Abstract number 025-0816

DEPLOYMENT OF RADIO FREQUENCY IDENTIFICATION TECHNOLOGY IN HEALTHCARE ORGANIZATIONS

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POMS 23rd Annual Conference
Chicago, Illinois, U.S.A.
April 20 to April 23, 2011

ABSTRACT

The Radio Frequency Identification (RFID) technology is a wireless technology that uses transmitted radio signals to tag, recognize, track and trace the movement of an item automatically. The study of this technology is actually considered a hot topic in all scientific areas and has been described as a major enabling technology for the automation of many processes. Although it is not a new technology it has only recently come to the awareness of the public and widely used in many sectors and particularly in the Healthcare.

This paper aims to illustrate the deployment of RFID technology in Healthcare, more precisely in infant security systems. A case study about the experience of three hospitals and one RFID technology provider is presented to highlight the main architectural characteristics, functionality, and advantages associated to its deployment.

After the case studies analysis it is possible to state that the infant security systems, using the RFID technology, are not so different among research case studies: they involve RFID tagging patients, they are easy to use not requiring an extensive training and also they are installed with an interface with others security systems.

Keywords: RFID, healthcare operations, case study.

1. Introduction

The RFID has been object of academics' attention from widespread fields of knowledge. We can find works on RFID in the following knowledge' areas: logistics (Ruiz-Garcia & Lunadei, 2010; Delen et al., 2007); supply chain management (Turcu et al., 2009); innovation (Holmqvist & Stefansson, 2006; Krotov & Junglas, 2008); marketing (Rundh, 2008); and manufacturing operations (Jones et al., 2007). This technology can also be found in a set of different sectors such as: automotive, wholesaling, retailing, aviation, pharmaceutical, agriculture and forestry, logistics, tourism and leisure, financial, public sector, educational, and healthcare.

In the Healthcare sector have been also some experiences with this kind of information technologies showing the promising applications of this technology (Cerlinca et al., 2010a; Iadanza, 2009; Laskowski et al., 2010). Kumar et al. (2009) had extended the deployment of RFID to the whole Healthcare supply chain as a tool of remotely tracking supplies, equipment, and even people as they move through the supply chain from manufacturers to suppliers, wholesalers, hospitals, pharmacies, and intermediaries.

This paper aims to illustrate the RFID technology deployment in infant security systems inside the hospitals. Adopting a case study methodology this study seeks to emphasize this technology deployment in Healthcare organizations highlighting the main advantages that hospitals reach with it. Also, the main characteristics of the infant security system, functionality and advantages are presented.

The paper is structured as follows; first, we focus on the main architectural characteristics of the RFID System in terms of the elements that constitute it (readers, tags, and software). Next, it focuses on the RFID deployment specifically in Healthcare organizations highlighting its main areas of application, advantages and disadvantages. In the following section, the research methodology is discussed, followed by a case study about the application of the RFID in infant security system within three hospitals and also the experience of a RFID-based systems provider. Finally, the main conclusions are presented.

2. Architectural features of the RFID technology

RFID intends to complement or to replace traditional barcode technology to identify, track, and trace products/persons automatically, adding intelligence and minimizing human intervention in the identification process by using electronic tags (Kasap et al., 2009). The tags are significantly different from barcodes in their capacity to hold data, the range at which the tags can be read, and the absence of line-of-sight constraints (Meyerson, 2007).

A RFID technology is composed by several elements as readers, tags, software, and security programs for the readers (Atkinson, 2004). Instead of visible light used in ordinary bar code labels, these tags use

radio waves to communicate with the readers. The readers generate signs that are able, by one hand to supply energy to the tag in order to generate data and, on the other hand, to send a sign of interrogation. The key component of an RFID system is the tag itself. Tags come in a large variety of forms and functional characteristics. The operating frequency of radio waves employed also varies. Low-frequency RFID tags operate at 125 to 134 kHz, for US and international use. High-frequency systems use 13.56 MHz. Frequencies of 866 to 960 MHz are used in UHF (ultra-high-frequency) systems, while microwave systems operate at 2.4 to 5.8 GHz (Dipert, 2004).

One useful way of classifying tags is to divide them into active and passive classes. To produce radio waves tags require some source of energy to power its electronics. Active tags use a tiny battery, a microchip, and a tiny antenna built into them. Active tags whose read/write range is longer and passive tags with shorter range. However, passive tags are much cheaper than the active tags and are therefore more widely used. The active tags have more possibilities and bigger flexibility than the passive ones. This is because, they have their own internal power source which is used to power the integrated circuits and broadcast the signal to the reader.

Passive RFID readers create a radio frequency field when they are turned on. When a reader detects passive tags, it activates them. These tags draw their power from the radio frequency field; they do not require battery power. Because they have no battery, the passive tags are smaller and lighter in weight than active tags (Meyerson, 2007).

When the active tags with power come into the reader's field, the reader switches to the read mode and interrogates the tag. However, the operating range of a linear-polarised antenna is more than that of a circular-polarised antenna (Intermec, 2004). When a tag communicates with an antenna, the radio frequency portion of the circuit between the tag and the antenna is called the air interface. This radio communication takes place under a certain set of rules called air interface protocol. Propriety protocols may cause interoperability problems with equipment from different vendors. In Healthcare systems the integration and exchange of information with similar systems can be achieve using Health Level Seven

standards (HL7) which is a standard for exchanging information between medical applications (Cerlinca et al 2010a). Information sent using the HL7 standard is sent as a collection of one or more messages, each of which transmits one record or item of health-related information.

Readers read or interrogate the tags. In reading, the signal is sent out continually by the (active) tag whereas in interrogation, the reader sends a signal to the tag and listens. To read passive tags, the reader sends radio waves to them, which energise them and them start broadcasting their data. This automatic process reduces read times.

Software is the glue that integrates an RFID system which depends upon the industry context, but usually a front end component manages the readers and the antennas and a middleware component routes this information to servers that run the backbone database applications.

3. RFID technology in healthcare

3.1 Main areas of deployment

The enormous advantages associated with this technology, has justified its large application in several functional areas. We can find the RFID technology in different contexts namely in: (i) anti-terrorism initiatives (Albright, 2005); (ii) electronic keys; (iii) warehouses (Meyerson, 2007); (iv) distribution centres (Borck, 2006); (v) points of sales; (v) security applications in the transport (Kevan, 2004), (vi) demotic (Kelly & Scott, 2005); (vii) retailing (Azevedo & Ferreira, 2008) (viii) e-business (Want et al., 1999); (ix) supply chain execution applications; (Meyerson, 2007); (viii) Healthcare (Hendrickson, 2004; Sini et al., 2008).

Since RFID can remotely identify and track tagged objects as they moved around the hospital area, it can provide solutions to theses challenges. In Healthcare the RFID has been deployed supporting several tasks and with different objectives. One of the primary applications of the RFID is improving patient safety and security including reducing medical errors and improving effectiveness of services. Tzeng et al. (2008) referred the RFID utilization during the 2003 SARS epidemic. This technology was used in

Taiwan hospitals to track patients in order to determine the paths of infection sources monitoring and avoiding contaminations.

Additionally, this technology has been used to scan prescriptions and transmit them to the pharmacy to eliminate hand-written prescriptions and reduce prescriptions fill-rate errors (Sun et al., 2008). In this case, the tag was used to identify out-of-date products contributing to reduce the possibility of a fatal or ineffective dose. Another interesting RFID application consists of embedding RFID tags into blister packaging systems to monitor electronically the date and time a patient opens a medicine package and takes out a pill. In outpatient settings, the patient would return the used packaging to the clinic, the package would be scanned and patient usage patterns plotted (Parks, 2003). This provides a more effective evaluation of patient compliance with prescription medication therapy. The RFID deployment can be also used to support drug anti-counterfeiting and to track recall counterfeit or contaminated medication and supplies (Laskowski et al., 2010; Cerlinca el al., 2010b). Beyond this, the RFID has been used to help improving the management blood distribution. Hospitals and laboratories are dealing with a highly perishable, hugely sensitive product that is always in short supply and is always difficult to procure. So, temperature sensitive tags can provide accurate tracking to ensure that blood stored at less than optimal temperatures would not be distributed to a patient (Roberts, 2004). Yeung et al. (2011) and Yao et al. (2010) also stress the value the RFID integration with other sensors for monitoring and management; for example wireless detection of patients temperature and for monitoring.

Brooke (2005) identified several aspects of the Healthcare services where RFID can be beneficial, including the ability to trace high value assets in the hospital and the ability to track assets over time, thus verifying that certain procedures have been completed (in this case, decontamination of surgical instruments). As state by Qu et al. (2011) an effective equipment management in hospitals is critical to deliver high quality care as well as reducing Healthcare cost**.** The surgical instruments management is a major problem for most Healthcare facilities. In addition to the loss issue, there has been a need to track both the instruments themselves and the entire process associated with them, aiming at optimizing

instrument inventory, and patient safety. The surgical instrument cycle includes procurement, assembly, packaging, sterilization, storage, distribution, utilization in the surgical suite and other clinical settings, and the decontamination process (Sini et al., 2008). The RFID also can be used to track the real composition of a sterile surgical kit, prior to the start of operations, allowing checking if there is any missing item after surgery (Iadanza, 2009). Some of the main areas of RFID technology deployment in healthcare organizations can be found in Table 1.

Table 1: Areas of RFID deployment in Healthcare organizations

RFID Deployment	Authors
Tracking/identifying patients	Fuhrer and Guinard (2006), Gambon (2010), Edwards (2010), Cerlinca et al. (2010a), Qu et al. (2011), Yeung et al. (2011), Wu et al. (2011), Sini et al. (2008), Najera et al. (2011), Yao et al. (2010), Iadanza (2009), Cerlinca el al. (2010b), Laskowski et al. (2010)
Tracking bags of blood, recording transfusions and ensuring the right match patient-blood	Fuhrer & Guinard (2006), Friedlos (2010), Swedberg (2010a), Roberts (2004), Wu et al. (2011); Najera et al. (2011), Iadanza (2009).
Tracking paths of infection sources	Tzeng et al. (2008)
Tracking equipment, staff and documents	Collins (2004); Raths (2008), Jeppsson (2010), Violino (2010), Gibson (2009); Qu et al. (2011), Wu et al. (2011), Sini et al. (2008), Najera et al. (2011), Yao et al. (2010), Iadanza (2009), Laskowski et al. (2010)
Managing surgical instruments and associated process	Brooke (2005), Qu et al. (2011), Najera et al. (2011), Iadanza (2009)
Developing security systems	Maselli (2003), Swedberg (2008), Collins (2005)
Tracking/monitoring medication therapy	Parks (2003), Wu et al. (2011), Iadanza (2009), Cerlinca el al. (2010b), Laskowski et al. (2010)

Moreover, the application of RFID in infant security systems deserves a special highlight. According to the National Center for Missing and Exploited Children (NCMEC, 2011) as of this date, there have been 128 identified infants abducted from hospitals between 1983-April 2011 (Table 2). Of this number, five are still missing. It is interesting to note also that among these cases 58 percent of the children were abducted from mother's room. Thus, it is obvious that the mother's room is where increased security efforts are needed. Infant tracking with RFID is becoming more and more common as hospitals in today’s competitive environment realize the benefits (Wang et al., 2009).

Table 2: Infant abduction from healthcare facilities (1983 to 2011).

Abductions	Numbers
From Mother's room	(74) 58 %
From Nursery	17 (13%)
From Pediatrics	17 (13%)
From "on premises"	20 (16%)

Source: NCMEC (2011)

3.2 RFID Technology advantages

There is a high investment in the RFID technology development and improvement because of the important advantages that organisations can reach with it when compared to bar code tags. On the plus side, RFID tags are often more durable than the easily smudged bar code' labels. In this context, one of the advantages pointed out to the tags deployment is its power of reading. The tags can be read independently of the environment conditions. They can be read in aggressive environments such as fire, ice, ink, noise and different temperatures (Knill, 2002). This system presents also a high, rigorous and simultaneous capacity of reading (So & Liu, 2006). According to Garfinkel & Rosenberg (2005) the benefits of the RFID could be identified in the RFID' tags, non line-of-sight and better information (Table 3). In Healthcare, RFID is considered generally more suitable than bar coding and has many potential advantages such as field reading, as opposed to line-of-sight reading. RFID devices can store more data than barcodes and some RFID tags can have data written to them by the interrogator (Symonds et al., 2008).

Table 3: RFID Benefits.

Area	Benefit
RFID tag	Small size Unique identifiable Memory capacity Reading range Write capability
Non Line-of sight	Penetrate material Independent of tag orientation Read multiple tags Process improvements
Better information	More information Accurate information End-to-end view

In Healthcare the main benefits pointed out are: (i) patient flow management; (ii) improve productivity; (iii) reduce human errors; (iv) reliable accurate and secure measures for tracking and authentication of pharmaceuticals (Reynes, 2007); (v) a triage system which employs facing massive casualty incidents through the news every RFID tags, which are silicon chips with IDs, radio frequency day. We also position it as a start point for new horizons in function and some additional logic and memory (Want et al., 1999); (vi) speed of data access and multiple item identification without need to have the tags on the line of sight; (vii) safety of electronic matches, item identification and data transfer; (viii) automation of some process activities and information flows; (ix) chance to implement workflow management rules, bounding workers to follow the implemented procedures; (xi) remote item/people tracking and real time process monitoring (Sini et al, 2008).

One of RFID's biggest selling points is that Healthcare staff can benefit without much understanding of the underlying technology. Unlike a complex electronic medical record system, RFID can operate quietly in the background, requiring little attention.

Healthcare organizations are looking to RFID as a way to maximize their use of equipment, boost patient volume and plug gaps in patient safety. Zhou & Piramuthu (2010) referred that while it enables an effective use of resources also reduces errors due to inadvertent mismatches (e.g. mother–baby and patient–blood bag mismatch). RFID-enabled equipment tracking systems improves equipment utilization and staff productivity by ensuring the equipment availability at the place when need and reducing the time the staffs spends in locating and managing inventory (Qu et al., 2011).

The RFID also could be used in patients who are put "on hold," such as those with head injuries or drug overdoses. If these patients try to leave the hospital, a sensor will detect their movement and trigger an alarm. The other costly option was a full-time security guard (Baldwin, 2005).

Lee & Shim (2006) identify the following perceived benefits associated with the use of the RFID in Healthcare: (i) overhead cost reduction; (ii) reduced error rates; (iii) improved customer service; and (iv) improved hospital image. Also Wicks et al. (2006) highlighted the following ones: (i) improved

marketing efforts; (ii) operational effectiveness and efficiency; and (iii) patient satisfaction. Moreover, according to Sini et al (2008) the RFID deployment can contribute also to (i) improved patients' care; (ii) optimized workflows; (iii) reduced operating costs; (iv) reduced costly thefts, and (v) avoiding severe mistakes (such as patients' misidentification). Some of the main advantages pointed out in the literature review on the RFID deployment in Healthcare organisations are in Table 4.

Table 4: RFID advantages in Healthcare organizations

RFID advantages	Authors
Easy to implement and start using	Swedberg (2010b)
Operational effectiveness and efficiency	Wicks et al. (2006), Vanany et al. (2008), Cerlinca el al. (2010b)
Overhead cost reduction	Lee & Shim (2006), Vanany et al. (2008), Yao et al. (2010), Cerlinca el al. (2010b)
Improved productivity	Reynes (2007)
Improved customer service	Lee & Shim (2006), Wicks et al. (2006), Vanany et al. (2008), Yao et al. (2010)
Improved hospital image	Lee & Shim (2006), Wicks et al. (2006)
Reduced error rates	Lee & Shim (2006), Reynes (2007)
Reliable accurate and secure measures for tracking and authentication of pharmaceuticals	Reynes (2007), Najera et al. (2011)
Increased equipment utilization	Swedberg (2010b), Qu et al. (2011)
Reduced costly thefts of materials/equipments	Wasserman (2010), Sini et al. (2008), Qu et al. (2011), Vanany et al. (2008), Cerlinca el al. (2010b)
Accurate inventory replenishment and consumer invoicing	Qu et al. (2011), Vanany et al. (2008)
Optimized workflows	Reynes (2007), Yao et al. (2010), Cerlinca el al. (2010b)
Improved triage system	Reynes (2007)
Reduced patient waiting time between services	Qu et al. (2011), Vanany et al. (2008), Yao et al. (2010)
Improved patients safety	Baldwin (2005), Vanany et al. (2008), Vanany et al. (2008), Yao et al. (2010), Cerlinca el al. (2010b)
Reduced errors on inadvertent mismatches (e.g., mother–baby and patient–blood bag mismatch)	Zhou & Piramuthu (2010), Sini et al. (2008),Wang et al. (2009)

3.3 RFID Technology Disadvantages

As it can be seen, the new application of the RFID technology in an organisation context can bring a lot of advantages in terms of optimization and of efficiency. Despite of the enormous advantages attributed to the RFID technology there are some limitations in the form of high implementation and operation

costs, the lack of standardization, and unawareness of its importance (Vanany et al., 2008; Smith, 2005). Another disadvantage of RFID technology according to Lai et al. (2005) is the high cost of tags.

The financial return of using RFID is also a major question in the hospital sector (Hendrickson, 2004). Due to the high cost of tags and readers it involves a big investment and the return of this investment is difficult to assess. If a short Return-on-Investment (ROI) was verified it could promote the use of this technology because according to Trunick & Williams (2005) this type of technologies presents a great level of obsolescence and innovation. Furthermore, the cost of each electronic tag is higher than the barcode one which leads organisations to think about it. According to Fisher & Monahan (2008) others critical issues in the RFID deployment in hospitals are the interoperability of RFID systems with existing hospital computer systems and the compliance with current medical regulations. If these two constraints can not be overcome the hospital administrators will postpone the adoption of RFID systems. Therefore, technology vendors should act positively to customize RFID systems for hospital needs and make it interoperable with current hospitals information systems (Yao et al., 2010).

The RFID level of security and privacy issues represents another disadvantage (Wu et al., 2011). From the point of view of Atkinson (2004) is relatively easy to have access to the information that flows in a RFID systems. It is only necessary to use a radio telescope in a relatively near distance. This can explain the fear of the organisations to adhere to the RFID technology. The complexity of this technology, the lack of know-how and standardisation are some obstacles referred by organisations for not use the RFID technology (Albright, 2005).

The privacy issues are related not only to patient information's but also with staff. The surveillance modalities of this new technology should be developed considering ethical issues, since the RFID ability to track, identify and monitoring people generate controversy. Resistance from hospital staff, especially physicians and nurses, can be a major inhibitor for a hospital to make changes (Wu et al., 2011; Fisher & Monahan, 2008). Some changes in nurse to patient interaction, doctor to nurse interaction and nurse to pharmacist interaction may be difficult to establish. However, efforts are being made to develop privacy

frameworks to guide the extent to which personally identifiable information can be gathered, stored, and used (Zhou & Piramuthu, 2010). One key ethical concern may be with the surveillance modalities of new technological systems. To overcome these issues Yao et al. (2010) suggest that patients and medical staff should be educated about the RFID technology so they have a better understanding on the benefits and possible privacy issues. Once they realize that RFID can help improve their safety and reduce medical errors, they will be more convinced to wear RFID tags and worry less about their privacy.

Another issue is the RFID accuracy. Yeung et al. (2011) study shows that RFID tracking systems with passive tags only provides a general estimation of the tag's location, i.e. inside the room but not the exact location in the room e.g. near the window etc. To overcome, this lack the authors suggested a special design for locating the antennas is required to ensure that the maximum number of tags can be read. Some of the main disadvantages associated to RFID deployment in Healthcare organizations are in the Table 5.

Table 5: RFID disadvantages in Healthcare organizations

RFID disadvantages	Authors
High implementation and operation costs	Smith (2005), Yao et al. (2010)
Tag cost	Lai et al. (2005), Baldwin (2005), Vanany et al. (2008), Yao et al. (2010)
High ROI	Hendrickson (2004), Vanany et al. (2008), Yao et al. (2010)
Lack of internal resources to support implementation	Vanany et al. (2008)
Organizational change management	Wu et al. (2011), Fisher & Monahan (2008)
RFID compliance with medical regulations	Fisher & Monahan (2008)
Lack of standardization	Smith (2005), Vanany et al. (2008), Yao et al. (2010)
Level of information security and privacy issues	Atkinson (2004), Fisher & Monahan (2008), Yao et al. (2010)
Accuracy of item/patient location	Yeung et al. (2011), Yao et al. (2010)
Electromagnetic interference with others equipments	Wu et al. (2011), Zhou & Piramuthu (2010), Najera et al. (2011), Yao et al. (2010), Iadanza (2009)
Interoperability with other IT systems	Vanany et al. (2008), Fisher & Monahan (2008)
Obstructive materials interface with readings	Wu et al. (2011)

In what is concerned to infant abduction protecting systems Saad & Ahamed (2007) had identified the main vulnerabilities of the system, namely in: (i) infant tag: using an alternative electric circuit or covering the tag with foil it is possible to cut the tag and remove infant from security area without generating alarms; (ii) portal exciters: approaching a magnet near to the surface mount door contact prevented the sensor from detecting that the door is open; (iii) controller PC: it is possible to access to the data base for monitoring and reporting, allowing unauthorized access to the application files and data base. To overcome, these vulnerabilities the authors suggested a set of protection measures as the followings: innovative design of bracelets and infant tags to prevent unauthorized cuts without alarms; protect RFID system components from sabotage or unauthorized access; isolating the controller PC in a separate LAN; integration of RFID systems with other security systems (e.g. security cameras).

There are many technical challenges associated with the deployment of RFID based solutions. Despite its potential, RFID has been slow in coming to Healthcare since the lack of awareness has worked against RFID. In addition, RFID implementations can be costly, particularly if a hospital lacks the wireless infrastructure needed to support far-flung applications, such as equipment tracking. RFID tags cost two to three times more than barcode labels (Baldwin, 2005).

The integration of new information technologies into hospitals often results in changes in management, division on labour, and accountability (Fisher & Monahan, 2008). According to Vanany et al. (2008) to a successful deployment of RFID in hospitals by top management should considered factors such as developing a clear RFID strategy, integrating RFID into existing IT architecture, coordinating among department and continually improving procedures.

4. Methodology

The main objective of this research is to illustrate the RFID technology deployment in infant security systems inside the hospitals, more precisely its main architectural characteristics, the way it works, and advantages.

Unfortunately, there is sometimes a gap between management research and practice (Shapiro et al., 2007). To fulfil this gap, the case study approach was selected. According to Ellram (1996) the case studies are the best means to understand a certain phenomenon as they provide depth and richness allowing the researcher to really understand the what, how and why questions pertaining to a given situation. From Rowley (2002) point of view, a case-study approach is adequate when the boundaries of a phenomenon are not only unclear but also there is no control over behavioural events, as it is in this case.

Attacking the same problem with a multiplicity of methods from a variety of angles can be useful, not only for the study itself, but also for the validity of the analysis. Further, using multiple data sources may lead to discoveries which would not have been made otherwise. To this end a triangulation approaches can be used (Singleton & Straits, 1999). It may involve combining multiple data sources (data triangulation), using multiple research methods to analyze the same problem (methodological triangulation), or using multiple investigators to work on the same task (investigator triangulation) (Oppermann, 2000).

In this research data and investigator triangulations were used as explained below. In this research the RFID deployment in Healthcare organizations is explored from the RFID user's point of view (hospitals) and also from the perspective of a RFID provider. Also, using a team of diverse researchers may help to reduce such bias (Oppermann, 2000). Regarding this point, the research team is composed by two researchers, one expert in industrial engineering and the other one in management and logistics. The case-study method has three distinct stages: design, collection and analysis. The final stage is an analysis of the individual case studies, allowing "cross-case" reports to be written (Yin, 2002). In general, the search for patterns can be conducted using within- or cross-case analyses. When using more than one case in a study, it is logical to find similarities and differences across the cases using various cross-case analysis tools. Among others, this practice can help in (1) identifying critical predictor variables and causal interactions, and (2) validating or extending existing theoretical models (Stuart et

al., 2002). Thus, pattern-matching is rightly characterized as a form of empirical validation for qualitative data (Johnston et al., 1999).

According to this, and to attain the research objective, was used a two stage research methodology similar to the one used by Kumar et al. (2009). In a first stage, three illustrative case studies were conducted based on secondary data using external sources, namely books, journals, business magazines and websites. Despite, the study was limited to the selected case studies and to the available data in external sources, this research design helps to define issues specifically before undertaking a primary study like an in-depth case study. Next, in a second stage, one case study in an RFID-based infant security system provider is conducted to obtain primary data related to the RFID deployment in Healthcare organizations.

This research is based on the qualitative data-analysis method developed by Miles & Huberman (1994), which consists of anticipatory conceptual model development and simultaneous data collection, reduction, display and conclusion testing.

Using a methodology similar to Kumar et al. (2009) the secondary data for this research was gathered from the analysis of published literature based on a broad range of sources from Healthcare and RFID experts including newspapers, conference proceedings, industry reports, white papers, press releases and books. In addition, was used the specialized magazine on RFID: the RFID Journal. Selected articles describing case studies were analyzed and, finally, picked aspects are briefly described with a special focus on the main characteristics of the RFID based infant security system, operational issues and advantages. The objective is not to offer further insight into the single cases, but to bring them together to get a wider picture and learn from the cross-case analyses (Tzeng et al., 2008).

As a way of reinforcing the validity of the analysis, beyond the three case studies constituted by RFID user's hospitals, an RFID-based infant security system provider case study was also incorporated in the research. The intention was to see the same phenomenon from the point of view of who provides the RFID technology solution to the hospitals. The selection of the case study representing the RFID-based

system provider was made according to a previous exploratory work on the Portuguese companies providing this kind of RFID technology solutions to the hospitals. After this, a set of companies were selected and the Safesis Company was chosen because it is the company with more experience in providing this kind of systems to the Portuguese hospitals. For the collection of primary data and to limit expert bias, the data concerned to personal judgment of the participants were obtained through semi-structure interviews according to the interview protocol in appendix A.

The primary and secondary data collected in the case studies was analysed in cross-case analysis allowing the identification of leading variables among all case studies, namely: the main architectural characteristics of the infant security systems deployed by the hospitals, their operational features and also the main advantages associated to it.

5. Case studies

5.1 CASE 1 - John H. Stroger Jr. Hospital

The John H. Stroger Jr. Hospital serves as one of 10 Illinois hospitals designated as prenatal centers for high-risk maternal and infant services. It has 460 beds of which 322 are adult and/or pediatric care, 8 are burn intensive care, 34 are intensive care, and 24 are surgical intensive care. This hospital has thousands of authorized transfer of babies per week, between its general maternity wards and its intensive care, pediatrics and obstetrics facilities. To protect babies from abduction a parental/baby mismatching safety solution based on RFID technology is used particularly when babies are transferred between departments.

5.1.1 Architectural characteristics

The RFID-based infant security solution deployed by the John H. Stroger Jr. Hospital is the BabyMatch and consists of 150 active, long-range, supervised RFID baby and 150 corresponding mother tags that transmit safe radio frequency and coded messages. These transmissions are received by strategically placed readers, and then automatically passed onto the BabyMatch host computer. A standard Windows

based touch-screen interface enables medical and security staff to monitor alarms; personalize tags, discharge babies, temporarily deactivate tags perform searches or follow the movements of a particular infant. BabyMatch's open standard architecture enables seamless integration with security, CCTV (Closed Circuit Television) access control systems as well as patient care and billing platforms.

5.1.2 How it works?

At the time of birth both the infant and the mother are issued preconfigured personalized tags that are only removed upon discharge from the hospital. The baby's tag (attached to the infant's ankle) is paired to the mother's wrist tag, which enables mothers to confirm that babies they are with are their own.

The strategically placed radio frequency readers (wall or ceiling mounted) throughout the hospital are used to determine the exact room location of the infants in real-time. Additionally, low frequency exciters are mounted at entry/and exit points inside the protected areas so when an unauthorized badged newborn is physically near the protected exit/entrance an alert notification is immediately generated by BabyMatch. This means that staff and family can move babies freely within the protected zones, but no infants can be removed without prior authorization.

5.1.3 What are the main advantages associated to the infant security system?

The main advantages recognized by the **John H. Stroger Jr. Hospital** in using the infant security system are: (1) the system ensures full supervision of each tag from the time of birth through discharge. Also, many supplemental baby and mother tags can be added to the initial installation without risk to infant safety; (2) babies requiring medical treatment from outside departments can be escorted through the protected exit by authorized staff members; (3) baby tags are easily attached the infant's ankle. If the tag is tampered with or removed, a tamper 'State' alert will automatically be generated; and (4) prevents accidental baby switching by permitting a mother to confirm that the baby she is with is her own. Match tests can be performed by both parents and supports twins, triplets and other multiple births.

5.2 - Case 2 - New Hampshire Hospital

New Hampshire Hospital (NHH) provides psychiatric services to the people of Concord district. This hospital has 212 beds and deploys the infant security systems supplied by the Accutech entitled "Cuddles". New Hampshire Hospital is a state operated, publicly funded hospital providing a range of specialized psychiatric services.

5.2.1 Architectural characteristics

The infant abduction prevention solution, based on active RFID technology, deployed in the New Hampshire Hospital, is the Cuddles. This system works on 418 MHz frequency and has a portable STAD units control tag functions and a windows-based software with password protection. This software enables to activate tags, admit and discharge patients and generate reports. No enrolment is necessary for instant protection, multi-floor monitoring capabilities are available, and the software can be updated for free to ensure that it is always operating with the latest features and benefits.

The Cuddles Soft Bracelet is a light-weight, non-allergenic, self-adjusting band that fits snugly and comfortably around the ankle or wrist. Made of an ultra-soft polyester blend, the bracelet won't cut or chafe the skin, and won't fall off due to movement or changes in weight. In the event of removal or cutting, the Soft Bracelet immediately activates an alarm — preventing abductions and ensuring the continued safety and security of the infant wearing it (Accutech, 2011).

A red, pulsating LED serves as a continuous visual indication that the tag is active. The tag can be turned on or off at any time to conserve battery power. If the tag is cut off or tampered with, it immediately locks down the perimeter and/or activates an alarm to alert staff. The bracelet design means greater comfort for the infant and easier cleaning for the nurse. The tag's small size and light-weight construction mean it will never hinder the infant's movement. The device provides universal activation capabilities, secured with unique user codes.

5.2.2 How it works?

This infant security system is strapped through a band (usually around the ankle) that incorporates skin sensing technology in case the band is removed.

The soft bracelet worn by infants is self-adjusting, preventing fall-off due to any post-birth weight loss. When the band is removed or cut from the baby's body, antennas placed throughout the facility pick up the alarm signal and relay it to a centralized alarm at the nursing station and on computer software. Usually the facility incorporates locks, and the hospital unit will go into a "lockdown mode" when a band alarm or attempted unauthorized exit occurs.

Some infant security solutions can also interface with existing systems in the hospital. For example, with the Cuddles system deployed in the New Hampshire Hospital, when the tagged infant's cradle approaches a door, a surveillance camera near the exit can be triggered. In addition to this, the alarm can be exported from the Cuddles software to nurse call pagers. The type of information that can be shown on the pagers is where the alarm is occurring, which baby is creating the alarm, and the type of alarm.

The recommended code to activate the hospital emergency response to an infant abduction (or suspected abduction) is code pink. When this code is announced, there are specific actions of specific staff to control various access points and perform searches. This code, announced overhead, alerts all staff to watch for an infant being openly carried or signs of possible concealment (in back packs, bags, etc.). This code can be used to include pediatric patients, as well as a newborn, but generally carries an age identifier and/or abduction location.

5.2.3 What are the main advantages associated to the infant security system?

The main advantages associated to the security system deployed in the New Hampshire Hospital are mainly the following ones: self-adjusting, soft Bracelet, simple operation, quick patient assignment, no

enrolment needed for instant protection, easy report generation, free on-site training, easy to use Windows-based software, reusable, easy-clean tags.

5.3 Case 3 - Centro Hospitalar do Médio AVE

The Centro Hospitalar do Médio Ave is a Portuguese Hospital which has 301 beds of which 101 are internal medicine, 71 are surgery, 10 are gynecology, 21 are obstetrics, 45 are orthopedics, 45 are pediatric/neonatology, and 8 intensive care.

5.3.1 Architectural Characteristics

The infant security system deployed in the Centro Hospitalar do Médio Ave is named Hugs & Kisses. It is constituted by hugs tags, receiver, exciters, security server software, and system manager software. It works in a standard Windows based PC environment. The hug tags are small radios that are attached to the infant with the tamper-proof strap. Receivers are radio frequency reception devices installed at regular intervals throughout the monitored area of the facility. They are installed in ceilings, usually out of view. Exciters monitor the exits from the safe area. Each exciter also includes two relays, which can be used to control a variety of devices, including magnetic door locks or audio and visual alarm devices. Like the receivers, exciters are continually monitored by the server software, and a warming message is automatically displayed if there is a problem. The security server software is installed on a server PC that is connected to the device network. As regards the system manager software, it is installed on the server and all client PCs. Also, it can be installed on any other computer with an Ethernet connection to the server PC.

5.3.2 How it works?

The security system is based on RFID technology and has the following as main components: exciters, tags, receivers and controller PC. Every infant wears a HUGs tags on the ankle, and every exit point of

the obstetrics unit is electronically monitored to detect the tags. This means staff and family can move infants freely within the protected Zone, but no one can remove an infant without the system alerting hospital staff.

The Hugs tag contains a tiny radio transmitter. Once activated, the tag emits a special signal every 10 seconds. These signals are picked up by reception devices through the monitored area and relayed to the server PC via network. If a tag in close proximity to an open exit is detected by door monitors, an alarm occurs. The Hugs application software shows the tag ID number and indicates the exact location on a floor plan map of the facility. In addition, with the integrated CCTV option, the Hugs system automatically displays images from the exact CCTV camera when an alarm occurs, so that staff can respond with full knowledge of the situation. The Hugs systems can also support magnetic door locks, and can be interfaced with other hospital security systems such as pagers and alarm devices.

The optional mother/infant matching component provides automatic matching of mothers and infants. Each time mother and baby are brought together, an audible signal will alert staff of a mismatch.

5.3.3 What are the main advantages associated to the infant security system?

The main advantages pointed out with the deployment of the infant security system are: (1) any unauthorized person trying to take an infant from the bed nursery will set off an alarm 10 feet before they hit the exit door since if the alarm goes off everyone comes running; (2) in operational terms, it is easy to attach the tag since it is done automatic enrolment; (3) no manual checks is needed given that the system software continually monitors the status of all devices, and will generate an alarm if something goes wrong; (4) it also allows an automatic mother/infant matching; the system immediately confirms that the right baby is with the right mother; (5) there are no buttons to push, no numbers to match and no wall-mounted lamps to check; and (6) it is user friendly given that the users only see the menus and commands they need, all in a standard Windows based PC environment

5.4 Case 4 - RFID-Based Infant Security System Provider

The experience of the Portuguese hospitals with the RFID technology is relatively recent and reduced in its scope. Among the seventy tree (73) hospitals that constitute the Healthcare system in the country the following Healthcare organizations are using RFID-based infant security systems: Hospital da Luz, Hospital do Barreiro (Lisboa), Hospital S. Teotónio (Viseu), Hospital de S. João de Deus (V.N. Famalicão), Casa de Saúde da Boavista (Porto), Hospital de S. Marcos (Braga), Hospital dos Lusíadas (Lisboa), Centro Hospitalar de Trás-os-Montes e Alto Douro (Vila Real), Centro Hospitalar de Trás-os-Montes e Alto Douro (Chaves), Centro Hospitalar do Nordeste (Bragança). Beyond these hospitals other ones are actually using the same system, the technology supplier refers:

> *[...] "More three hospitals are in the introduction phase of this technology: Hospital Infante D. Pedro (Aveiro), Hospital da Cruz Vermelha Portuguesa (Lisboa) and Hospital Conde S. Bento (Santo Tirso)" [...]*

When asked to the system' supplier about the hospitals' past experience on this kind of technology, he says:

> *[...] "All the thirteen hospitals where the infant security system was deployed did not have any previous experience with this kind of systems" [...]*

As regards the time spend to install the RFID-based infant security system, he refers:

> *[...] "In average the installation process leaves one week. He said also that the system were requested by hospitals and not proposed by his firm" [...]*

How this infant security system works? The security system is based on RFID technology and has as main components the following: (i) exciters, tags, receivers and controller PC. The exciters monitor the exits from the safe area. The hug tags incorporate a tamper mechanism that is enabled as soon as the tag is attached with the tamperproof strap. The receivers receive hugs tag transmissions, time stamp them and relay them to the controller PC. The controller PC contains the Hugs system software and controls the operation of the entire system. Besides these components, he says:

[...] "The infant security system has beyond these components also electromagnets, sirens with flash (strobe) and doors' magnetic contacts" [...]

Unlike bar codes, an RFID chip can be sensed from many feet away and without human intervention. Sensors, for example, in the ceiling detect a chip that is embedded in a baby's wristband, triggering an alarm if the child is in an off-limits zone, or prompting a jingle when the baby comes close to its mother's pre-programmed RFID band.

Every infant in a medical unit wears a tag with a unique ID number on the ankle, and every exit point is electronically monitored to detect the tags. This means staff and family can move infants freely within the protected zone, but no one can remove an infant from the unit without the organisation' staff being alerted. Beyond this superior and active supervision of infants, the system monitors its own functionality and alerts staff of any problems.

In the event of an alarm, the system can automatically activate magnetic door locks or hold an elevator. It can also integrate with and activate other security and access control systems, such as alpha-numeric pagers and cameras. When asked the interviewed about the situations in which the alarm goes on, he said:

[...] "The alarm goes on in the following situations: (i) someone tries to exit via a monitored door or elevator with a protected infant, without authorization; (ii) the strap has been cut or tampered with; (iii) the tag's signal has not been detected by the system for a specified time period, (iv) the tag's battery power is low; (v) an authorized exit has occurred but someone tries to "piggyback" through the protected exit with another infant; and (vi) an authorized exit has occurred but the infant has not been returned to the designated safe area in the specified time." [...]

For security purposes, all system transactions are password controlled, time and date stamped and logged into the database on the system controller. A permanent record is possible of who is admitted, signed out and discharged of all babies. Also have a record of when and where alarms occurred and who cleared them can be obtained. The system controller itself is equipped with a watchdog timer card to

output an alarm signal in the unlikely event of a problem with the operating system, providing an extra level of security. When mother and baby are brought together with a correct match, a pleasant lullaby will sound from tag. An incorrect match generates a buzzing tone.

As regards the interoperability of the system, he said:

> *[...] "The Hugs system's advanced radio frequency technology not affects or be affected by other electronic hospital equipment which represents an important advantage." [...]*

Each tag has a unique code to ensure easier identification of every infant, the strap is easily "snagged-up" to accommodate weight loss and extremely durable and the tags are also reusable and waterproof which allows its permanence with the baby all over the time.

Also, a full supervision is granted by the system. Beyond the advantages pointed out, he refers:

> *[...] "The deployment of this system in hospitals allows these organisations to improve its image, customer service and babies' flow control, to decrease the number of babies' shrinkages and thefts and also to get more durable tags." [...]*

We asked the infant security system supplier on the main difficulties faced in the introduction phase of this system. He said:

> *[...] "The human resources have some reluctance to accept new security practices and to change the way they usually develop their tasks, also in some cases the hospitals layouts are*

After the four within-case analyses it is important to do a cross-case analysis in order to identify similarities and differences in the RFID-based infant security systems deployed in the hospitals and systems provider. To illustrate how the RFID-based infant security system works the Figure 1 is drawn from the evidences collected in the case studies.

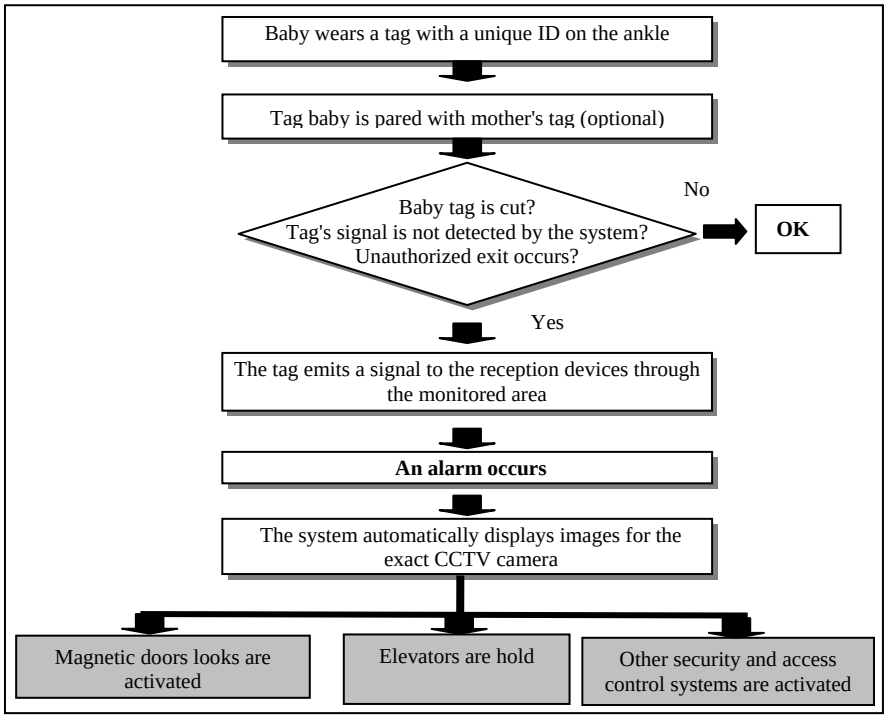

Fig. 1. RFID-based infant security system overview

First, every infant wears a tag on the ankle with a unique ID which is can be paired to the mother's wrist tag; this functionality is optional in Hospital of S. João de Deus and RFID provider. If the band is removed from the baby, an unauthorised exit occurs, or the tag's signal is not detected by the system, antennas placed throughout the facility pick up the alarm signal and relay it to a centralized alarm on computer software. After this, the tag emits a signal to the reception devices through the monitored area and an alarm occurs. Following, the system automatically displays images for the exact CCTV camera, activates magnetic door looks and other security and access control systems, and holds elevators. To identify the main architectural characteristics, functionality, and advantages associated to the RFID deployment, the evidences in four case studies were compiled in Table 6.

Table 6. Cross-case analysis of the infant security systems deployed in the four case studies

		John H. Stroger Jr. Hospital	New Hampshire Hospital	Centro Hospitalar do Médio AVE	RFID provider
Who?	Babies	√	√	√	√
	Mother	√		√ (optional)	√ (optional)
How?	RFID tag in patients (transmit & reception)	√	√	√	√
	Strategic position of receivers (hospital departments exit and entry points)	√		√	
	Interface with others existent security system	√	√	√	√
	Easy handle interface with PC	√	√	√	
	Automatic alarm if tag is removed without authorization	√	√	√	
	Automatic alarm if the baby is out of the authorized zone	√	√	√	√
Advantages	Automatic supervision of each tag maintenance state	√		√	√
	Easy and safe use of the tag i babies and mother	√	√		√
	Babies can be escorted by authorized staff members	√			√
	Avoid babies switching	√		√	√
	Easy scalable for multiple births	√			
	Quick patient assignment		√		
	Easy to use the RFID without extensive training	√	√	√	√
	Reduce implementation time				√
	Real time location of the patients			√	
	It not interfere with other hospital equipment				√
	Improve hospital image				√
	Improve customer service and babies' flow control				√
	Improve babies safety				√

Summing up, doing a cross-case analysis it is possible to state that the RFID-based infant security systems deployed among the research hospitals and RFID provider are very similar. They have the following main components: exciters, tags, receivers, controller PC, CCTV and windows-based software. Also, the way they work it is quite similar. A unique identification tag is associated to each baby, with the ability of transmit and receive radio frequency signals. The RFID security system is supported by windows-based software being easily interfaced with others conventional security systems (e.g. CCTV camera or activating magnetic door looks). The system automatically triggers alarms when the tag is out of the safety/secured zone or if the tag is removed without authorization. Despite the enormous improvements in the children safety, one the main advantage of the RFID-based infant security system recognized by the research case studies is the operations simplicity associated to the tag attachment since it is done automatic enrolment. This advantage reflects the perspective of the hospitals professionals which had to adapt their daily routines to the RFID system deployment.

6. Conclusions

In a business context the RFID technology has reached many adepts by the huge potentials that it presents for organisations. The RFID technology has received also considerable attention from academics and practitioners because of its potentialities and diverse fields of use in organisations such as: manufacturing, transportation, distribution, information systems, Healthcare, and others. The increased use of the RFID has been pointed out by several kinds of organisations because of the advantages gathered with its use.

It has been recognized that the deployment of this technology in Healthcare organizations allows a better patient flow management, improve the organisation' productivity, reduce human errors, the speed of data access and multiple item identification, the automation of some process activities, the

remote item/people tracking and, so on. The main disadvantage signalled appointed is its cost. The RFID-based security system deployed in Healthcare organizations beyond others applications it intends to prevent infant abductions and inadvertent child mishandlings in hospitals.

After the case studies analysis it is possible to state that the infant security systems deployed in Healthcare organizations with different characteristics and sited in diverse countries are not so different. In all case studies the infant security system involves RFID tagging patients. Also, in the research, the three Healthcare organisations had implemented RFID solutions with an interface with others security systems and if the baby is out of the authorized zone an automatic alarm goes off. As regards the advantages pointed out, all of them highlight the RFID easy to use not requiring an extensive training.

Besides the Healthcare organizations had already wake up to the potentialities of the RFID Technology in some specific applications there are however other medical services and valences that could be improved through the RFID technology. The Joint Commission (2007) has signed up some errors that must be avoided in any kind of Healthcare organization such as: (i) patient care hand-over errors; (ii) wrong site and procedures; (iii) wrong person surgical errors; (iv) medication errors; and (v) high concentration drug errors. Also To overcome these errors the RFID technology could be the answer. Being so, we propose as future directions other researches on the application of the RFID in these areas as a way of improving the performance of Healthcare organizations. Another suggestion is to extend this investigation to other departments inside hospitals.

7. Acknowledgements

Helena Carvalho was supported by a PhD fellowship from Fundação para a Ciência e Tecnologia (SFRH/BD/43984/2008).

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APPENDIX A

Structured Interview Protocol

This framework is intended to support research regarding the deployment of the RFID technology in healthcare, more precisely in infant security systems inside the hospitals and from the point of view of the RFID technology provider.

A) Beyond the following Portuguese hospitals which are actually using more the RFID-based technology security system?

Hospital da Luz, Hospital do Barreiro (Lisboa), Hospital S. Teotónio (Viseu), Hospital de S. João de Deus (V.N. Famalicão), Casa de Saúde da Boavista (Porto), Hospital de S. Marcos (Braga), Hospital dos Lusíadas (Lisboa), Centro Hospitalar de Trás-os-Montes e Alto Douro (Vila Real), Centro Hospitalar de Trás-os-Montes e Alto Douro (Chaves), Centro Hospitalar do Nordeste (Bragança).

B) Which is the hospitals past experience with the RFID technology?

C) Which is the average time necessary to install an RFID-based infant security system?

D) Can you describe the main architectural characteristics of your infant security system?

E) In which situations the alarm goes on?

F) The RFID-based infant security system affects or is affected by other electronic hospitals equipment? If Yes, which?

G) What are the main advantages of the infant security systems that you would like to highlight?

H) From your point of view, what are the main difficulties faced with the introduction phase of the system?