MIT has used the Time Division Multiple Access (TDMA) anticollision scheme to help deal with this problem. Using this scheme, readers are programmed to read tags at different times rather than simultaneously. This just means more overhead costs because tags found in areas where two readers overlap in coverage will have to be read twice. An ancillary system for deleting duplicating codes has also been devised to support the anticollision scheme.

The second type of collision problem occurs when readers are reading many chips in the same field. The Auto-ID Center has addressed this problem by making readers ask tags to respond only if their first digits match the digits communicated by the reader. The reader keeps querying the tags until such time when one and only one tag responds, which is the desired condition.

Significant time savings in processing the crates were experienced and, over time, emergency shipping charges were eliminated.

The second major issue with readers has to do with the frequency with which they communicate with the tags. Radio waves are used when readers communicate with tags. Radio waves are part of the electromagnetic spectrum whose use is regulated by governments around the world. A problem with RFIDs is that governments have assigned different uses for the various parts of this spectrum. There is practically no part of the spectrum available everywhere in the world with the exception of special ISM (i.e., industrial, scientific, and medical) bands. This means a tag operating at a certain frequency in one country may not be readable in another country where the same spectrum is used for a different purpose.

To circumvent this problem, the Auto-ID Center at MIT has designed reference specifications for "agile readers" that can read chips of different frequencies. This will enable firms to use only one reader in situations where multiple frequencies are involved and save them the costs of having separate readers for each frequency. Thus far, in terms of cost, agile readers could be available for U.S.$100 per unit if purchased in volume. This introduces the related issue of reader cost, which is expected to go down as newer technologies are developed for its use.

Supply-Chain Benefits

Although the performance benefits are, for the most part, anecdotal at this point, the seven case summaries below illustrate the significant potential of the RFID technology.

Case #1: Unilever. Unilever uses the Texas Instruments RFID technology to support its smart pallet system designed to move, handle, and track its consumer products in its warehouses (www.ti.com/tiris/docs/solutions/supply/logsup.shtml). Transponders have been installed at the bay doors of the warehouse to track pallets that pass through them. Thereafter, another transponder transmits that information about the passing transport vehicle to the computer system. This information on the individual pallet weights stored in the computer database is used in comparing the weight of the total load of a truck. As a result of the RFID system, the number of pallets handled daily has increased and the information on the movements of the physical loads has become more reliable.

Case #2: Chevrolet Creative Services. Chevrolet Creative Services usually needs to gather about 3,500 crates of materials for trade shows from their Wixom, Michigan, storage warehouse. Today, it uses an RFID system to process the legal documents (manifests) used to support shipments of goods for crates that go in and out of this warehouse (www.ti.com/tiris/docs/solutions/supply/logsup.shtml). The crates have RFID tags embedded in them, which are read by readers mounted on warehouse bay doors and readout antennas installed on the floor. Information on the crates that pass over these antennas is compared with the information that is stored on a host database; an information match fires a green light to indicate that the crate could proceed to shipping. Any information discrepancies are flagged by a red light and the crate is stopped from further movement through the pipeline. Chevrolet Creative Services has been freed from frequent interruptions in the movement of the pallets or crates through different inspection points to allow for human inspection of the labels. Staff members are no longer needed to key in crate information into the system, thus reducing human-based errors. Significant time savings in processing the crates were experienced and, over time, emergency shipping charges were eliminated.

Case #3: United Biscuits. The application of RFID technology in a food manufacturing plant presents interesting lessons because it is an environment that involves moisture, metal, and variable temperatures. United Biscuits uses RFID technology to control raw materials movement and in the weighing, mixing, and baking processes involved in the preparation of biscuits, cakes, and prepared foods in its Ashby, U.K., plant (www.ti.com/tiris/docs/solutions/supply/logsup.shtml). A bin has a mounted tag that is read at the beginning of the food processing sequence to ensure that there are no errors. Human operators are informed through the use of overhead displays that either things are going smoothly or that there are food processing problems to attend to. United Biscuits has reported improved efficiency in the manufacturing process, improved information accuracy, better tracking of the food products, and a decline in incidence of errors.

Case #4: Semiconductor Industry. Fluoroware, Inc., developed a patented turnkey system (FluoroTrac) using RFID technology for firms in the semiconductor industry, which has been used by firms such as Motorola, SGS Thomson, and Wacker (www.ti.com/tiris/docs/solutions/supply/logsup.shtml). The system oversees a series of steps in the chip manufacturing processes designed to eliminate errors in product processing, improve operator efficiency, and increase equipment usage. The RFID technology eliminates mistakes in tracking wafers in the manufacturing process by taking about 800 "readpoints" for each wafer carrier. The system has also eliminated the need for human operators to scan products or key in ID numbers or access codes. The system also tracks manufacturing equipment usage, which has led to the elimination of manufacturing bottlenecks and to the enabling of smoother workflows.

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Case #5: The Port of Singapore. The Port of Singapore has used RFID technology in conjunction with its Electronic Data Interchange (EDI) system in tracking the thousands of multi-ton cargo containers and managing the comings and goings of about 50 ships daily (www.ti.com/tiris/docs/solutions/supply/logsup.shtml). The port has invested in the installation of thousands of RFID transponders on the asphalt road of the port shipyard in an effort to create a multi-dimensional grid. A centralized EDI system places and locates containers on the port shipyard based on the *X, Y,* and *Z* coordinates provided by the unique codes on the tags.

Case #6: Ford Motor Company. The Ford Motor Co.'s facility in Cuautitlan, Mexico, produces 300,000 to 400,000 cars and trucks annually, with parts supplied with just-in-time techniques (Johnson, 2002). With the help of the consulting firm, Escort Memory Systems (EMS) of California, Ford is using RFID for accurate and efficient routing and identification of vehicles through an automated production process.

Forty antennas were installed on the floor throughout the plant: 25 in body production, 12 in the painting area, and 3 in the final assembly area. As the vehicle moves from one stage of production to another in the assembly process, the reader references different parts of the 20-plus-digit serial number on the RFID tags, which indicate the specific operation that needs to be done at each station.

Case #7: Toyota. Toyota replaced its old job card system with an RFID-enhanced automatic tracking system in its manufacturing facility in South Africa, which had $860 million in revenue in 2000 with a production volume of 100,000 vehicles (Anonymous3, 2002). Using the EMS RFID product line, auto paint shop dollies and hangers have tags mounted on them to track vehicles being painted and document the performance of each dolly or hanger. This has led to a reduction in production downtime.

THE MIT AUTO-ID CENTER AND EPCGLOBAL

In late 2003, EPCglobal, a nonprofit joint venture between EAN International and the Uniform Code Council (UCC), was organized to establish and support the EPC network as the global standard for the automatic and accurate identification of any item passing through the supply chain of any industry and to provide information about the item's location, history, and count. This global standard combines radio frequency identification technology, the electronic product code, and networking communications infrastructure elements.

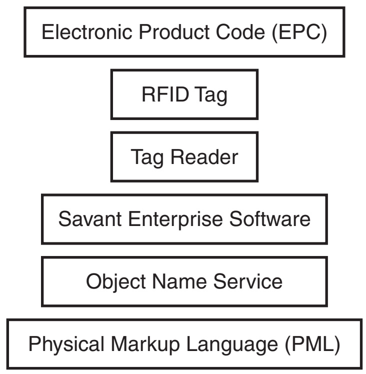
EPCglobal (www.epcglobalinc.org) was initiated by the Massachusetts Institute of Technology (MIT) Auto-ID Center, an academic research project initially undertaken by MIT in cooperation with the labs of five leading research universities in the world (Kambil and Brooks, 2002; Castelluccio, 2002). The center was sponsored by more than 100 firms and organizations that cut across different industries, which support efforts in research and developing standards for the use of the next-generation auto-ID (Kambil and Brooks, 2002).

During its inception, the Auto-ID Center attempted to achieve near-perfect supply chain visibility through the implementation of Auto-ID in-house developed technologies (Auto-ID Center, 2002). A number of technologies (i.e., RFID, barcodes, smart cards, voice recognition, some biometric technologies, optical character recognition, etc.) enabled machines to identify objects and give them the capability to capture information about these objects without human keystroke operations. Figure 1 shows the EPC network elements.

Electronic Product Code (EPC)

The auto-identification concept rests on the use of an electronic product code, which has gained the support of the Uniform Code Council and the EAN International, both of which oversee the use of international barcode standards. The EPC consists of an eight-bit header

FIGURE 1 EPC Network Elements
(*Source*: Auto-ID Center, *Technology Guide,* 2002, http://www.autoidcenter.org/)



and three sets of data: EPC Manager (28 bits), object class (24 bits), and a serial number (36 bits). The header identifies the EPC version number. The EPC Manager identifies the manufacturer of the product in question. The object class refers to the exact type of product or stock-keeping unit. The serial number is the unique code that identifies the specific product item.

The Auto-ID Center has proposed both a 64-bit and a 96-bit EPC. The latter will be the most likely one that will be implemented extensively and can provide unique identifiers for 268 million firms, which, in turn, can each have 16 million object classes and 68 billion serial numbers in each object class. As a transitional device, the 64-bit EPC code is being temporarily implemented to keep the costs of the RFID chips low at the initial phase of implementation.

Savant Enterprise Software

A major challenge to be dealt with is the continuous stream of EPCs that readers need to interpret as millions of tagged physical products interact with readers. Savant is an enterprise software system designed by the Auto-ID Center meant to act as the central nervous system managing the networks of which the readers will be a part. Organized in a hierarchical mode to manage the flow of data, Savant runs under a distributed network architecture platform. Trucks, cargo planes, stores, distribution centers, regional offices, factories, and so on, will each be running their own Savant. Each of these Savant nodes will pass the information from the tags to the other Savants in the network. For instance, a Savant at the shipping dock may inform another Savant at a warehouse that a shipment is forthcoming as of a particular date and time.

The Savant performs a number of major tasks supporting the network of readers, namely, data smoothing, reader coordination, data forwarding, data storage, and task management. Whenever errors occur in the network system as a result of tags being read incorrectly or overlooked, for instance, Savant handles the situation by applying algorithms employing data smoothing techniques to correct these errors. Savant is also designed to delete duplicate codes whenever signals from two readers overlap after reading the same tag. Savant also forwards only appropriate information up and down the supply chain. For example, a Savant in a cold storage facility will forward only stored food temperature changes to the next point in the chain.

A unique requirement of the database systems supporting a dynamic supply-chain system is the ability to quickly respond to the information needs of other enterprise applications tied to the supply-chain information-gathering infrastructure. Ordinary databases usually cannot handle more than a few transactions each second. Savant has been powered so that it maintains a "real-time in-memory event database (RIED)" that takes EPC data and stores it intelligently. This means that it can immediately respond with the appropriate information needed by affected enterprise applications involved in the entire supply chain. Savant also has load-balancing capabilities so that it is not paralyzed during periods of high-volume transactions or queries. The Savant could also be programmed to perform very specific data management and data monitoring tasks under its Task Management System module. For instance, a stockroom manager in a store could be alerted by a Savant unit in that location when inventory levels fall below a certain minimum at different times of the day.

Object Name Service

The network will need a system for matching the EPC with more detailed information associated with that code. This can be achieved through the Object Name Service (ONS), which works in a manner very similar to that of the Domain Name Service (DNS), a service that associates an IP address with a domain name. When the reader reads a tag, the EPC code is transferred to a nearby Savant, which, in turn, contacts the ONS on the local network or the

Each node will gather information from the tags and pass the information along to the other nodes in the network.

Internet to find out the location of more detailed information on the product in question. ONS will locate the appropriate server containing the information for the product about which Savant is querying. Product information is retrieved by Savant and then forwarded to the supply-chain applications needing this information.

Firms participating in a specific supply chain will need to invest in and maintain ONS servers to ensure rapid information retrieval. Thus, a boat manufacturer will want to store and maintain ONS data from its suppliers on its local network rather than download information from the Web each time a shipment of boat-building raw materials arrives at the assembly plant. Firms should also invest in backup sites for such servers to ensure fault tolerance and zero interruptions during operations.

Physical Markup Language

The information that describes the product items will be written in a new computer language called the Physical Markup Language (PML), which has been based largely on the eXtensible Markup Language (XML). PML is intended as the global standard to be used across industries for describing physical objects, processes, and environments using a hierarchical basis of taxonomy. For example, a can of orange drink may be described as a carbonated drink, subsumed under the subcategory soft drink, further subsumed under the category food. PML will also take into consideration the rate of change of certain data classes. PML will characterize data attributes that change constantly, such as temperature of a shipment of fruit or vibration levels of a machine (i.e., dynamic data), or slowly over time, such as the location of a cargo container (i.e., temporal data). Allowing for both product attribute categories will enable firms to provide more detailed and helpful product information. A firm could use dynamic data to set triggers so that the price of a bag of flour, for example, falls after hitting a specific expiration date. Air freight service providers could offer service-level contracts specifying refrigeration or freezing of goods set at certain temperature levels while in transit to their destination. PML servers containing product files are expected to be maintained by manufacturers.

Logistics Example of Auto-ID Application in the Supply Chain

To demonstrate a logistics application using Auto-ID, the narrative below features the flow of a fictional product, Great Rootbeer, through the delivery chain from the manufacturer site to the shelves of a supermarket in San Francisco, California.

Great Rootbeer, Inc., uses an RFID tag in every rootbeer can that is made. Along with a miniscule antenna, the tag contains a unique electronic product code. Rootbeer cans are identified, counted, and tracked through the use of the tags. The cans are packed and moved in tagged cases that will be loaded onto tagged pallets as well. Once the pallets of rootbeer cases leave the manufacturing floor, RFID readers mounted over the loading dock door will hit the tagged cases with radio waves that will eventually power the tags and enable them to broadcast their unique EPCs one by one.

The reader is connected to the computer system that runs Savant, the enterprise software product designed to manage the nervous system of the network using auto-IDs. After picking up the EPC information, Savant will send a query over the Internet to an Object Name Service database to obtain a server address where more extensive information about the product is stored.

Savant runs under a distributed network architecture platform and is organized in a hierarchical mode to manage the flow of data. Multiple Savants will be running in trucks, cargo planes, stores, distribution centers, regional offices, factories, and so on. Each of these nodes will gather information from the tags and pass the information along to the other nodes in the network. For instance, a Savant at the distribution center can inform another Savant at a retail store that a shipment has been received as of a particular date and time.

The pallets of rootbeer product will, then, arrive at the shipping service's distribution center. Because of the way the Auto-ID network operates, Savant will automatically provide a description of the cargo and identify the right truck in the freight forwarding area that will be used to carry the goods, thus eliminating the need to manually open the cases and inspect the contents or to even physically contact the truck driver responsible for the delivery. Within the scheduled time, the shipment reaches a supermarket in San Francisco, which is expecting its arrival because it has its own Savant unit that has been tracking this shipment. The receiving area of this supermarket also has

The empty cans can be collected and sent back to the appropriate manufacturer for reuse.

its loading dock readers that will automatically update its inventory file with the information on the newly arrived rootbeer pallets. The supermarket is instantly made aware of quantities and location of these pallets upon arrival in their receiving premises. This same supermarket uses intelligent store shelves that have built-in tag readers in them as well.

Once the rootbeer cans are stocked on the shelves, the shelves will sense a change in state and know that they are "fully stocked." Incrementally, as customers take rootbeer cans from the shelf, signals will be sent to the supermarket's automated replenishment systems designed to inform Great Rootbeer, Inc., of the replacement stock quantities needed. This system eliminates the need for the supermarket to hold a safety stock in both nearby and/or remote warehouses.

The auto-IDs are also used to eliminate the need for customers to line up and be processed at the checkout counters. Point-of-sale terminals are no longer needed to record the sales transaction as customers can now simply walk through the supermarket doors that also have built-in tag readers to detect the goods purchased and credit or debit card readers to process electronic payments.

When the rootbeer cans are disposed of and sent to the recycling centers, more RFID readers at these centers will sort the cans into their appropriate recyclable category, thus eliminating the manual sorting process. In addition, as a result of this process, the empty cans can be collected and sent back to the appropriate manufacturer for reuse.

PROCESS FREEDOM AND SUPPLY CHAIN VISIBILITY

Keen and Mackintosh (2001) argue that the unique value from mobile commerce should come from the ability of its supporting technologies to offer "process freedom." This means the ability to make mobile as many of the steps, people, information, documents, and communications needed within a business process design to make the supply chain far more effective. These authors also carefully distinguish between a "freedom" and a "convenience":

> The difference between a freedom and a convenience is that a freedom removes a barrier and creates a new space of value, while a convenience offers a new option within an existing value space, but does not add a new degree of possibility.

Kalakota and Robinson (2002), on the other hand, value the ability of mobile commerce technologies to make information increasingly visible throughout the supply chain.

RFIDs hold the potential for both providing significant "freedoms" that will liberate considerable human labor from certain workflows, as well as facilitate the possibility of making information visible to all participants throughout the value chain. Specific examples of RFID solutions to achieve both of these supply-chain objectives in the retailing industry are provided below for two major business processes (based on Chappell et al., 2002):

- Distribution processes (receiving and check-in, putaway and replenishment, order filling, and shipping)
- Transportation (product and asset tracking)

These specific RFID-enabled capabilities are described below, along with a published case example.

Distribution in Retailing

1. Receiving and Check-in. RFID portals, mounted in strategic points in the distribution center, can be used to read tags and automatically update inventory quantities as tagged cases and pallets enter the center. The incoming merchandise will be matched against the correct purchase order and discrepancies will be identified much more easily. The process freedom will be attained in freeing up labor-intensive manual labor involved in the quantity check-in and receiving processes. These activities could include printing and receiving checklists and labels and making detailed comparisons between incoming product lists and the purchase order.

2. Putaway and Replenishment. With Auto- IDs, putaway drivers will be headed for only the correct pickup locations and will be freed from having to scan barcode identifiers. The inventory location system will automatically adjust its quantities each time a load is dropped by the putaway driver at that location. Likewise, replenishment operators would not have to deal with searching for loads that are not at specific locations. These operators also would be freed from scanning products that they offload at certain locations. Dropped-off loads will be automatically located and clerks will be freed from conducting any more product

The conveyors will also run at higher speeds because of the increased read speeds of RFIDs and the elimination of laser barcode technology that requires line-of-sight readings.

scans or verification procedures. In the unlikely event of products being found in the wrong locations, alerts will automatically be activated.

3. Order Filling. In the course of fulfilling orders, pickers will be directed to the correct picking locations so that they can retrieve the ordered cases or items and place them on the appropriate material-handling equipment. Once the cases or items are picked up, the system will automatically verify that the correct products in the correct quantities have been removed and the inventory files will also be automatically updated as a result of that action. Pickers will be freed from having to manually update inventory databases. Alerts will be activated if pickers remove inappropriate quantities of cases or items from inventory.

4. Shipping. Auto-IDs will streamline shipping operations as loaders transfer cases and pallets directly onto trailers freed from the need to scan the physical goods. The conveyors will also run at higher speeds because of the increased read speeds of RFIDs and the elimination of laser barcode technology that requires line-of-sight readings. The system will also generate shipping documents that are increasingly error-free.

Distribution Case: Kitchens, Inc.
Kitchens, Inc. (Chappell et al., 2002) is a specialty retailer in home furnishings in the United States with annual sales of about $2 billion, a chain of about 500 stores nationwide serviced by three distribution centers. A warehouse management system is used in the rather modern facilities of these distribution centers. This, however, does not compensate for the fact that Kitchens, Inc. has not been up to speed about deploying EDI or Advanced Ship Notice (ASN) in dealing with its vendors. This has resulted in the slow check-in process of shipments and losses caused by vendor and paperwork errors.

To remedy the situation, Kitchens, Inc. deployed case-level Auto-ID solutions in its distribution centers by using tags already attached to the cases that arrived from its vendors. The receiving and check-in processes were automated with the use of reader portals installed in inbound doors and on material-handling equipment and vehicles to enable the recording of product locations. Subsequently, Kitchens, Inc. reported 35 percent improvement in direct labor productivity and 88 percent improvement in vendor and paperwork error shrink. The firm also experienced annual savings of $16.7 million in labor expense and $6.9 million in shrink reduction. All these benefits were obtained at the cost of $7.8 million, to include the hardware, software, and integration per distribution center.

Transportation in Retailing

Product and Asset Tracking. Tagged assets and products will pass through reader portals that will be installed in critical points of the supply chain on the premises of major supplier shipping docks, freight forwarders, consolidators, distribution centers, and pool points. Product and asset tracking systems will automatically be updated when tagged products or assets pass through the reader portals. Retailers will be able to track the movements of shipments and their transporting vessels from the time the shipment is released by the supplier until it arrives at the retailer's receiving dock. Tracking systems will generate alerts if shipments stay at certain nodes longer than expected and prompt transportation managers to contact the freight firms involved and explore the matter to ensure timely delivery. The system will be freed from the use of human labor normally deployed for handling and inspection. Lower safety stock inventory levels are expected as the products move more swiftly through inspection points. With increased information visibility throughout the supply chain, retailers will be better able to respond to problematic and exception-handling cases.

Asset tracking systems will monitor the location and usage of the different types of product handling and storage assets such as pallets, totes, trays, hanging racks, and flats that are used throughout the supply chain. The ability to do so could save retailers detention and demurrage charges for third-party-owned assets by as much as 80 percent.

Underused assets could then be effectively removed or retired from service, and missing assets could be more easily found.

Transportation Case: Fast Lane. A retailer of sports apparel (Chappell et al., 2002), Fast Lane has garnered annual sales of about $5 billion. Thirty percent of the firm's suppliers are overseas and responsible for about 65 percent of the firm's shipments, which are first handled by consolidators before arriving at the firm's distribution centers and finally shipped to the retail stores. Fast Lane has consistently experienced delayed shipments and, as a result, has found the need to maintain seven days' worth of safety stock inventory. The firm expended significant resources locating and tracking inbound shipments, and often misplaced expensive assets such as trailers, thus incurring high detention and demurrage charges.

Fast Lane implemented an Auto-ID system used to perform asset tracking functions that resulted in a one-time benefit of $2.5 million in reduced assets, due to its improved planning capabilities, with an accompanying annual benefit of $375,000 in depreciation charges. The Auto-ID technology also allowed Fast Lane to share data with its vendors and logistics service providers, resulting in a four-day reduction in the level of safety stock. Additional financial benefits include $58 million inventory reduction; $5.8 million reduction in inventory carrying costs; and $280,000 in reduced detention and demurrage charges for the use of third-party assets. In exchange for all these benefits, Fast Lane made an investment of $1.35 million.

MANAGERIAL GUIDELINES FOR RFID DEPLOYMENT

This section articulates some guidelines for IT and business managers for the proactive implementation of RFID technologies, by stage of the implementation process (see Table 1).

Make the ROI Case for RFID

The process of developing a Return on Investment (ROI) case for RFID implementation needs to be framed within an organization's business context. For many organizations, RFID usage is now being mandated by a powerful customer. For example, Wal-Mart has announced that it will ask selected major suppliers to use RFID at the pallet and case levels by the year 2005 (*RFID Journal*, June 16, 2003). The Department of Defense (DoD) will mandate the use of RFID for 100 of its top-tier suppliers by the year 2005 as well (Roberti, Oct. 6, 2003). Consider the multiplier effect of this edict: Boeing, Lockheed Martin, Northrop Grumman, and Raytheon (which are only a few of the many suppliers that provide the DoD defense systems) will need to tag all items supplied to the DoD. To streamline their value chains, these suppliers, in turn, will require their suppliers to do the same, and so on. Firms directly affected by these mandates have no choice but to implement RFID if they are to continue doing business with these organizations. The adoption and eventual diffusion of RFID technology is therefore likely to follow the pattern that EDI did after major players in the automotive and retailing industries mandated its use by their suppliers.

TABLE 1 Proactive Implementation of RFID Technologies

+ Make the ROI case for RFID
+ Choose the right RFID technology
+ Anticipate RFID technical problems
+ Manage the IT infrastructure issues:
    - Data management concerns
    - Integration with back-end applications
+ Leverage pilot project learning experiences

Sources: RFID Journal, Sept. 16, 2002; Sept. 23, 2002; Mar. 31, 2003; and Sept. 22, 2003; Roberti, *RFID Journal,* Mar. 31, 2003.

PwC Consulting has sketched out preliminary cost/benefit figures for a "typical" retailer that maintains 800 stores (*RFID Journal*, Sept. 16, 2002). The required investment for this retailer in the amount of $50 million to support an RFID system on a pallet/case level is expected to yield $55 million in savings on labor costs and generate about $43 million in additional sales from decreased out-of-stock incidences. Understandably, the calculations of costs and benefits resulting from RFID implementation will vary across different pilot implementation experiences of pioneer users. Even though these firms may have to eventually replace a significant portion of their internal IT infrastructure when RFID technology is implemented, they highly value the learning experiences they have gained from having started early.

The Auto-ID Center posted an electronic ROI calculator developed by IBM and Accenture on its Web site. Twenty-five firms that were among the corporate sponsors of the Auto-ID Center tested and validated the ROI calculator (*RFID Journal*, May 5, 2003). The calculator takes into account the nature of the business of the inquiring firm (i.e., manufacturer, distributor, retailer, etc.); the level of tracking required (i.e., pallets, cases, or items); the expected benefits (e.g., savings in labor costs, lowered inventory levels, decreased theft or shrinkage, etc.); and more detailed information about the firm's operations, among other factors. The user can change the nature and number of variables it would like to include in its "what-if" scenarios.

Pilot projects help firms calculate the major intangible benefits from RFID within the firm's business environment. Peter Abell of AMR Research estimates that it takes most firms a year before they obtain funding for a pilot project (Roberti, Mar. 31, 2003). This may prove too long for those firms that need immediate RFID readiness in response to trading partner mandates. (See the guidelines described for Pilot Projects below.)

The "frequency" issue refers to the ability of the auto-IDs to operate in free areas of the wireless communications spectrum across the regulatory boundaries of countries and different areas of the world.

Choose the Right RFID Technology

A critical decision is the choice of the type of RFID technology the firm will adopt (*RFID Journal*, Mar. 31, 2003). Key decision makers will have to take into account the needs of the following three constituencies in making their RFID technology choice: (1) the needs of their corporate environment, (2) the needs of their valued trading partners, and (3) the needs of the industry to which the firm belongs. A fail-safe choice is the selection of the technology that has the greatest adoption potential in the marketplace: not only does this encourage the observance of industry standards, but also, the economic impact of wide technological adoption favors lowering RFID hardware and software component prices.

Anticipate RFID Technical Problems

Firms need to anticipate a number of technical problems still facing the use of RFID technology (*RFID Journal*, Sept. 23, 2002). One of the challenges is that of false reads as a result of radio waves being easily distorted, deflected, absorbed, and interfered with. Radio frequency portal readers can still be "distracted" by metallic objects within their field of detection. For instance, a portal reader could be distracted by a metal buckle worn by a storage clerk, resulting in the RF signal being reflected in multiple directions and thus causing the reader to pick up tag information from products two or three bays away.

There is also a question about whether a reader can distinguish one shelf tag from another. If a forklift driver, for example, passes by a shelf tag about three times to fix the placement of a pallet, it is not certain if the reader system will record three separate pallets or recognize that one pallet information as one and the same. Until software and readers that are capable of correcting such false reads are available, some reader manufacturers are considering building touch screens that will allow forklift operators to activate the reader only after an item has been placed properly. This sounds onerous, but may be an intermediate solution for now. Firms will also need to establish procedures and routines for properly handling products as they are appropriately packaged.

Another false read problem concerns the inability of a reader to pick up information from every item on a pallet as the forklift moves this pallet through a portal when that pallet is packed with items having metal foil packaging or high water content. Firms are still devising different ways around this specific problem; one firm, for instance, stacks pallets on a turntable, which is then spun around many times until readers placed around this turntable have read all items on the pallet. It is not certain, though, that this technique produces reliable information about what, in fact, has been packed on the pallet.

The "frequency" issue refers to the ability of the auto-IDs to operate in free areas of the wireless communications spectrum across the regulatory boundaries of countries and different areas of the world. Frequency affects a number of important performance elements in using auto-IDs: the physical design and size of the antennae, the read range between the tags and the readers, and electrical interference between the auto-ID systems and other electronic devices in the proximate area. The Auto-ID Center has explored the concept of "agile" readers that will allow the network to operate at different frequencies in a wide variety of geographical locations (Haller and Hodges, 2002; Kambil and Brooks, 2002).

Manage the IT Infrastructure Issues

Data Management Concerns. The use of RFID technology presents a number of data collection and usage issues for which IT managers should be prepared. First, considering the volume of product data that will be incoming, there is the issue of redesigning product/item master file data structures so that they are consistent across the firm and its value chain participants (*RFID Journal*, Mar. 31, 2003). Firms that have tracked pallets and cases with RFID tags report at least a 30 percent increase in data that needed to be processed. The level of granularity for data collection also needs to be determined. Goods that may need to be recalled such as fresh perishable produce or meat or high-value items such as expensive electronic gadgets or luxury designer goods may require a more detailed record of their movements through the purchase experience.

Then there is the concern for having the appropriate capabilities to interpret the voluminous data coming in at fast speeds (*RFID Journal*, Sept. 23, 2002). First of all, many firms are used to transmitting data in batch mode; for

After being released from routine and structured tasks that can easily be automated, managers can, instead, devote their time to cultivating more effective supplier and/or customer relationships.

instance, a manufacturing shop tracks the number of pallets shipped out hourly and daily and uploads the information in batch mode, possibly every few hours, every shift, or daily. As RFID technologies become more ubiquitous, the appropriate IT systems overseeing their work will take over these routine functions, but this time in real-time mode, and will need to transmit the data reliably to interlinked business applications. Real-time transmission of data, though, poses additional challenges in the ability of managers to process the information in a timely manner. Whereas, traditionally, managers controlled most aspects of operations, this time many of the tasks will need to be automated and managers will come in only to handle alerts and exceptional cases. For instance, human intervention would be needed when a planning system in a particular distribution center cannot fulfill the need for a product. The system will need to route the decision-making process to alternate distribution centers or manufacturing facilities and will call the attention of a human planner who is authorized to reprioritize customers or shipments at those alternate sites.

To ensure a quick turnaround in the interpretation of the data and an appropriate response to the rest of the value chain accordingly, the IT software team may have to program in the business manager's expertise and experience in handling routine decisions. Thresholds or triggers for passing on data from one application to another will also have to be set up (*RFID Journal*, Mar. 31, 2003). For instance, a reader on a smart shelf that tracks expensive Prada handbags will not pass on information about the luxury item unless the inventory count has dropped below the Economic Order Quantity (EOQ) level or the fact that three of the bags for the latest season have been returned by shoppers and were placed in the wrong display area. After being released from routine and structured tasks that can easily be automated, managers can, instead, devote their time to cultivating more effective supplier and/or customer relationships.

Database administrators need to be able to deal with the potential stresses on the databases, both in terms of speed and volume involved in processing RFID applications.

> This consumer goods manufacturer estimates that tracking all its items from production to point of sale would require 3,000 database transactions per second on the low end and upwards of 30,000 on the high end. If each product has 1,000 bytes of data associated with it, the RFID system would generate 10 terabytes of data per year. If you store your data for five years, you'll have a 50-terabyte database.
>
> —*RFID Journal*, Sept. 22, 2003

In addition to server data storage capacity, there is strong concern as well for redundancy or fail-over capability so that backup servers could take over automatically in times of processing disruptions to avoid inefficiencies in the value chain (*RFID Journal*, Sept. 23, 2002).

Integration with Back-End Applications. Backend integration issues are also not insignificant. At this time, software products designed to integrate RFID data with enterprisewide applications are few and new in the market (*RFID Journal*, Sept. 22, 2003). Firms are left practically on their own to find ways to make RFID data interface with related business applications such as accounts receivable, inventory management, and the like.

> It's even worse if you've grown through acquisition and have 72 different legacy systems that require a custom format for the RFID data. One major aerospace company hired a large IT consulting and systems integration company to do the coding, but the firm backed out just before work was set to begin because it was concerned about completing the task. Two of the company's own programmers wound up spending five months creating a custom application that could route RFID data to the right application in the right format. And that was just for phase one of its project.
>
> —*RFID Journal*, Sept. 22, 2003

A firm may have to invest in new hardware and software before implementing a pilot project testing RFID technology (*RFID Journal*, Mar. 31, 2003). A faulty approach would be to run a pilot that narrowly focuses on the technology's ability to read tags, without actually tying in the RFID technology to the firm's existing IT business application systems. This leaves the firm with an incomplete understanding of the consequences of RFID technology on its existing operations and is an inaccurate representation of how things will eventually run when in production mode. One firm that ran a pilot on a 280,000 square-foot facility in Florida upgraded

TABLE 2 Selected RFID Technology Vendors

Vendor Name	Hardware	Software	Services
SAP		Auto-ID Infrastructure (AII) (networked software platform)	Auto-ID “ecosystem” including installation, integration, maintenance, and support services
Microsoft		Windows CE for managing RFID readers; middleware for RFID data management; infrastructure for supporting real-time decision making; retail and warehouse management applications for mid-sized firms	
Sun Microsystems		Enterprisewide Auto-ID software; EPC Event Manager for Savant Software; EPC Information Service	Deployment services
IBM-Philips	Philips makes chips for RFID tags and smart labels	IBM will offer specialized RFID software applications	IBM will provide consulting and implementation services
Texas Instruments	RFID tags and readers; UHF EPC-compliant RFID tags		
Alien Technology	RFID tags, readers, and development kits for short- and long-range		
Applied Wireless Identification Group (AWID)	Multi-protocol UHF reader in the form of a PCMCIA card that can be plugged into any handheld computer or barcode scanner		
SAMSys Technologies, Inc.	RFID readers for different business applications		
Intermec Technologies Corp.	Intermec makes barcode scanners, label printers, wireless local area networking equipment, and handheld computers — products that make it possible to capture data virtually anywhere		

Source: RFID Journal, Vendor Profiles, http://www.rfidjournal.com/article/archive/6/.

its local area network to enable the system to handle the speed of transaction processing, and thus avoid delaying the work of forklift operators who depended on the computer system responses.

Another viable option for firms is the services of application services providers that are now developing Auto-ID “ecosystems” that will include software products, installation and integration services, and maintenance and support (Violino, 2003). Continuous network monitoring and maintenance takes on a new level of perceived value because of the much more interconnected nature of RFID technologies when digital interfirm implementations are taken into consideration. There will be near-zero tolerance for disruptions in value chain operations and speed and the ability to crunch much higher volumes of data will be critical. ASPs also provide the added convenience of laying forth an IT infrastructure that can be shared by participants in the same value chain.

Major hardware and software vendors are already lining up their product/service offerings to support the RFID-enabled environment (see a sample list in Table 2). For example, SAP is developing an auto-ID infrastructure (AII) based on RFID technologies and its workings

Firms running pilots need to manage user expectations and should capitalize on system errors (that will likely occur) as concrete opportunities for learning.

within the adaptive business network context (Violino, 2003). SAP's AII will gather, analyze, and manage real-time data from tagged items, environmental sensors, global positioning systems, and wireless devices. Item-level tagging will produce enormous volumes of data on such attributes as product location, shelf life, price, inventory levels, and so on, from numerous readers.The system will also store and summarize data about shipping containers, pallets, cases, and items. In addition it will receive and maintain data about the physical location of specific items within a particular container, for instance. SAP has another product offering that uses software agents in running automated replenishment systems interacting with RFID technologies. As part of a joint development experience with Procter & Gamble, Sun Microsystems, and another unnamed retailer, SAP showed how software agents tracked inventory levels upon the removal of tagged items from the shelf and compared these with preplanned stock levels. When more items were removed from the shelf than was warranted, the agents forecasted that the specific item would be out of stock and triggered a replenishment alert.

Other key vendors to watch are the IBM–Philips joint effort to provide an end-to-end solution for retailing and consumer goods manufacturing firms (Collins, Jan. 27, 2004). Philips, a giant global maker of chips for RFID tags and labels and for contact and contactless smart cards will be a natural collaborator for IBM, a premier software and consultancy firm that has already launched its first package of RFID services consisting of specialized software and consulting and implementation services. Recently, too, Microsoft announced that it intends to provide the software infrastructure large firms will need to use real-time data within an RFID environment and will develop a suite of RFID business applications software useful to mid-sized corporations (*RFID Journal*, Jan. 30, 2004).

Leverage Pilot Project Learning Experiences

A simple pilot project can be used to test different types of tags and readers, understand how RFID works in the firm's unique environment, observe required business process changes, perform rudimentary back-end integration tasks, and upgrade directly affected hardware and software infrastructure elements (Roberti, March 31, 2003). In deciding where to deploy pilot projects using RFID, the advice is to choose those business processes where the most benefits can be garnered within the shortest period of time in exchange for the initial pilot project investment outlays that will need to be made (Roberti, 2004).

Experts and observers of early adopters are in agreement that although the financial returns on an early pilot project may not be clear, the lessons learned from early initiation are well worth it. However, it is also important to note that firms running pilots need to manage user expectations and should capitalize on system errors (that will likely occur) as concrete opportunities for learning.

Leading-edge firms such as Wal-Mart, Proctor & Gamble, and Gillette have been experimenting with RFID (and other promising emerging technologies). The following accounts detail their learning experiences.

Gillette. Based on the results of the pilot projects conducted by Gillette, the firm is experiencing reductions in labor capital and inventory levels, an increase in accuracy, and an improved capability to address out-of-stock situations (*RFID Journal*, June 16, 2003). The Gillette Devens pack center and distribution center project used EPC tags on cases and pallets of the firm's Venus women's shaving system originating from its East Coast distribution center to a number of the firm's selected customers. Gillette intended to understand the process through which its products move from factory to the customer sites and identify "pain points" in the value chain where the RFID tag could add value, reduce costs, increase efficiency and accuracy, and ensure that its customers are, indeed, getting what they ordered.

Proctor & Gamble. P&G in Spain used RFID to improve logistics throughput at its manufacturing site by using forklifts designed to load 33 pallets onto delivery trucks every 20 minutes (*RFID Journal*, Feb. 3, 2003). Readers are mounted under each forklift truck, and holes drilled in the floor of the facility at key points.The 4-cm-square RFID tags were buried 5 cm deep inside about 90 holes, which were subsequently filled with concrete. Readers, apparently, could still pick up information from the tags at that depth. The pallets are given a barcode with a unique serial number read by scanners along the conveyor system, which relay the position of the pallets to a control personal computer (PC) system running the Rockwell Automation software. The PC is

This technology promises to offer both process freedoms and near-perfect information visibility throughout the supply chain across different industries.

aware of the pallets that are ready for pickup by the forklift operator. So, if pallet ABC is waiting to be picked up at Station 8, the RFID antenna on forklift truck No. 6 reads the tag on pallet ABC and transmits its location to the control PC wirelessly. The system then matches pallet ABC with forklift truck No. 6. This same truck then reads the RFID tag embedded in one of the holes in the floor of dock No. 10 and wirelessly conveys this information to the control PC. This computer system then looks up the warehouse management system to check if pallet ABC is, indeed, meant to be loaded on the truck at dock No. 10. If this is so, the system records the information. Otherwise, system alerts are generated to inform the truck driver of the situation and a computer on board the truck, in turn, tells the driver where the pallet should be delivered instead.

P&G has realized gains in terms of increasing loading speeds by 40 percent, decreasing work-related errors, and cutting back on the number of drivers the firm needed to hire for the same scale of operations.

Wal-Mart. One of the major pioneers in the use of key supply-chain management technologies, Wal-Mart has been experimenting with RFID for a long period of time. True to its tradition of being one of the first to deploy leading-edge technologies, Wal-Mart has completed a series of pilot projects involving RFID in its effort to reduce out-of-stock incidences, track products, and cut costs along the supply chain (*RFID Journal*, June 16, 2003). Phase one of its pilot projects was initiated on October 1, 2001, when Wal-Mart cooperated with P&G, one of its tier-one suppliers, and had the firm ship 500 pallets of Bounty paper towels from the P&G factory in Cape Girardeau, Missouri, to Sam's Club in Tulsa, Oklahoma (*RFID Journal*, Mar. 17, 2003; June 16, 2003). In Phase two, which began in February 2002, cases were tracked from factories located throughout the Midwest to a Supercenter and a Wal-Mart distribution in Broken Arrow, Oklahoma. Cases of the following products were tracked: Coca-Cola two-liter bottles; Bounty paper towels and Pantene shampoo (P&G); Mach 3 razors and 10 oz. cans of Right Guard deodorant (Gillette); Liquid All and Caress soap (Unilever); Carefree feminine hygiene products (Johnson & Johnson); and Maxwell House Coffee (Kraft Foods). In Phase three, supplier firms that participated in Phase two will be asked to tag their products at the item level.

CONCLUSION

This article has presented information to support a business case for the adoption of RFIDs (and Auto-ID solutions in particular), as well as managerial guidelines for proactively implementing such applications, based on reports from the trade literature. This technology promises to offer both process freedoms and near-perfect information visibility throughout the supply chain across different industries.

The year 2003 was pivotal for RFID technology: both Wal-Mart and the Department of Defense announced that they will be using RFID tags for pallets and cases in conducting business with selected top-tier suppliers by the year 2005. Important vendors have subsequently responded and hardware/software/consultancy services are now being developed to capitalize on these initiatives. The EAN International and UCC have joined forces to support and maintain EPCglobal, the international standard for the use of the EPC network. These initiatives have set into motion the beginnings of more widespread RFID technology adoption among trading partners within several industries. The initial phase of a potential widespread diffusion of this important technology is at hand.

Research on the actual achievement of the promises of RFID and a more detailed understanding of effective implementation strategies and best practices now needs to be undertaken. ▲

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