Review: RFID-enabled Applications to Improve the Delivery of Healthcare Services: A Typology and Supporting Technologies

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Received 3 Sep 2012; Accepted 29 Nov 2012; doi: 10.5405/jmbe.1279

Abstract

The adoption of novel technologies such as radio-frequency identification (RFID) along the healthcare value chain are transforming the sector by enabling automatic identification and tracking of products, people, and assets, resulting in real-time visibility and improved efficiency in the delivery of healthcare services. Although a lot of information on RFID applications within the healthcare sector is already available, there is a need to clarify the role of RFID-specific technologies and systems in supporting such innovative healthcare applications. This paper provides a background for healthcare practitioners and researchers to clarify the role of RFID technologies in the healthcare sector. It then proposes a typology of the main RFID-enabled application domains and identifies specific technological designs that support such innovative healthcare applications. The living laboratory approach is used to assess and validate various technological designs that can be selected when envisioning the implementation of such applications.

Keywords: Healthcare services, Radio-frequency identification (RFID), Real-time location system (RTLS), Living laboratory

1. Introduction

The adoption of novel technologies along the healthcare value chain are transforming the sector. Among innovative technologies, short-range wireless communications, real time location systems (RTLS), sensor networks and radio-frequency identification (RFID) technologies, are enabling automatic identification and tracking of products, people, and assets, resulting in real-time visibility and improved efficiency in the delivery of healthcare services.

RFID involves tags that emit radio signals that are picked up by a reader, which transmits the data to an information system. This information can then be shared among the healthcare stakeholder value chain for decision-making. While the concept is simple, the implications are numerous and the derived concepts sometimes fuzzy, such as “ambient intelligence”, “connected healthcare”, “smart medications”, “intelligent medical devices”, “autonomous mobile hospital assets”, etc. Hence, although RFID technologies offer great potential for improving the delivery of healthcare services by changing the way some core processes are designed, many challenges remain before healthcare institutions can really benefit from such innovations. For instance, (i) identifying RFID areas of opportunity, (ii) selecting relevant RFID technologies for improving the performance of a specific hospital’s activities, (iii) designing RFID-enabled solutions that support these activities, and (iv) implementing them in real-life settings require that managers can keep up with the latest advances in operations management, healthcare services, and information technology (IT) domains. Additionally, since there are numerous approaches to classifying RFID applications in healthcare and because various RFID technological designs can support a single solution, it is difficult for a potential adopter to discriminate which RFID technology supports which healthcare delivery scenario and to properly assess which technological design is most adequate to fulfill the purpose of a specific application in a particular context. Although information on RFID projects within the healthcare sector is already available in the professional literature, a lot of it is not vendor-neutral, resulting in some confusion for decision makers. Furthermore, from an academic perspective, the literature related to RFID in healthcare is still scarce, but growing at a healthy pace.

The objectives of this paper are hence to provide a background for healthcare practitioners and researchers to clarify the role of various RFID technologies and systems used in the healthcare sector. This study aims to propose a typology for the main RFID-enabled application domains in healthcare and identify specific RFID technological designs that support

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such innovative healthcare applications, and validate the technical feasibility of such applications.

2. Materials and methods

2.1 Research design

To improve our understanding of RFID technologies in the healthcare value chain, the research design is that of an exploratory research initiative following three steps. This research aims to increase our understanding of the technical and business elements of RFID solutions in healthcare, to define a typology of RFID applications in healthcare settings and match specific technology and technological design in supporting discussed applications, and to validate the technical feasibility (and limits) of such applications.

As a first step, semi-structured interviews were conducted between 2008 and 2011 with different series of professionals working in the field of RFID and healthcare such as RFID hardware vendors (i.e., tags and readers/interrogators) and RFID middleware solution providers. These interviews focused on RFID technical and business elements within the healthcare sector and were related to (a) RFID technologies and applications, (b) RFID role in supporting emerging concepts (e.g., “autonomous assets”, “smart shelves”, “intelligent medical carts”), and (c) RFID role in improving healthcare core processes. Most of the interviews were carried out during various RFID conferences (e.g., RFID Journal Live!), and workshops attended by the author. Respondents were asked questions such as:

1. Your company advertises [specified RFID-enabled concepts]. Could you explain practically how RFID technology can enable the operationalization of such concept?
2. Why use [vendor’s specified] RFID technology to support [identified] applications?
3. Justify why the proposed [vendor’s specified] RFID technology would be more appropriate than [competitive] RFID technology in supporting [identified] applications?
4. Could you identify the main RFID application domains in the healthcare sector and position your offer within this context?

As a second step, with regards to validating RFID areas of opportunity, face-to-face meetings, conference calls, and joint working sessions were organized with GSI Canada, EPCglobal Canada, and Carenet Canada representatives. GSI Canada is a member of GSI World, a leading organization responsible of collaborative commerce and global standards initiatives. EPCglobal Inc. is its standards arm that manages the (GSI EPC) global standard for real-time, automatic ID of information in the supply chain. Carenet Canada is an organization that promotes, facilitates, and supports the use of electronic commerce among Canadian healthcare providers and suppliers. The aim of this step was to propose and validate a typology of RFID applications in healthcare and match specific RFID technologies to particular applications. As [1] highlighted, there is “an impressive variation in approaches to classifying RFID applications in healthcare”. For instance, researchers proposed an exhaustive RFID application classification matrix based on four key enabling functions (i.e., tracking, identification and authentication, automatic data collection and transfer, and sensing) and four healthcare applications (i.e., patient safety and quality of care, pharmaceutical applications excluding supply chain and counterfeit drug issues, management of medical devices, supplies and biological material, and patient and healthcare provider support/management) [1].

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Typology of RFID applications in healthcare

2.1 Passive UHF RFID-enabled portal/choke point for object identification (mobile assets/items/persons)
2.2 LF exciter to activate hybrid tags (e.g., active RFID-Wi-Fi tags)
2.3 Passive UHF RFID-enabled mobile cart for the tracking of in-transit medical supplies
2.4 “Smart” cabinet equipped with passive UHF RFID reader and various configurations of antennas (e.g., on the side of the cabinet, under the shelves)
2.5 Passive HF bracelets
2.6 Reader to identify patients & ensure tracking and matching of medication with patient
2.7 Passive UHF hand-held reader for inventory management & exception handling

Figure 1. Living lab experiments for RFID-enabled healthcare applications.

The laboratory approach allowed testing the technical limits of these applications through their development, design, and prototyping. Laboratory experiments were also compared with discussions and demonstrations presented at specialized conferences (RFID Journal Live!), and workshops attended by the author. Finally, a literature review of professional and academic reviews was conducted in order to provide more specific examples of RFID applications discussed in the paper.

2.2 RFID system

RFID technology is a wireless automated identification technology (AIT) used to track and manage objects (i.e., products, people, and assets) in real time. Figure 2 shows various RFID technologies that can be found in healthcare institutions and summarizes how the information is managed throughout different layers of the system.
This includes (i) the object identification layer composed of various type of tags (passive, semi-passive, and active) containing encoded data and attached to mobile objects, (ii) the object data capture layer composed of fixed, mobile-mounted, or portable readers and antennas/access points used to automatically communicate with the tags, (iii) the data communication layer used to transmit the data through a network, and finally (iv) the data management layer composed of RFID middleware (e.g., patient flow management logic, geo-localisation engine) where basic captured data are transformed into usable information managed by back-end hospital information systems (HIS) such as Clinical Medical Systems (CMS). A more detailed explanation of this system will be used to support the discussion in Section 3 to demonstrate why RFID should not be considered as a standalone solution but rather as a part of a larger integrated solution implemented to support the operations of healthcare institutions.

2.3 Healthcare system

Globally, healthcare costs are rising at an alarming rate and the health system’s share of program spending is constantly rising. For instance, in Quebec, Canada, in his budget speech delivered before the National Assembly, the Minister of Finance [8] declared that “The health system’s share of program spending rose from 31% in 1980 to 45% in 2010 (and if nothing is done), this budget will account for two thirds of program spending in 2030”. With a steady 5% annual growth of the health funding envelope, this also means that in a few years (in 2016–2017), the government will allot $38 billion to the health system. Practically, that is more than $100 million a day [9]. While resolving the issue of healthcare funding is absolutely crucial to regaining control of public finances in developed countries, this is a challenging task since the healthcare demand increase is combined with an increasing shortage of doctors, nurses, and skilled ancillary personnel, undue work pressure, ineffective communication mechanisms, and already existing but unreadily available clinical information [10].

In other words, healthcare “is on a collision course with patient needs and economic reality” [11]. Among the proposed initiatives for improving the health system’s efficiency and productivity, work process improvements and the implementation of promising new technologies have been identified as priorities by governments [8] and constitute a significant driving force in the adoption of healthcare IT systems globally [12].

2.4 RFID market in healthcare system

RFID technologies are already enabling innovative mobile service applications in the healthcare sector, in particular with “closed loop” indoor applications where the technology has been implemented within hospitals. The global RFID market for RFID transponders, readers, software, and services is expected to show a year-over-year growth of 17% to 18% in the coming years [13,14] and generate $70.5 billion in revenues from 2012 until the end of 2017 ($7.62 billion in 2012). The RFID market in the healthcare industry has even higher growth, which is expected to reach a compound annual growth rate (CAGR) of 29 % over the period of 2010-2014 [15]. Although this represents a marginal part of the world healthcare IT market ($99.6 billion in 2010 and expected to grow to $162.2 billion in 2015, at a CAGR of 10.2%) [12], the urgent need to reduce operating costs and improve the efficiency of healthcare delivery (e.g., enhanced clinical/administrative workflow of hospitals, reduced medical errors) is also an area of opportunity for RFID healthcare providers.

3. Results and discussion

3.1 RFID applications in healthcare: a typology and supportive technologies

A typology of six intertwined categories of current and emerging RFID applications in healthcare is proposed (Fig. 3).

![Figure 3. RFID applications in healthcare. A typology and supporting technologies.](image-url)
This typology is derived from the data collected in step 2 of the research process. Attached to each category, underlying supportive RFID technologies are indicated. This information is derived from the data collected in steps 1 and 3 of the research process. Although it is not surprising that respondents in step 1 of the research process had different views on the “best” RFID technologies to support specific healthcare applications (since each respondent/vendor promoted his own solution), data gathered in this step helped to develop a better understanding of existing RFID offers and allowed a better grasp of which particular technology and technological design could support a specific RFID-enabled healthcare scenario. Step 3 (laboratory experiments) helped to balance the theoretical performance of selected RFID technologies/applications and test various technological designs.

Category 1: IT and medical asset management. This category represents the most exploited area of opportunity for RFID in the healthcare sector [15,16]. In fact, return on investment (ROI) has been proven for RTLS used for applications such as equipment tracking, where the knowledge of the real-time location and status of mobile assets is important. Drivers for the adoption of RTLS include the need to reduce time wasted searching for equipment required for patient care (i.e., available for use) or preventative maintenance (i.e., ensuring regulatory compliance), over-procurement and rentals of mobile assets, and concerns over lost, misplaced, or stolen mobile assets (e.g., computers, wheel chairs, infusion pumps, etc.). Furthermore, back in the mid 2000’s, the U.S. Food and Drug Administration (FDA) started to work on a draft ID system that requires manufacturers of medical devices and supplies to apply unique device identification (UDI) mechanisms (bar codes or RFID) to individual items so they can be automatically tracked and traced in the supply chain [17]. Recently, the FDA proposed a regulatory action to support its initiative in order to “reduce medical errors that result from misidentification of a device or confusion concerning its appropriate use” [18].

Category 1: Supportive RFID technologies. Although passive RFID technologies present some interest for RTLS applications [19,20] and passive tags have specifically been designed for on-metal applications (e.g., Xerafy rugged tags for tracking metallic assets in healthcare [21]; or Confides IronSide family tags and William Frick & Company weldable metal RFID tag for industrial applications), presently, most RTLS are supported by active RFID technologies. Active tags use an onboard battery to power the tags and allow a read range of over 300 feet (91.44 m). Important active-solution providers in the healthcare sector include Aeroscout, Ekahau, and Zebra Enterprise Solutions, which have developed tags that can leverage a hospital’s existing wireless local area network (WLAN) infrastructure and use the Wi-Fi network for communication. Other options have been proposed by various solution providers, including readers that plug into electrical outlets to form a ZigBee-based wireless mesh network (e.g., Awarepoint), hybrid tags based on RFID and infrared (IR) technologies (e.g., Versa Technology, Teltracking and CenTrak), RFID proprietary 433-MHz technology (e.g., Guard RFID Solutions, Radiance, RF Code), or active ultra wide band (UWB) RFID technology (e.g., Time Domain, Ubisense). Competitors to RFID include ultrasound identification (USID) tags (e.g., Sanitor) [22]. While these RTLS-based RFID technologies are presented separately, most of the vendors are now proposing hybrid tags that combine various ATIs on a given tag. For instance, an active Wi-Fi RFID tag can also be equipped with an IR captor (e.g., Ekahau) or a low-frequency receiver (e.g., Aeroscout) for more precise detection/location (i.e., counterbalance Wi-Fi signals that can travel through walls) and eventually trigger an immediate alert. Generally, active RFID tag suppliers complement their hardware offers (see layers 1 and 2 in Fig. 2) by (i) partnering with an IT network provider (see layer 3 in Fig. 2), and (ii) providing a software platform (RFID middleware-see layer 4 in Fig. 2) to manage tracked objects in order to improve their operational capability, and generate useful business intelligence data. Examples of such platforms include proprietary middleware platforms such as AeroScout MobileView and Ekahau RTLS or compatible and independent middleware such as IntelligentInsites or Awarepoint/Patient Care Technology Systems (PCTS). It is interesting to note that early adopters of RFID-based asset management learned from initial implementations and paved their way for other applications. A recent example includes the Sloan-Kettering Cancer Center (MSKCC) in New York City, which has been using the technology since 2006 [23].

Category 2: Security and access control. The use of RFID technology in security and access control such as monitoring patients/staff/visitors’ access to specific hospital facilities, or prevention of theft of mobile assets (e.g., wheel chairs, laptops) is becoming increasingly important. For instance, RFID can help security personnel quickly respond to emergency situations by locating personnel in difficult situations, leading to a safer working environment. As an example, the Tuusula Hospital in Finland was among the first hospitals to implement an RTLS-based personnel safety system in the emergency unit and the inpatient’s ward. In unexpected situations, employees can trigger an alarm by pulling on the tag of a pager, which is worn as a badge to summon help. The signal is automatically transmitted to the security personnel via a mobile device (e.g., mobile phone). A more recent example is the Department of Psychiatry and Psychotherapy at the University Hospital of Innsbruck in Austria using a similar RFID-based system to protect more than 200 individuals working in the department [24].

Category 2: Supportive RFID technologies. Many security and access control systems are based on RTLS supported by active tags for ensuring wide-area coverage. For instance, the Mahkota Medical Center in Malacca [25] and the St. John’s Children’s Hospital Medical Center in Springfield, Illinois [26] are currently employing an RFID-enabled tracking system using active dual-frequency transmitter RFID tags/bracelets to increase security in their facilities and protect newborns and children. The RFID system also alerts staff members if a patient’s ID tag is tampered with, or if that tag approaches an exit. However, more simple passive RFID technology can also work for access control. For instance, the Beth Israel Deaconess
Neonatal Intensive Care Unit in Boston opted for a passive high-frequency (HF) wristband system to detect babies passing in and out of the hospital [27]. Passive tags are not equipped with a battery; they are powered by the reader radio-frequency (RF) signal with a read range from a couple mm up to 15 m depending on the type of tag. In terms of performance, HF tags (e.g., TagSys, UPM RFID) are less sensitive to metallic and liquid products omnipresent in hospitals environments. They are used in short-range read applications, and are safer for applications with potential electromagnetic interference (EMI) caused by the RFID system. More importantly, HF tags can offer increased security features and are being increasingly used in mobile devices, like mobile phone and tablets, to support applications based on near-field communication (NFC). NFC allows a mobile device to collect, share, and write data from another device or from an HF NFC tag in close proximity. While traditional applications include payment, loyalty program, access control, and ticketing using contactless cards, mobile handsets equipped with NFC capabilities (i.e., HF chips, RFID reading capabilities, and supportive operating systems such as Android OS) can emulate cards or act as a reader and access information stored in tagged objects. Since NFC-enabled smart phones are becoming pervasive in healthcare environments, this technology and other AITs are going to play a major role in supporting multiple healthcare scenarios [28], contributing to the so-called pervasive healthcare or ubiquitous healthcare [29,30]. In the last five years, the development of ultra high frequency (UHF) technology has led to the adoption of UHF RFID tags for applications traditionally reserved for HF RFID tags. There have been advances in integrated circuits (ICs), antennas design, form factor, security options, and data capacity. For instance, in 2011, Zebra released a UHF RFID card for access control and personnel tracking. The use of a more advanced RFID IC such as the Monza tag chip from Impinj and redesigned antennas allow a read range of 50 feet (15.2 m) while offering other possibilities such as optional memory configuration to protect privacy information, optional read range reduction to protect users from unauthorized tracking, and 48-bit UID against card cloning [31].

Category 3: Patient safety and management. This category involves two important and related aspects of health care delivery: (i) safety and (ii) management of the patient.

Regarding patient (flow) management, a study on quantifying the economic impact of communication inefficiencies in U.S. hospitals [32] estimated that a typical 500-bed acute-care hospital could experience an annual economic burden of about $4 million due to wasted physician and nurse communication time and increases in length of stay. The study suggested that any actions that hospitals could “take to streamline the processes related to care coordination and discharge planning, especially those that involve communication, are likely to have a significant bottom line impact”. It is not surprising that this RFID-related area of opportunity has been exploited. Indeed, various projects have been conducted in hospitals around the world to implement process improvement related to patient flow. For instance, the Christiana Care Hospital in Newark, Delaware [33] and Providence St. Vincent and Providence Portland Medical Centers in Portland, Oregon [34] were among the first to adopt RFID to redesign their existing workflows and integrate an automatic patient tracking system (using Patient Care Technology Systems-PCTS as their intelligent platform) and respectively active IR-RFID tags and USID as their tracking system. In both cases, besides locating and identifying patients and monitoring patient progress (i.e., care status), the RFID-enabled tracking and tracing system helped reduce length-of-stay and patient walkouts. Of note, in emergency situations, such an RFID system can allow a department to enhance its state of preparedness by giving access to real-time and historical data regarding the patient, staff, and medical assets. This allows quick reaction by sorting patients by acuity as well as retrieving an instantaneous summary of tagged objects (i.e., patient/staff/medical assets) with contamination and infectious agents [33]. AITs such as RFID enable “the medical center of the future” where the processes are patient-driven, while providing clinic personnel with real-time information on the locations and status of patients, care providers, and equipment [35]. Observing patient flow at the micro level can also be done using RFID. For instance, researchers at the University of Bristol’s School of Biological Sciences are using RFID to understand how simple animals (i.e., ants) make collective decisions. They glued RFID tags to the thorax of the ants to uniquely identify each individual ant and placed readers over the entrances of the nests to track their behaviors [36]. For this specific application, the form factor of the tag is important. In this case, the researchers selected short-range 500-µm square tags from PharmaSeq equipped with photovoltaic cells to capture laser light emitted by the reader to transmit the unique IDs via RF waves.

Regarding patient safety, it is well known that medication errors, including contamination, can result in additional treatments, extended stays, disabilities, and even loss of life. Developing patient care strategies is hence an important area in which RFID can play a role and support the “rights” of patient safety (i.e., the right patient, the right drug, the right dose, the right route, the right time, the right documentation) while providing the basis for a warning system. Examples will be provided in the section below. RFID can be used to ensure traceability for recalls. This will be discussed in more detail in Category 4: Supply chain management and condition monitoring.

Category 3: Supportive RFID technologies. Pinpointing a specific RFID technology as best for patient safety and management would oversimplify the complexity of the case, since identifying the patient, the drug, the medical assets, the medical personnel, and the medical records that converge toward the point of care may require different RFID technologies. For instance, automated patient flow is generally supported by active RFID technologies. This can be done using tags designed as patient badges or bracelets that provide a hospital-wide coverage while ensuring a desired level of precision (i.e., radius of measurement in which tag can be accurately located; i.e., room, sub-room, or bed level) and accuracy (i.e., consistency of signals being emitted, received, and interpreted). If any additional condition monitoring is
required for a specific patient or asset, tracking technology that includes sensors should be used. Fortunately, many active RFID tags are equipped with onboard sensors such as motion, tamper detection, or temperature sensors (e.g., tags from *AeroScout* or *Ekahau*). In addition to providing ID information, sensor tags are used in applications where the monitoring of the environmental conditions is important. For patient monitoring, recent cases include the implementation of *Cardi Scientific* active UHF RFID tags implemented at the Tan Tock Seng Hospital in Singapore [37] and at the Pantai Hospital Ipoh in Malaysia [38]. Tags provide real-time patient temperature monitoring while ensuring location tracking, therefore removing highly work-intensive tasks.

Although active tags can be detected and identified throughout the hospital and at specific zones (when equipped with choke point/zone detection capabilities such as a LF RFID receiver or IR captor), passive tags can only be detected at specific locations where fixed readers are installed. For instance, the Commonwealth Newburyport Cancer Center in Newburyport uses passive RFID (from *Xecan*) to automate the patient check-in process and track patients and their charts to ensure that they receive the proper treatment. In this case, the patient’s ID number is automatically used to open the patient’s chart on the oncology EMR system [39]. Patient safety applications can also be supported with HF RFID technology for physical verification of patients using patient wristbands to track surgery procedures (e.g., Taiwan’s Chang-Gung Hospital in Taipei), recording information for specific point-of-care tests, such as blood pressure and oxygen saturation, using a mobile device equipped with an HF RFID reader (e.g., East Savo Hospital District, in Finland) or for tracking and matching medication systems from a pharmacy to intensive care units and to specific patients (e.g., Klinikum Saarbrücken Hospital and the University Hospital in Jena, Germany).

Subcutaneous tags could be used for patient identification (not tracking). LF RFID tags containing a unique ID that points to a medical record in a database can be implanted into a human body (e.g., *Verichip*) because LF tags are less sensitive to the water present in the human body and their very limited read range enhances security [40]. Theoretically this technology is not different from that used to identify cattle in the farm industry. As innovation continues towards a “wireless body platform,” other more sophisticated types of tag are being introduced, including implantable temperature sensing microchips and tags equipped with bio-sensing capabilities such as the ones proposed by *Positive ID*.

The World Health Organisation (WHO) reported that 5 to 15% of people admitted to hospitals in developed nations end up needing treatment for the infection which they acquired during their stay. One emerging application related to patient safety is hygiene management using an RFID-based hand-washing compliance system. The systems are generally supported with RFID tags designed as caregiver badges that are detected at hand-hygiene dispensers (e.g., *AeroScout’s* tags integrated with *Gojo Smartlink* dispensers; *nGage* RFID-enabled hand-washing stations). Besides forcing and educating the medical personnel to comply with the hospital hand-hygiene protocol prior to visiting patients, hospital managers can get the history of tag movements (i.e., who was in contact with whom? When? Where?). For instance, ever since the *nGage* active RFID solution based on 2.4 GHz (IEEE 802.15.4 specification) was installed at the Princeton Baptist Medical Center in Birmingham, patient visit time reduced by 36% [41]. Passive HF or UHF tags can be also be used to detect personnel IDs entering or leaving patient rooms. However, using such a design can only record the tag ID, and alert the personnel via a displayed message on a screen mounted above the station, but it is more difficult to use a passive RFID-based design to capture movement (entering or leaving a room) and ensure that personnel has washed hands.

**Category 4: Supply chain management and condition monitoring.** Supply chain management (SCM) is “the integration of business processes from end user through original suppliers that provides products, services, and information that add value for customers” [42]. Since most clinical decisions involve managing medical supplies, supply chain activities have an important role in effective and efficient service delivery in hospitals and substantial benefits can be obtained by improving supply chain processes [43]. From a healthcare supply chain perspective, RFID enables end-to-end traceability of medical products and contributes to enhanced supply chain performance [44,45]. More specifically, RFID can enable more efficient physical control of medical supplies and allow faster replenishment and improve expiration date management by automating inventory movements, ensure traceability in the event of a recall by facilitating item retrieval, allow temperature monitoring using sensor based tags, and reduce counterfeiting of pharmaceuticals when complying to e-pedigree requirements by ensuring a traceability whenever a change in ownership occurs from sale by a drug manufacturer through to the pharmacy (e.g., California e-pedigree law for 2015).

Prevalent SCM applications include RFID-enabled cabinets, “smart shelves”, refrigerators, and freezers equipped with a reader/antennas and supporting software used to manage high-value products by providing real-time inventory management. Companies like *Wavemark, Mobile Aspects, Stanley InnerSpace, Terso Solutions, CareFusion*, and *Omnicell* offer such solutions. When integrated with a back-end inventory management HIS, benefits include the improvement of expiration date and recall management and elimination of the need to maintain excess inventory. The cloud computing approach to RFID is also an interesting option for supporting customer business models and facilitating adoption. For instance, once a hospital rent RFID-enabled cabinets, most of the providers will offer a monthly fee that includes cloud based hosted inventory management software applications, and 24/7 monitoring of equipment status, with the only requirement to use such systems being an internet connection [46]. Since item-level tagging is not warranted for a very high percentage of hospital medical supplies, an alternative tagging approach is to tag the container in which the items are stored instead of the items themselves. In such situation, automated replenishment can be achieved by using an E-Kanban 2 bin replenishment system where the tag is used at the bin level [47]. Besides automating and improving the replenishment process, it also
eliminates counting and needs assessment in different storage locations, freeing up hospital staff for more value-added activities related to patient care.

**Category 4: Supportive technology.** Supply chain and inventory management have been at the forefront of RFID adoption since Wal-Mart and the US Department of Defense (DoD) mandated their suppliers to adopt the technology back in 2003. Passive UHF RFID tags (e.g., Alien technology, Impinj, UPM RFID, Avery Dennison, Invengo) are most commonly used in applications where convenience and automated processing of multiple tags is required. Typical applications include warehouse applications such as automated receiving, put away, picking and shipping, and replenishment of medical supplies. Passive UHF RFID tags allow bulk reading of up to hundreds of tags per second, a read range of up to few meters with no line-of-sight requirements, and operation in harsh environments. However, these tags generally can still be inhibited by water and metal environments, have limited storage capacity (96 bits+) and feature limited data security. Nonetheless, performance improvement of passive UHF RFID technologies has been exponential with features such as anti-collision algorithms, improved communication protocols, hybrid HF and UHF antenna designs, increased data capacity, dynamic authentication, and ruggedized designs. These innovations allow passive UHF RFID to be used for applications traditionally reserved to LF and HF RFID such as patient identification, bio-bank management, blood bag tracking, medical file tracking, and laundry management. For example, Tagsys HF tags and Smart Trac LF robust tags that use a special injection molding process (offering high mechanical resistance, and resistance to water, chemicals, heat, and pressure) now coexist with passive UHF RFID tags such as Tagsys UHF linTRACK tags or the ones used by the InvoTech garment tracking system to automatically track and report on the movement of hundreds of linens and uniforms per minute. This example highlights that RFID tags are just one component of a whole system. Similarly, RFID-enabled document tracking solutions such as the ones proposed by Filetrail or 3M facilitate the management of patient medical records and other regulated documents which in turn benefit audit compliance by allowing documents to be retrieved very rapidly. Such solutions are now being applied to other business processes such as the tracking of lab notebooks or tissue samples [48].

For temperature-sensitive product supply chain applications such as cold chain management, where it is essential to track product IDs and monitor the condition of items, the usage of sensor tags is required. This generally includes semi-passive tags or active tags equipped with sensors. Active tags can be programmed to automatically transmit specific information and generate alerts, whereas semi-passive tags are less expensive but do not send any information unless they are interrogated. They are equipped with embedded sensors (i.e., temperature logger, and humidity, shock, light exposure sensors), powered by a battery, and have an internal clock that associates a timestamp with each piece of sensory data collected. They operate at different frequency ranges for close-proximity reads (e.g., HF American Thermal Instruments’ Log-ic), up to an extended read range (e.g, CAEN Easy2Log family or Intelleflex temperature sensor tag that claims 100-m read range in free space).

**Category 5: Toxic waste management.** This category is closely related to RFID-enabled SCM and focuses particularly on traceability processes. RFID supports healthcare waste traceability and ensures that hazardous materials will be managed and disposed safely and efficiently (i.e., in compliance with local legislations), preventing healthcare personnel and waste managers from being exposed to infections, toxic effects, and injuries. Healthcare waste that can be tracked and traced with RFID includes blood, body parts, chemicals, pharmaceuticals, medical devices, and radioactive materials with which hospitals deal with on a daily basis due to chemotherapy drugs, laboratory chemicals, and X-ray films.

**Category 5: Supportive technology.** The use of RFID e-seals equipped with physical protection as well as active or semi-passive tags (with lock and tamper proof sensors) can help to keep track of a container’s transactions, ensuring that potentially hazardous waste is not compromised en route to the waste management plant from the hospital. Keeping track of a container’s movement requires RFID tags to be equipped with a Global Positioning System (GPS) receiver and satellite or cellular connectivity, such as Global System for Mobiles (GSM) [49]. Examples of RFID-enabled e-seals include passive UHF technologies such as the ones proposed by M-ID Cargo, Conair/United Security Applications ID, and Yeon Technologies, and more advanced ones from Savi/Lockheed Martin, Hi-G-Tek, and System Planning.

**Category 6: Employee management.** With up to 80% of expenses tied to patient care activities, healthcare institutions can garner substantial savings and improve clinical practices by better managing their labor force. Similar to the discussion on asset management and patient flow management (discussed in Categories 1-3), RFID technologies are used to support employee management by improving the ability to locate and identify employees in real time, and streamline the processes related to care coordination and discharge planning, especially those involving communication.

Section 3 has highlighted the fact that applications have specific requirements, which in turn call for different technological designs. For instance, for an RTLS application, (a) one hospital’s manager may require full coverage with no latency (immediate detection of a location change for a tagged object), a precision of 3 m (radius of measurement to accurately locate the tag), and a 95% accuracy, whereas another hospital’s manager may require (b) choke-point coverage with a precision of 1 m. It is therefore more appropriate to define the requirements in terms of questions to answer rather than in terms of fixed parameters such as what (application) do you specifically intend to manage with RFID? or what are the derived business and technical requirements that should be derived from this application?

4. Conclusion

The goals of adopting RFID technologies are “efficiency,
improved operational capability, and the ability to generate useful (business) intelligence data” [13]. Since improved information and communication are vital for increasing the efficiency of hospital processes and are pillars of “lean health care management” [50], RFID will become ubiquitous in the delivery of healthcare services. Even though this paper presented RFID-enabled applications separately, it is important to note that they are all interrelated and will co-evolve. Similarly, active, passive, and semi-passive RFID should not be understood as competing technologies but as complementary [51].

This paper provided focused background information for healthcare practitioners and researchers to clarify the role of various RFID technologies and systems used in the healthcare sector. A categorization of RFID applications in the healthcare sector was given and the ecosystem of RFID technologies in supporting such applications was clarified. Many examples were provided to indicate how different technological designs can be selected to support similar application domains, highlighting the importance of the requirement management process that should be conducted in order to design any RFID system. Although numerous documented business cases can support managers in their projects (and many examples were provided in this paper), the rate of innovation and the constant introduction of novel RFID solutions to support healthcare practitioners complicate the adoption process, suggesting a continuous surveillance of the market. In such a dynamic context, the living lab approach represents an opportunistic research environment, which is particularly well fitted for exploring emerging RFID-enabled healthcare delivery models, as it provides appropriate support to networked innovation collaborative processes commonly required in IT healthcare projects.

In term of limits, it is important to mention that not all RFID technologies were used in the living lab, suggesting that vendor-neutral research in this direction is an interesting area to explore. Although various technological designs were suggested for each application domain, there is a need to present the information in more structured ways, to facilitate the linkage between specific business and technological requirements for each application domain. A RFID requirement analysis tool should be developed to help practitioners and researcher’s more accurately link desired applications to specific RFID technological designs, and conduct trade off analysis more easily. Using a living lab approach involving a cross functional team (IT, bio-med, nursing, project management, etc.) and educating the team on RFID and its potential to improve the delivery of healthcare services, helps project stakeholders to (a) realistically understand the potential and limits of the technology and applications, (b) assess their potential impacts, and (c) formalize the related technological requirements [6]. This safer approach to innovation supports managers as they move from fuzzy front-end concepts to pre-project planning and pilot project, as it allows a better understanding of the real complexity behind the adoption of such emerging healthcare applications.

Among RFID implementation issues, security and privacy should be carefully considered. In terms of security, RFID tags are susceptible to many of the same data security concerns associated with any wireless device. In terms of privacy, if RFID tags contain personal information (e.g., health information or data linked to personally identifiable individuals) without the proper security or integrity mechanisms in place, privacy should be heightened. RFID technology ranges from less secure RFID solutions (e.g., passive UHF tags used in SCM which offer basic protection capabilities such as obfuscation of the tag unique ID or password-protected tag kill procedures) to highly secure RFID solutions (e.g., HF tags used in e-documents or active tags). Understanding the technology options for a specific application allows for the mitigation of these risks. See for instance [52]. Since wireless sensor network technologies are considered an important research area in computer science and healthcare [30], there are no doubts that research on RFID will keep growing in importance, especially in less covered application domains such as patient safety/monitoring and SCM, as these areas present great potential for ensuring patient care while improving hospital operational performance.

Acknowledgments

The author would also like to thank GS1 Canada representatives for their collaboration. The typology proposed in this paper is also used in the online educational webinar offered by GS1 Canada, namely “Electronic Product Code/Radio Frequency Identification (EPC/RFID) in Healthcare”.

References


