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RFID in Healthcare: A Framework of uses and opportunities

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RFID IN HEALTHCARE:

A FRAMEWORK OF USES AND OPPORTUNITIES

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ABSTRACT

Although radio frequency identification (RFID) is not a new technology, it has only recently received interest beyond a few niche areas and is now on its way to becoming a mainstream technology in many industries. With its potential and unique uses, healthcare is one of the major sectors that RFID is being considered and adopted. Improving the healthcare supply chain, patient safety, and monitoring of critical processes are some of the key drivers that motivate healthcare industry participants to invest in this technology. Already, RFID is being used in the broad areas of asset management, inventory management, authenticity management, identity management, and process management. However, more research has to be done on the technology development and more applied investigations have to be conducted on integrating the technology within the industry in order to fully utilize RFID. This study provides a framework of current RFID uses in the healthcare industry and opportunities for continued deployment.

Keywords: RFID, healthcare, supply chain, hospitals, empirical applications.

RFID in Healthcare:
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1. Introduction

Although RFID has been around for more than 50 years (Jervis, 2005), it has only recently received much attention due to the very well publicized and promoted mandates by Wal-Mart and the United States Department of Defense for its use in their supply chains. This increased awareness of the technology has resulted in various uses in a variety of industries, well beyond the niche applications it has enjoyed for the past 50 years. As one extension of its use, RFID has started to emerge as a major technology in the healthcare industry. The Food and Drug Administration (FDA) of the Department of Health and Human Services (HHS) has recommended using RFID on all drugs at the unit level by 2007 to prevent drug counterfeiting (Wicks, Visich, and Li, 2006). In addition, a number of pilot projects have been seen in the industry to improve the quality of care and reduce costs. Furthermore, these pilot programs have shown that RFID applications have unquantifiable benefits that include saving lives, preventing injuries, and reducing medical errors. Since the healthcare market's consumption of RFID services is expected to increase more than 23 times, from $90 million in 2006 to $2.1 billion in 2016, it makes sense to take a closer look at the current status to see how RFID is being used in the industry (Harrop, 2006). As RFID technology becomes cheaper and more reliable, the next topic that needs to be discussed is how to strategically implement RFID into healthcare operations.

This study provides an overview of current RFID technology deployments in the healthcare industry and the potential opportunities for expanding the deployments. While not exhaustive, enough representative uses are given to provide good insight into the uses and

potential uses of RFID in healthcare. The paper is structured as follows. First, a brief background on the technology and an overview of the healthcare participants are provided, followed by an analysis of the current uses of RFID in healthcare. Then, the opportunities for RFID in healthcare are discussed, followed by the major challenges RFID currently faces in the healthcare industry.

2. RFID Technology Background

RFID is a data collection, acquisition, and storage technology, which uses radio waves to automatically identify individual items and provide real-time information. The goal of any RFID system is to carry data in suitable transponders, generally known as tags, and to retrieve data at a suitable time and place to satisfy particular application needs (Finkenzeller, 2003). RFID was originally developed for and used in military applications, such as in World War II where it was used to identify friendly aircraft (Jervis, 2006). In the late 1960s, it found its way into the retail industry with the intent of creating electronic article surveillance products to fight shoplifters. It was in the 1970s that the first commercial application of the technology was introduced in vehicle tracking (Shepard, 2005).

Typically, RFID systems consist of three components (Keskilammi, Sydanheimo, and Kivikoski, 2003): (1) a small electronic data-carrying device called a transponder (also called a tag); (2) a reader that communicates with the transponder; and (3) a data processing system that contains information about the tag-carrying item. There are two types of RFID systems: active systems and passive systems. The tags in active systems are powered by an internal battery while the ones in passive systems derive the power to operate exclusively from the field generated by the radiation emitted by the reader. Active tags are generally bigger than passive tags. In

addition, they also have larger storage capacity and transmit continuously or at a reader's request (Jervis, 2006). According to new research by IDTechEx, the healthcare industry represents only 3% of the active RFID market worldwide (Monegain, 2007).

Passive tags, on the other hand, generally do not transmit unless they are interrogated by a reader. They are smaller and less expensive and don't depend on a power source. However, passive tags have a shorter read range than active tags. In a basic passive RFID system, the following general operating procedures take place: the reader generates an electromagnetic field to supply a voltage that is rectified inside the tag; the reader transmits information to the tag by modulating the carrier wave; finally, the tag back-scatters the carrier wave by modifying its own impedance to transmit information back to the reader. Read ranges depend on several factors, such as frequency, the power of readers, environmental factors, and material interventions (Jervis, 2006). The recent increase in RFID utilization is due in part to the rapidly declining cost of passive RFID tags, which are cheaper than active RFID tags (Jervis, 2006). Although today's tags contain a silicon chip for data storage, there is a slow trend towards chipless RFID tags which will drive down costs even more (Harrop, 2006). Table 1 summarizes the main differences between active and passive RFID systems.

Table 1 Differences between active and passive RFID systems

	Active RFID	**Passive RFID**
Tag Power Supply	Internal to tag	Energy transferred from reader via RF
Tag Battery	Yes	No
Availability of Tag Power	Continuous	Only within field of reader
Communication	Long Range (300+ feet), networking of tags & readers	Short Range (<30 feet), no communication between tags or readers
Multi-Tag Collection	Collection of 1000s of tags from readers, millions of square feet	Collection of hundreds of tags from single reader
Sensor Capability	Continuously monitoring and record sensor input with date / time stamp	Read & transfer sensor data only when tag is powered by reader (no date / time stamp)
Data Storage	Large read / write data storage directly on tag	Small read / write data storage directly on tag

Source: Supply Insight Inc., 2006

Currently, RFID tags may operate at several different frequency bands, including low, high, ultra-high, and microwave. Low frequency ranges between 125 kHz and 134.2 kHz; high frequency is set at 13.45 MHz; ultra-high frequency ranges between 860 MHz and 960 MHz; and microwave frequency is set at both 2.45 GHz (same frequency used by Bluetooth and WiFi) and 5.8 GHz (Jervis, 2006; Das, 2006). Frequency directly affects the read distances and response times (or transfer rates) of RFID tags. Generally, lower frequencies have shorter read ranges and slower response times. Higher frequencies have longer read ranges and faster response times. Typically, for passive RFID, low frequency (LF) tags can be read from within one foot; high frequency (HF) tags can be read from 3 to 5 feet; and ultra-high frequency (UHF) tags can be read from up to 30 feet (Philips Semiconductors, 2004). Although higher frequencies have the advantage of longer read ranges and faster response times, they have less advantage when it comes to interference. Usually, higher frequencies encounter more read interference from high permittivity or reflectivity materials, such as liquid and metals (Philips Semiconductors, 2004). The low frequency range is the least prone to interference from liquids and metals (Scher, 2004). Since different frequency bands have different advantages, the most effective implementation would be to match the unique characteristics of each tag type and frequency to the objective at hand. Unfortunately, each frequency range requires its own type of tag and reader; thus, making the use of multiple frequencies within a supply chain or unit (e.g., hospital) problematic (i.e., requires multiple technical architectures for the various frequencies).

3. Healthcare Participants

Merriam-Webster dictionary defines healthcare as “the maintaining and restoration of health by the treatment and prevention of disease especially by trained and licensed professionals (as in medicine, dentistry, clinical psychology, and public health).” This broad definition of healthcare allows us to encompass all healthcare participants. The three main participants of the healthcare industry discussed in this paper are the manufacturer, distributor, and healthcare provider.

Manufacturers are companies that produce healthcare products and supplies ranging from prescription drugs and syringes to wheelchairs and ventilators. Some examples include pharmaceutical companies Purdue Pharma L.P. and Pfizer, Inc., and medical equipment companies Invacare Corp. and Medline Industries, Inc.

Distributors operate as the middleperson between manufacturers and the healthcare providers. Sometimes, there is an overlap where manufacturers also perform distribution work, but other times distribution is done by companies whose main purpose is to buy and sell equipment and supplies. For example, Group Purchasing Organizations (GPOs) for hospital supplies are companies who purchase large quantities from manufacturers and sell in smaller quantities to hospitals and other healthcare providers (Leahey, 2005). This benefits the individual healthcare providers which cannot afford the overhead of purchasing in large quantities and carrying excess inventory. However, large companies, such as Wal-Mart, may have their own distribution centers.

Healthcare providers include hospitals, medical laboratories, and medical products retailers (such as pharmacies). These companies receive goods and services from manufacturers and distributors. In addition, they often interact with consumers or patients directly.

4. RFID Uses

After a thorough investigation of the current known uses of RFID in the healthcare industry, we have classified these uses into five major categories: asset management, inventory management, authenticity management, identity management and process management. Asset management involves managing medical equipment throughout the supply chain to improve its visibility. It requires tracking the assets, monitoring their status and checking/updating their conditions. Inventory management broadly means managing the inventory produced or used by the healthcare participants. This covers standard medical supplies such as syringes and test tubes, and pharmaceutical products such as prescription drugs. Authenticity management focuses on ensuring that a product is genuine. The goal of authenticity management is to prevent counterfeiting and improve safety by having a recorded history of where the product has been. Identity management involves knowing the location and identity of patients and medical staff in order to provide better care for patients and sometimes to protect medical staff members. Process management encompasses the managing of all processes in healthcare that would improve the quality of care for patients, increase efficiency of processes, and reduce costs. Essentially, this is done by accurately identifying patients and substances, verifying correct procedures, monitoring conditions, and alerting appropriate authorities to prevent accidents and errors from occurring.

4.1. Asset Management

Perhaps the most common current use of RFID in healthcare is asset management. Asset management is the process whereby an organization collects and maintains a comprehensive list of the equipment it owns (e.g., a heart monitor in a hospital). The goal of asset management, via RFID in healthcare, is therefore to improve the visibility of medical equipment, which can lead to reduced cost and improved patient care. It is not unusual for healthcare participants to have

thousands of assets, many of which are worth several thousand dollars. Although many assets are very large, some of the equipment is small enough to put into a suitcase or bag. Thus, in an effort to minimize shrinkage and misplacement of items, RFID can be used to track assets and make sure they stay within the organization.

Already, several healthcare participants have implemented, or plan to implement, RFID for asset management; primarily in hospitals. Wayne Memorial Hospital, in Goldsboro, N.C., recently implemented an RFID asset management program. The hospital tagged and tracked infusion pumps, diagnostics machines, blood warmers, wheelchairs, etc. Once the organization collected data from the system, Wayne Memorial found that only 50-60% of their infusion pumps were being utilized. Subsequently, the hospital reduced the number of pumps purchased from 300 to 250, which saved them $276,000 and an additional $27,000 in maintenance cost. In total, Wayne Memorial saved $303,000 by improving the visibility of infusion pumps through RFID technology (Bacheldor [1], 2007). Reading Hospital in Pennsylvania is also using an RFID system to track infusion pumps in an effort to avoid ordering excess pumps (O'Connor, 2006). Given the success of current implementations, Catholic Medical Center-KangNam St. Mary's Hospital in Seoul, Korea and the Dwight David Eisenhower Army Medical Center in Georgia plan to more efficiently use their equipment by deploying similar real-time location systems (RTLS) systems (O'Conner, 2007) and Presbyterian Healthcare Services in Albuquerque plans to use an RFID system to track 6,000 pieces of medical equipment at Presbyterian Hospital (Havenstein, 2005).

RFID technology gives healthcare employees the ability to more efficiently find equipment through an RFID-based tracking system. Secours Health Systems, located in Richmond, Virginia, tagged 12,000 pieces of mobile equipment which included IV poles, pumps,

wheelchairs, stretchers, and beds (Wicks *et al.*, 2006). Secours found that employees were spending 25-30% of their time hunting for equipment (Wicks *et al.*, 2006) which could be reduced dramatically with RFID. Before RFID was implemented in Wayne Memorial Hospital, it took an average of 20 minutes for nurses to find a wheelchair for patients. After RFID was installed, it took less than five minutes for a patient to receive a wheelchair (Bacheldor [1], 2007). Similarly, Boston's Beth Israel Deaconess Medical Center uses RFID to track its emergency room equipment and was able to reduce the time it takes to find the equipment (Havenstein, 2005).

The visibility of assets and the associated information can help a hospital reduce shrinkage (e.g., theft, misplacement) and improve proper maintenance. Agility Healthcare Solutions estimates a 200-bed hospital can save $600,000 annually from less shrinkage, fewer rentals, deferral of new purchases and improved staff productivity. A 500-bed hospital could save $1 million annually (Wicks *et al.*, 2006). Columbus Children's Hospital tracked surgery equipment and found that they lost over $100,000 due to expiration dates, but predicts RFID will save 10%-15% in loss charges (Swedburg, 2007).

Overall, early deployments suggests that RFID-tagged equipment can generally improve asset visibility / provide for real-time location of assets, reduce asset surplus, improve the efficiency of finding assets, reduce asset shrinkage, and ensure proper asset maintenance.

4.2. Inventory Management

Inventory management is a challenge that every industry faces; RFID technology has already been implemented and proven successful in retail and manufacturing environments. In healthcare, inventory management applications of RFID can be seen primarily in laboratories and hospitals. As stated earlier, the FDA recommends an ID system to help prevent

pharmaceutical counterfeiting; RFID is an exceptional solution to this problem. In medical labs, RFID is used to locate, track, and identify specimens. At the Pathology Laboratory of the Portsmouth NHS (National Health Service) Trust in the UK, RFID is used to match blood samples to patients. When nurses take a patient's blood sample, they enter the patient data on an RFID handheld device. The data is then stored on an RFID tag attached to the blood sample tube. The lab can then use this to quickly and easily identify who the blood belongs to (Philips Semiconductors, 2004).

RFID is also used effectively in hospitals to manage inventory. Four of the top 15 hospitals in the U.S. have implemented an HF-based inventory system using RFID-enabled cabinets. The cabinets contain readers; the supplies are tagged with RFID tags, and the system is integrated with the hospital's information systems. When equipment and other items are removed from the supply cabinets, the RFID system automatically keeps track of what was taken out by which person and records the time the items were taken. This technology configuration allows the system to automatically order items and replenish the hospital's supplies, which reduces inventory management costs and simplifies the process (Philips Semiconductors, 2004). Advocate Good Shepherd Hospital implemented RFID in 2003 and found that 10% of their inventory was reduced annually (Wicks *et al.*, 2006).

Mercy Medical Center, in Des Moines, Iowa, is a 917-bed hospital that has also implemented an RFID inventory management. Mercy has tagged 1,600 items ranging from $100 to $2,500; items include cardiovascular stents, balloons, filter wires, etc. Advantages of the system include keeping an automatic count of inventory at all times, providing data about product usage for replenishment modeling, and easy monitoring of expiration dates. The data supplied by the system also showed errors in patient billing; e.g., patients were given items and

the items were not charged to the patient. The hospital found that the implementation of RFID helped solve some known problems (i.e., inventory) and gave visibility to new issues (i.e., patient billing) (Bacheldor [2], 2007).

St. Olavs Hospital, in Trondheim, Norway, is a hospital that employees 7,500 people, treats 65,000 patients, and owns 130,000 garments (operating gowns, robes, scrubs, etc.). Using passive HF tags, St. Olavs implemented RFID in a uniform tracking system in September 2006. The RFID tags are sewn into the garment. The uniform tracking system keeps track of how many uniforms have been taken from a specific locker and the employee getting the uniform. The hospital found it saved on inventory space, labor, and operational costs (O'Conner, 2007).

Overall, RFID has proven useful for inventory management in healthcare by helping to identify and locate inventory, matching inventory to owners, improving ordering and replenishment, providing accurate inventory counts, monitoring expiration dates, and decreasing errors in billing. Many of the benefits seen by other industries, such as retail and defense (e.g., Wal-Mart and Department of Defense), seem to apply to the healthcare supply chain as well.

4.3. Authenticity Management

The World Health Organization estimates that the worldwide sale of counterfeit drugs is a $26 billion a year industry (Hardgrave and Miller, 2006). Faced with such a significant threat to the security of the drug supply chain, the U.S. Food and Drug Administration (FDA) issued a report, *Combating Counterfeit Drugs*, which outlined measures that could be taken to combat counterfeiting (FDA, 2004). One of the primary measures presented in the report is the use of RFID for item level tagging (ILT). The purpose of ILT is ultimately to help prevent counterfeiting by knowing the full history of the package, or establishing pedigree and product authenticity (Harrop, 2006). The technology can also be used to detect tampered or unacceptable

drugs, such as ones that have expired or been recalled, thus benefiting the pharmaceutical supply chain, from manufacturer to retailer (Reiner and Sullivan, 2005).

An authentic drug product is enclosed in the genuine package supplied by the manufacturer (Pearson, 2006). To this end, in 2004, the United States Department of Defense began tagging all drugs and medical supplies in its supply chain (Brooke, 2005). Also, Pfizer, Inc. added RFID tags to bottles of Viagra in 2005 in an effort to prevent theft (Havenstein, 2005). Accurately authenticating products will reduce counterfeiting of drugs and increase consumer safety. According to the Pharmaceutical Research and Manufacturers of America (PhRMA), a pedigree system is "the recording of a series of authentications at each trade once the package unit has left the manufacturer", maintaining a full history of the package. In 2006, the FDA started to require pedigree for prescription drugs and has suggested using RFID technology to store electronic pedigree (ePedigree) to meet the goals of automatically identifying and tracking each package of drugs (Pearson, 2006). The FDA has also promised companies that it would provide assistance with RFID adoption throughout the drug distribution system (Whiting, 2004). However, states like Florida and California have already mandated pedigree information for prescription drugs that move within or across their borders (Pearson, 2006). Some companies have already heeded this requirement. For example, Purdue Pharma L.P., a Stamford, Connecticut-based pharmaceutical company, has used RFID tagging at the individual item level on 100-tablet bottles of pain relief drugs OxyContin and Palladone at the manufacturing level to provide ePedigree data that follows the products' movements throughout the supply chain (Burt, 2005; Havenstein, 2005). Using RFID, Purdue Pharma reads each carton of drugs shipped to distribution centers such as Wal-Mart and H.D. Smith Wholesale Drug Co. On arrival, the distribution centers read the cartons to verify they are the originals sent by Purdue

Pharma. In essence, by one scan they will know the authenticity of all 48 bottles of drugs in each carton (Burt, 2005).

The counterfeiting of drugs and supplies in healthcare is on the rise. The FDA considers RFID to be the "most promising approach to reliable product tracking and tracing" (FDA, 2004). Although RFID may not be the panacea for this problem, it does appear poised to greatly attenuate it. Subsequently, RFID use is expected to grow in this area (Hardgrave and Miller, 2006).

4.4. Identity Management

Many healthcare participants, especially hospitals, deal with a high volume flow of people everyday, including patients, doctors, pharmacists, nurses, etc. Identity management is concerned with keeping track of people and RFID technology can be used to help solve some people-related problems, such as controlling access to various areas, locating key personnel in a time of need, monitoring the location of patients, and tracking patient flow. In a healthcare setting, the two primary groups of people are patients and healthcare employees. Some examples of identity management for patients are tracking patient flow through an emergency room or tracking Alzheimer's patients for safety reasons. An example of identity management for healthcare employees is being able to find a nurse or doctor when they are needed for an emergency.

The Alzheimer's Community Care (ACC), in West Palm Beach, Florida, is a provider of support for approximately 2,000 Alzheimer's patients and their caretakers. During the summer of 2007, the ACC conducted a pilot in which they implanted RFID chips into 200 Alzheimer's patients. The goal of the pilot was to put medical record information within the chip located in the patient's forearm. Then, when an Alzheimer's patient has an accident and goes to the

emergency room, the emergency room attendant can retrieve the patient's medical history in situations where the Alzheimer's patient is unable to remember his or her medical information. The ACC is using the technology provided by VeriChip Corp. which currently has 300-400 patients implanted with RFID chips. The main concern with this technology is the patient's privacy as some worry about third-party people getting patient information. However, the chip only contains a unique identifier that must be used in conjunction with a database. VeriChip has been very careful about ensuring a high level of security for the database (Swedburg, 2007). Another application for Alzheimer's patients is tracking them in a long-term care facility. The system can keep track of patients and notify personnel when they enter a restricted area. Similarly, there are approximately 1,000 patients, some with dementia and other illnesses, in Mexico City who are implanted with the VeriChip for identification purposes (Schwartz, 2004). At Hospital St. Louis in Luxembourg, high risk dementia patients are required to wear RFID tags which signal the hospital personnel when the whereabouts of a patient puts them or others in risk (Read, Timme, and DeLay, 2007).

Rockhampton Base Hospital, in Queensland Australia, has implemented RFID to improve worker safety. Nurses that work in the psychiatric ward were given RFID identification cards with RFID chips that also have an emergency button. When nurses are in jeopardy or need assistance, they can push the button and the system will alert other coworkers with the nurse's photo, name, and location (based on the RFID system). If needed, the system can also activate an auditory alarm. The application of this RFID system can be moved over to the patient side. If a patient is having an emergency while walking down a hall, for example, he or she can push the button and receive assistance at a location other than their room.

The Bhagwan Mahaveer Jain Heart Center, located in Bangalore, India, uses RFID to monitor patient flow and track assets in the hospital's outpatient center (Bacheldor [3], 2007). When a patient arrives at the outpatient facility, they are given an RFID tagged patient card. This card allows for patient tracking and collects data on how long a patient stays in a certain area, such as the waiting room. The system is also linked to the patient's medical records and works with the billing system.

Jacobi Medical Center in New York uses RFID tags on patient wrists to identify them and ensure nurses match the correct drug and dosage to the patient. The process also creates a history of nurse visits for the record (Crounse, 2007). In addition to patient identification, accurately identifying specimens will help prevent the numerous medical errors that come about because of incorrect lab tests. For example, to add a level of safety, Georgetown University Hospital's Blood Bank explored how RFID wristbands can increase the safety of blood transfusions by verifying transfusions where bar code identification is not as effective (Philips Semiconductors, 2004).

RFID is not only used to track vulnerable or at risk patients, but also to accurately identify and secure newborn babies (Reiner and Sullivan, 2005). South Tyneside Healthcare Trust in England is using an RFID-based system to prevent newborns from being taken without authority. When a mother gives birth, both the mother and baby receive wrist or ankle bracelets containing passive RFID tags with matching numbers. The postnatal ward exits have integrated RFID readers that lock the doors if a baby is being taken out without authority (Jervis, 2006).

In another area of patient care, Boston's Massachusetts General Hospital is using a Radianse system as part of an innovative care program. The tags are battery powered and are attached to equipment or worn by people. Buttons on the tag allow personnel to transmit status

information about patients and equipment to the hospital's existing Local Area Network (Baker, 2004). In a similar way, the U.S. Navy is also using an RFID system at Pensacola Fleet Hospital in Iraq to identify, locate, and get status on its patients (Reiner and Sullivan, 2005).

Identity management is a fast growing area due to the huge number of people associated with the many functions of a hospital. More and more hospitals are using RTLS to identify and locate personnel, patients, and medical equipment. These systems help find medical personnel in an emergency, enhance patient safety, and better utilize equipment (O'Conner, 2007).

4.5. Process Management

A 1999 study by the Agency for Healthcare Research and Quality (an agency within the U.S. Department of Health and Human Services) found that medical errors account for between 44,000 and 98,000 deaths each year. These preventable medical errors are the eighth leading cause of death in the U.S. and cost a large hospital $5 million a year, which raises the cost of healthcare for everyone (Patty, 2007). Hospitals must do their part to prevent errors and ensure the five patient rights, which are: the right patient, the right drug, the right dosage, and the right procedure at the right time (Brooke, 2005). RFID can help improve processes within healthcare units and reduce preventable errors.

Studies have shown that one in twenty patients suffer from unfavorable drug effects. In order to reduce this number, Jena University Hospital in Germany has implemented RFID to monitor medicine dispersion in the intensive care unit as a way of ensuring patients get the right drugs and the proper does of the right drugs (Wessel [1], 2006). Jena believes that RFID can eliminate all drug errors for their hospital (Wessel [1], 2006).

Similarly, Ospedale Maggiore, a hospital located in Bologna, Italy, has implemented RFID to reduce the number of blood transfusion errors. The purpose of the RFID technology is

to reduce the errors associated with matching the blood bags with the patients. The patient and the cabinet holding the blood are equipped with RFID tags. Once the blood is tested, the nurse giving the blood to the patient has to go through a process where he/she validates that the patient is getting the correct blood type. The blood bags can only be retrieved from a locked cabinet, which is opened using patients' RFID tags. RFID increases the speed of the system and helps keep the hospital in compliance with its procedures (Wessel [2], 2006). At Massachusetts General Hospital, RFID is used to prevent blood transfusion errors by giving off a warning to alert medical staff of possible mismatches. This type of error prevention is very useful for busy places like operating theatres (Jervis, 2006).

Birmingham Heartlands Hospital, located in the United Kingdom, applied RFID to reduce the number of surgical errors – another common medical error. The NPSA's National Reporting and Learning System pilot study, conducted in 28 acute NHS organizations between September 2001 and June 2002, recorded 44 patient-safety incidents related to the wrong procedure, site, operating list, consent or patient name and notes. The system that Birmingham implemented allows nurses and doctors to scan the patient's RFID wristband and determine who they are and what surgical procedures the patient is having. This validation process implemented by Birmingham will hopefully reduce errors associated with surgery (Bacheldor [4], 2007).

ClearCount Medical Solutions, located in Pittsburg, has developed the SmartSponge System to track surgical sponges. The main objective of this RFID system is to reduce the number of sponges left in the body after a surgery. According to ClearCount, 0.2% to 1% of every surgery results in a foreign object left in the body. The SmartSponge System scans and checks the body for any sponges (RFID chips sewn into the sponge). The system reduces the

number of manual counts by the nurses and costly x-rays typically used to locate missing sponges (Bacheldor [5], 2007).

In addition to identification of equipment, tools, and patients, RFID can be used to monitor environmental factors and bodily changes. University of Texas Southwestern Medical Center and University of Texas at Arlington have developed a passive RFID solution for monitoring acid reflux disease. Moreover, Digital Angel and VeriChip have teamed up to research a potential solution to monitor glucose levels in diabetic people and animals (Read *et al.*, 2007). RFID manufacturers are building additional functionality in their tags, like sensors, that enables the detection of pressure, temperature, humidity, and mechanical stress changes. For instance, in development at Auburn University's Detection and Food Safety Center is a tag that can detect bacterial growth (Jervis, 2005). Furthermore, companies have attempted to make RFID tags that are edible which can be used to detect whether pills are taken and properly absorbed in a patient's body. Some companies like ACREO of Sweden and M-real of Sweden and Finland have created organic ink stripes that are safe to digest (IDTechEx, 2007). However, these tags have a very short read range of only a few millimeters, therefore rendering them useless for monitoring pill absorption. But in 2007, Eastman Kodak patented the use of printed RFID to detect pill consumption and absorption in the body when the tag dissolves (IDTechEx, 2007). These edible RFID tags do not have a silicon chip. This technology is useful for monitoring patients in hospitals as well as in the home because 40-50% of patients at home take their medications incorrectly (Harrop, 2007).

RFID can also be used to ensure that proper hygiene (and other) procedures are followed. Resurgent Health and Medical, located in Golden, Colorado, developed an automated hand washing system that uses RFID technology. According to a guide published by the Centers for

Disease Control and Prevention, healthcare-related infections annually affect nearly two million people in the U.S. and are responsible for approximately 80,000 deaths (Bacheldor [6], 2007). The system keeps track of the employee washing their hands (through an RFID card), as well as the cycle time of the hand washing process. This system can reduce the number of infections passed by employees by utilizing the simple process of washing the hands.

Properly managing medical processes is one of the most important components to improving patient care because it leads to a large reduction in the number of errors that occur. RFID can be used to ensure the proper procedure or drug is matched with the proper patient, monitor environmental and bodily changes, monitor drug consumption, monitor operating room procedures (such as verifying removal of sponges), and ensure adherence to proper procedures (such as hand washing). Currently, error prevention constitutes the biggest use of RFID in healthcare in terms of the number of tags sold, considering the 40 million tags used on AstraZeneca Diprivan® syringes (Harrop, 2006).

5. RFID Opportunities

As demonstrated in the previous section, RFID has been deployed across many different healthcare participants for a variety of uses. Table 2 provides a summary of these uses by healthcare participant. As shown, the majority of efforts to date have been with the healthcare provider. Logically, one would expect this pattern since the healthcare provider is the unique participant in the healthcare supply chain (i.e., manufacturers and distributors are not unique to the healthcare industry; in fact, many manufacturers, such as Johnson & Johnson, could be both a retail supplier and a healthcare supplier). When viewed holistically, the current use of RFID in healthcare (as depicted by the populated cells) is quite impressive; one would expect the

adoptions to continue. Organizations can use the populated cells in Table 2 as a guide to understanding where RFID has been deployed and, thus, potential areas for deployment within their own organization. These deployments, while not adding unique uses, drive adoption across the industry and continue to provide insights into the proper use and advantages of RFID. It is also hoped that the uses demonstrated in this paper (and Table 2) will trigger ideas on other uses of RFID. It is expected that the populated cells will grow in size (number of uses) as additional uses are discovered for RFID.

Table 2 is also revealing in the amount of empty cells in the table. So far, with the exception of authenticity management, healthcare manufacturers and distributors do not appear to be using RFID to improve the healthcare supply chain (or, at least, not reporting it). The empty cells, thus, represent great opportunities for RFID deployment. It could be argued that the cells are empty because the applications are not unique to healthcare and, indeed, this could be the case. For example, is asset management different for healthcare manufacturers and distributors compared to non-healthcare companies? Perhaps not. However, even if not unique to healthcare, these healthcare participants can learn from and adopt the technology as used in other industries and potentially improve the overall healthcare industry.

Table 2 Framework of Uses and Opportunities

Uses	Healthcare Participants			
		Manufacturer	**Distributor**	**Healthcare Provider**
	Asset Management			• Improve asset visibility / provide real-time location of assets • Reduce asset surplus • Improve efficiency in finding assets • Reduce asset shrinkage • Ensure proper equipment servicing
	Inventory Management			• Identify inventory • Locate inventory • Match inventory to owner • Improve ordering and replenishment • Accurate inventory counts • Monitor expiration dates • Decrease errors in billing
	Authenticity Management	• Reduce counterfeiting • Provide ePedigree	• Reduce counterfeiting • Provide ePedigree	• Provide ePedigree • Detect tampered or unacceptable drugs
	Identity Management			• Automatically identify people • Locate patients • Locate employees • Monitor movement and locations of people • Match patient identity to patient records • Track patient flow
	Process Management			• Reduce medical errors due to procedure or drug mismatches • Monitor environmental and bodily changes • Monitor drug consumption • Monitor operating room procedures • Ensure adherence to proper procedures

Inventory management is one particular area that appears to provide tremendous opportunity for improvement. Already, supply chain innovators, such as Wal-Mart, have shown improvement with RFID (Hardgrave, Waller, and Miller, 2006). The healthcare industry is

similar to the retail industry in its movement of inventory through the supply chain. Thus, learnings from the retail supply chain may be easily transferred to the healthcare supply chain. Authenticity management appears to be applicable to all healthcare participants and will continue to grow in importance as the need for ePedigree broadens. Similarly, identity management may also be useful throughout the supply chain, especially as it relates to the security and reliability of pharmaceuticals. Identify management complements authenticity management by providing visibility into the people involved in the process and their access to equipment, inventory, etc. Finally, all healthcare participants could benefit from process management (beyond the healthcare providers currently using RFID). The visibility provided by RFID could lend insight into processes of developing and shipping healthcare-related products regardless of where it occurs in the supply chain.

Overall, healthcare supply chains have been long known for their inefficiencies and the more successful healthcare providers are those that learn how to minimize costs / maximize efficiencies in their supply chains (Colletti, 1994). Given the current state of the healthcare supply chain, there appears to be ample opportunity for improvement (Pasin, Jobin, and Cordeau, 2002).

6. RFID Challenges

The deployment of RFID is not without its challenges. The first-movers in this arena have learned much from these early implementations and from those in other industries. The technology continues to change and evolve as the various industries find innovative ways to use it. The future use of RFID will depend on finding solutions to the challenges it faces.

One of the major obstacles that prevents the healthcare industry from adopting RFID is the required high investment for this new technology (Xiao, Senhua, Kui, Qiang, Janecek, and Norstad, 2007; Bean, 2006; Vijayaraman and Osyk, 2006; Faber, 2002). Even though prices have dropped in the past few years, the technology may still be too expensive for many companies with limited budgets to implement RFID systems. For a large manufacturer, costs can range from $10-$16 million. A large distributor can have costs ranging from $3-$16 million (Wicks *et al.*, 2006). The HDMA Healthcare Foundation published a preliminary cost/benefit analysis of using RFID in 2004 (see Table 3) which showed high investments with sometimes long payback periods. The period of time it takes to breakeven before realizing a return on investment has typically taken too long to be seriously attractive. Companies are waiting for affordable technology and short payback periods before investing in the technology (Reiner and Sullivan, 2005). A 2005 survey of 500 U.S. companies revealed that 28% of companies state concerns about having a positive return on investment from an RFID implementation. Moreover, another survey conducted by Vijayaraman and Osyk (2006) of 211 companies found that 56% of companies do not expect positive savings from their RFID implementations.

Table 3 Benefit Analysis for RFID Technology in Healthcare Industry

Estimated Aggregate Quantitative Business Case Results*		
	Large Manufacturer	**Large Distributor**
One-Time Benefits		$2 Million - $4 Million
Annual Benefits	$20 Million - $55 Million	$10 Million - $20 Million+
One-Time Startup Costs	$15 Million - $20 Million	$9 Million - $20 Million+
Annual Ongoing Costs	$20 Million - $40 Million initially $8 Million - $20 Million (After tag prices fall)	$3 Million - $4 Million

*Source: HDMA Healthcare Foundation, Adopting EPC in Healthcare Costs & Benefits, 2004
Assumptions include: Tagging of 50% to 100% of items, an average cost of $65 per item

The lack of industry standards and the need for technology refinement are additional challenges. Most RFID readers are not standardized since they have custom applications for their

manufacturers and customers (Xiao *et al.*, 2006). For example, the radio frequency band for UHF is not consistent across various different regions of the world (Philips Semiconductors, 2004). However, EPCglobal, a non-profit joint venture between EAN International and the Uniform Code Council, has established the Electronic Product Code (EPC) which provides standards for air interface protocol, tag data, and frequency ranges in various parts of the world. Perhaps the biggest standards problem currently existing for healthcare participants is the lack of a common tag type (active and passive) and frequency band (i.e., HF, UHF, microwave, etc.). Different tag types and frequency bands require different systems – i.e., an HF reader cannot read UHF tags or vice versa. Thus, if an organization receives products containing HF tags, they must have an HF reader infrastructure, for example. If they also received products containing UHF tags, then they must have two reader infrastructures – one for HF tags, another for UHF. It would be difficult, if not impossible, for a company to justify or support multiple radio frequency infrastructures. Our analysis of the existing deployments suggests the use of many different tag types and frequency bands (as shown in Table 4). This disparity among technology infrastructures will slow adoption.

Table 4 Technology Use by Category

Category	**Technology**
Asset management	Tag types: Active Frequencies: Microwave
Inventory management	Tag types: Passive Frequencies: HF
Authenticity management	Tag types: Passive Frequencies: HF, UHF
Identity management	Tag types: Active, passive Frequencies: Microwave, HF, UHF
Process management	Tag type: Passive Frequency: HF, UHF

The other two challenges are associated with RFID data. First, patient confidentiality is a major concern in the healthcare industry. Third-party organizations cannot be allowed to get patient information from an RFID tag. RFID systems have to be secure from anybody that is not associated with the healthcare provider. However, measures can be taken to protect privacy. For example, data can be encrypted, transmission protocols can be designed to reduce interception, and password protection can be built in. Concerned citizens will need to be educated about such privacy protections. The second data associated challenge is data quality. RFID technology is not perfect at the current time; data received from the RFID system can have a significant amount of noise and incomplete data. As the technology grows and develops, the data quality should be improved (Wicks *et al.*, 2006).

7. Conclusion

RFID technology has been around for many decades and still needs time to grow to achieve its full potential. Healthcare is a unique industry for adopting and integrating the use of RFID technology and many healthcare participants have already adapted RFID to fit their needs and to improve their performances. The technology has made huge impacts in asset management, inventory management, authenticity management, identity management and process management. It is always improving and with each improvement, new applications in healthcare are being discovered. We have seen in implementations and pilot programs around the world how RFID suppliers and the healthcare industry have creatively and innovatively designed RFID specifically adapted for the medical field. As government mandates and other organizations push further for adoption of RFID technology, and other factors prove RFID to be a favorable

investment, such as the creation of standards and the drop in price, along with further innovations, the industry may see a trend in moving towards RFID adoption.

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