RFID applications in hospitals: a case study on a demonstration RFID project in a Taiwan hospital

Shang-Wei Wang[a], Wun-Hwa Chen[b], Chorng-Shyong Ong[a], Li Liu[c], Yun-Wen Chuang[b]
[a] *Department of Information Management, National Taiwan University*
[b] *Department of Business Administration, National Taiwan University*
[c] *Graduate Institute of Medical Informatics, Taipei Medical University*
weiwang@ntu.edu.tw (S-W. Wang), andychen@ntu.edu.tw (W-H. Chen), ongcs@ntu.edu.tw (C-S. Ong), david@mail.tmch.org.tw (L. Liu), angelcppkimo@yahoo.com.tw (Y-W. Chuang)

Abstract

After manufacturing and retail marketing, healthcare is considered the next home for Radio Frequency Identification (RFID). Although in its infancy, RFID technology has great potential in healthcare to significantly reduce cost, and improve patient safety and medical services. However, the challenge will be to incorporate RFID into medical practice, especially when relevant experience is limited. To explore this issue, we conducted a case study that demonstrated RFID integration into the medical world at one Taiwan hospital. The project that was studied, the Location-based Medicare Service project, was partially subsidized by the Taiwan government and was aimed at containing SARS, a dangerous disease that struck Taiwan in 2003. Innovative and productive of several significant results, the project established an infrastructure and platform allowing for other applications. In this paper we describe the development strategy, design, and implementation of the project. We discuss our findings pertaining to the collaborative development strategy, device management, data management, and value generation. These findings have important implications for developing RFID applications in healthcare organizations.

1. Introduction

Wal-Mart's announcement in June 2003 that it was committing itself to RFID systems boosted the technology's development [15, 16]. RFID may dramatically change an organization's capability to get real-time information on the location and properties of tagged people or objects. By now RFID has been used in many areas, such as marathon races, airline luggage tracking, electronic security keys, toll collection, and asset tracking [2, 14, 19, 32]. It is considered the next revolution in supply chain management [32]. Current research and development on RFID focuses on manufacturing and retail sectors to improve supply chain efficiency and learn more about consumer behavior. There are problems still waiting to be resolved, including standard settings, technical limitations, software/middleware development, systems integration, higher costs, benefit appropriation among participants, privacy issues, etc. [23, 32] Nevertheless, some firms are implementing RFID on a small scale and many firms are joining together to develop and promote the technology [23].

Healthcare is considered to be the next home for RFID after manufacturing and retail [14]. Generally, the healthcare industry has been investing ever more money in information technology (IT) to reduce operating costs and improve patient safety, and RFID is expected to become critical to healthcare organizations achieving these two goals [4]. Therefore, some hospitals and medical institutes are starting to conduct their own small-scale RFID testing projects. However, "the hospitals have the form of a professional bureaucracy in that clinical staff, especially medical staffs, act with a considerable level of autonomy" [30]. Implementing IT in hospitals has not been too successful, with many authors reporting failure cases [1, 6, 17, 22, 31]. The reasons for failure include user (mostly physician) resistance, and technical, clinical/professional, organizational, and implementation issues. These problems may affect the implementation and adoption of RFID in hospitals, even as the uncertainty of RFID in terms of technical aspects and application feasibility might invoke other concerns.

In Taiwan, several research institutes and firms are researching the use of RFID in supply chain management. Meanwhile, the application of RFID in hospitals has accelerated since late 2003 due to the rapid spread of SARS in Taiwan that year. Because of the pressing need to contain the spread of SARS, some hospitals, with subsidies from the Government, initiated preliminary RFID projects as early as October 2003. After twelve months, these efforts achieved significant results. This paper reports on one of the projects, the Location-based Medicare Service (LBMS) project at Taipei Medical University Hospital (TMUH). We adopt an exploratory case study approach to inquire about the strategy, process and the experience of the RFID project.

We organize this paper as follows: the next section describes RFID and its current applications in healthcare. In Section Three, we discuss our methodology. The case itself, including the background of the hospital and the

0-7695-2507-5/06/$20.00 (C) 2006 IEEE

project, is presented in Section Four. Section Five discusses our findings, while the last section provides closing remarks.

2. RFID and its current applications in healthcare

RFID allows the wireless storage and automatic retrieval of data [15]. It provides a significant improvement over not only conventional identification, tracking, and stocking of objects, but over the barcode system as well. Barcodes can only be read in "line of sight," but RFID needs no "line of light" [21, 29]. RFID is expected to help boost supply chain efficiency, improve security, cut down on theft and counterfeiting, increase asset visibility, enhance inventory control, automate stock replenishment, etc. However, RFID is not a single, simple technology. It consists of tags, readers, computer networks, and systems including middleware, databases, and so forth. No single firm dominates this technology. There exists a whole "ecosystem" of companies trying to develop a platform to support RFID development and applications [23].

The US Department of Defense has been using the technology for years. Some big firms, such as Wal-Mart, Target, and Gillette, have been aggressive in adopting and promoting RFID [32]. Their purposes in adopting RFID have included such goals as reducing the labor cost of scanning items, reduction of out-of-stock items, reducing theft loss, providing proof-of-delivery, inventory reduction, and facilitating promotions at stores. For supply chain management, the adoption of RFID, an inter-organization system (IOS) in a new form, has been a collective action because related companies need to adopt the technology simultaneously to ensure effective functioning [34]. Trust, coordination, negotiation and bargaining power have proved to be important issues in deploying RFID in a supply chain. But, in a hospital, the adoption of RFID may not necessarily be as collective an action because medical services rely more on staff and internal processes than on external suppliers. Nevertheless, any organization that plans to adopt RFID has to face multiple challenges, including the overcoming of technological, managerial and organizational problems. Sarma [27] considers three major challenges, mainly from the technical viewpoint: non-line-of-sight reading, handling of serial numbers, and real-time data volumes. He thinks that solutions may depend on building an RFID infrastructure, together with middleware and impedance-matching of the RFID system to current systems such as Enterprise Resource Planning (ERP) systems. Rush [26] asserts the importance of team work involving people from IT and business departments. Janz et al. [18] emphasize project management.

The application of RFID in healthcare has, in fact, just begun. Healthcare organizations do expect that RFID can help save costs and improve patient safety, and limited but increasing numbers of hospitals are testing RFID, but most, if not all, of the few projects that we see are on a small scale. Many of them started with tracking and managing equipment. For example, Richmond, Va.'s Bon Secours hospitals tagged their 12,000 pieces of mobile medical equipment — from wheelchairs to portable heart monitors — in 2004[16]. Few hospitals are conducting trials on tagging patients, staff and equipment in particular rooms or areas. In October 2004 the emergency department of the Washington Hospital Center in Washington, D.C. deployed an RFID system with 20 readers and around 100 tags. This system was expected to allow tracking the status and exact location of patients, staff and essential equipment [10]. A decision by officials of the US Food and Drug Administration (FDA) announced in February 2004 may allow nearly the entire pharmaceutical supply chain to use RFID by the end of 2007 [8, 33].This may boost the adoption of RFID in hospitals.

Although tagging objects, such as medical equipment, drugs, etc., is a potential area for RFID in hospitals, the tagging of patients involves both more value and more challenges. Janz et al. [18] studied an RFID application at a Level-1 trauma unit in the emergency department of a hospital and found that data collected from tagged patients helped improve medical processes, decision making, and resource management. Equipment tagging may be easier in that experience from manufacturing and retail is already available. Tagging people is more challenging because it involves patients, physicians, medical know-how and practices, and organizational issues.

3. Methodology

Since the application of RFID to medical services is at the emerging stage, it is appropriate to adopt an exploratory case study approach [35]. For our study, data collection involved establishing a case study database consisting of archival records, including the project proposal, final reports, meeting minutes and other relevant materials. Interviews were conducted with major TMUH participants in the project, including one of the top managers of the hospital, the project manager, senior management information systems (MIS) staff and the CEO of a cooperating firm, Lion Information Inc. We developed open-ended questions focusing on the development and the implementation process of the project. The interviews were recorded and transcribed. We also visited the sites where RFID devices were installed, and took notes during and after the interviews and visit.

4. The Case: the Location-based Medicare Service (LBMS) project

4.1 Background of the Hospital

The Taipei Medical University Hospital was established in August 1967 for patient-care, clinical teaching and medical research in Taipei, Taiwan. In 2000, TMUH was accredited as a grade-A regional teaching hospital and today is one of the most renowned hospitals in the country. The hospital currently has 416 beds, and will have 700 beds in total in the near future. The hospital employs 660 persons, including physicians, interns, nurses, pharmacists, and medical technologists.

TMUH has been aggressive in adopting IT to improve its medical services. One of its five vice superintendents is exclusively in charge of information systems. Most of the personnel in the MIS department are experienced and skillful; their major task is to develop advanced applications for knowledge extraction to support medical practice and research. The hospital has an integrated healthcare information system that complies with HL7 (Health Level 7) and DICOM (Digital Imaging and Communications in Medicine) standards. This system consists of a laboratory information system (LIS), a radiology information system (RIS), and a hospital information system (HIS). Most of the patient medical records are digitalized.

4.2 The Location-based Medicare Service project

On 12 March 2003, the World Health Organization (WHO) issued a global alert on atypical pneumonia, called severe acute respiratory syndrome (SARS). SARS is highly infectious, and quickly challenged the effectiveness of infection control measures in hospitals. Some hospitals in Taiwan closed for weeks in an effort to contain the further spread of in-hospital infectious cases. As it happens, the contact history of the SARS-infected patients is essential to identifying and tracing other possibly-infected individuals. It takes time and effort to construct the history of a patient's contacts with others, but the powerful, automatic identification and tracking capabilities of RFID seemed full of potential to greatly help with this task. In May 2003, two Singaporean hospitals, the Alexandra Hospital and National University Hospital, first implemented an RFID system — the Hospital Movement Tracking System — in their Accident and Emergency Department, thus tracking visitors, patients and staff [3]. Inspired by the two Singaporean hospitals' initiative, TMUH started to consider a similar plan.

In August 2003 the Taiwan Department of Industrial Technology (DoIT), Ministry of Economic Affairs (MOEA), prepared a subsidy plan to encourage domestic firms and institutes to research and develop technologies to detect, contain and cure SARS. Funds were appropriated for hospitals to apply for exclusively. TMUH proposed a one-year plan to develop the Location-based Medicare Service (LBMS) system, a hospital-wide RFID-based system. The Government approved the plan and granted the hospital about US$475,000, or about 49% of the project's estimated cost. The goal of the LBMS system was to enable the real time identification and tracing of tagged person(s) and object(s) inside and outside the hospital.

The project was neither an experiment nor a pilot test; the intent was to build a workable hospital-wide system. In essence it was an application development, as well as an implementation project. It required expertise and knowledge from different domains including medicine, RFID technology, information systems development, telecommunications, and systems integration. A survey of the domestic and foreign market established that there was no similar project anywhere in the world, and no vendor or consulting firm capable alone of building such a system. The hospital decided to adopt a collaborative strategy. Three parties were to be involved: TMUH, Lion Information Inc., and an advisory group. Lion Information was a new firm operating in the University's Innovation Incubation Center and specializing in system development and integration; this project was its starting point. The advisory group consisted of professors from renowned universities with backgrounds in electronic engineering, experts from a famous information research institute in Taiwan and other professionals from relevant fields. The three parties played different roles in the project. TMUH specified the relevant medical processes and requirements based on its medical expertise; it also arranged for installation and system testing. Lion Information was responsible for platform development, RFID technology sourcing and acquisition, and system integration. The firm acquired technology from research institutes and technology venders, collaborating with one university to develop new technologies and solutions, especially in telecommunications integration. The advisory group acted as a think tank. The three parties gathered regularly, almost every week, to review progress and to discuss problems encountered. This strategy worked well and contributed notably to the success of the project.

As seen in most projects, the hospital also set up a project team led by the superintendent of the hospital and consisting of representatives from different departments and offices, including the Development Planning Office, Office of Medical Affairs, Emergency Department, Department of Internal Medicine, Department of Surgery, Department of Anesthesiology, and Department of Psychiatry. The hospital established a project office and placed it in charge of administrative affairs.

The project had a clear objective, namely to build a system that could detect and track (potential) SARS cases. This objective determined the orientation and major design of the system, including what data was to be collected; who and what were to bear the tags; how often data was to be transmitted and processed; and most importantly, what value and benefits were to be generated. Medical knowledge and practice was the basis and core for developing the system. RFID was to be considered a tool

to support medical practice; the system should reflect such assumptions. It was a demand-pull, rather supply-push project.

After studying the process of handling SARS-infection cases and suspected cases, the hospital decided that the system should have active real-time position-tracking as well as temperature taking abilities and monitoring abilities for tagged patients. After reviewing several types of tags, TMUH chose 916.5 MHz UHF active tags. This active tag was much more expensive than passive ones, but had a longer reading range and better reading speed, enabling it to better continuously monitor tagged persons and objects. The hospital decided that tags for SARS patients should be embedded with a thermometer. Through automatic temperature taking and transmission, the system could thus collect real-time data and reduce the risk of staff infections due to periodic contact with patients. However, no such tag was available at the time, so a RFID vendor was asked to build one. In the event, due to the unexpected difficulty of developing such a tag, the devices were delivered almost two weeks behind schedule. This delay forced individuals to work overtime to meet the project deadline. For use with objects such as infected waste or clothing for which location data alone was enough, the hospital also acquired other 916.5 MHz UHF active tags lacking the thermometer-design. As for the readers, they had to be designed for fast and easy system integration without loss of performance, functionality, or security. The reader used in the project contained important features including the following: 10 megabits of memory, multi-tag read capability allowing the 916.5 MHz operating frequency from tags, a 433 MHz wakeup frequency to tags, and a 3 to 85 meters tag read range. Because readers are expensive, in certain places some field generators were used instead. A field generator is a small, efficient tag wake-up device that communicates directly with the reader. It periodically turns on and calls tags for a specified time, then turns off for a specified time; it can be turned on by a motion sensor as soon as movement is detected; or the user can call a specific tag ID, tag type, or all tags at any time. The cost of a field generator is much less than that of a reader. In order to increase the position accuracy, the field generators deployed in this project were divided into three types: normal generator, floor generator, and area generator. Floor generators were installed within staircase areas and area generators were installed in the interfaces of adjacent areas. The detection range of floor and area generators had to be controlled for shorter distances, and the detection intervals had to be as short as possible to ensure that the movement of every tagged person or object from one area or floor to another was sensed.

After much testing and adjusting, a hospital-wide RFID infrastructure (as depicted in Figure 1) was completed, including 163 field generators, 41 RFID readers, 27 Yagi antennas, 15 programming stations (SW) and one system API (SW). The architecture of the LBMS system was also developed as depicted in Figure 2. This architecture shows how data was collected, processed, stored and transformed into useful information for medical services in the hospital.

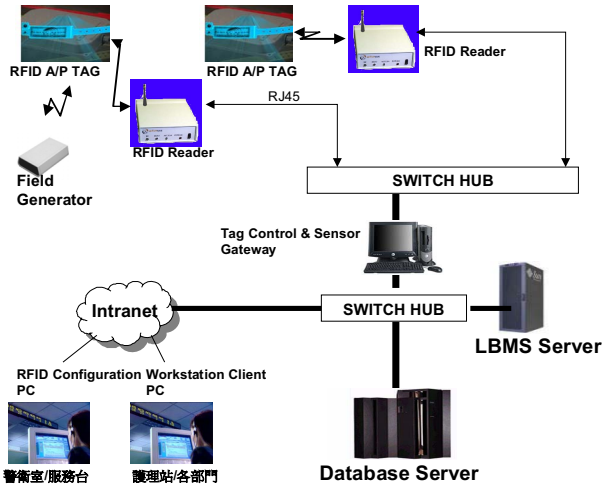

Figure 1. The RFID infrastructure of Taipei Medical University Hospital (Source: [12])

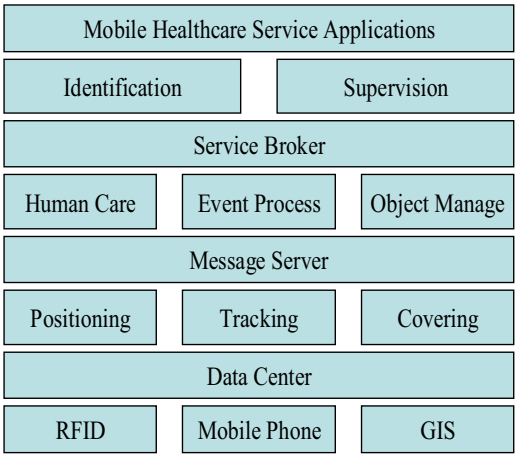

Figure 2. LBMS system architecture (source: [12])

There were different modules in the system, including ones for tag control and sensor gateway (RFID C-API, JNI wrapper, signal dispatcher, signal filter), medical monitoring (medical data transfer, inference engine), and application (message service, map service, tracing services).

Data was filtered according to pre-set rules before it was transmitted, and stored in the positioning database and vital information databases, respectively. The system automatically retrieved patient medical records from healthcare information systems and ran an inference engine (named Rulebase) to judge whether there was an

infectious event. The LBMS system had a graphic user interface (GUI) design and adopted the web-service approach. When the system detected an infectious event, a message to that effect was dispatched immediately to relevant personnel via alarm, email and short message services (SMS). The interaction of the LBMS modules is depicted in Figure 3. The system could also help enforce community quarantines outside the hospital through readers connected with telecommunication networks in the quarantined area.

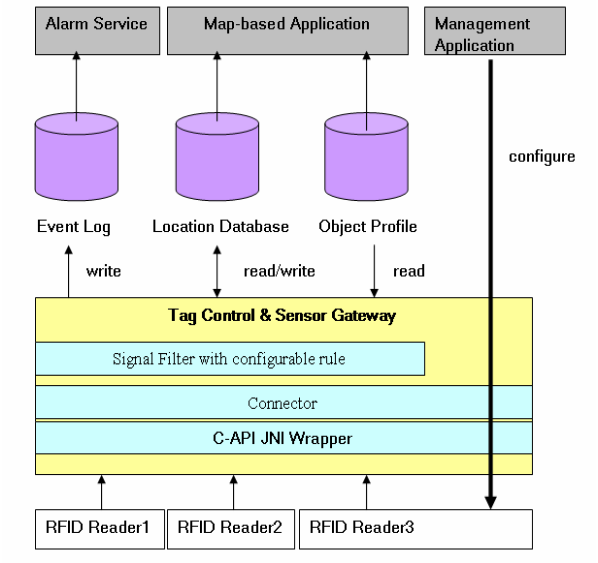

Figure 3. LBMS modules (source: [12])

The hospital's management was very satisfied with the system and is now planning to develop other medical applications based on the LBMS system, such as precious equipment tracing, in-patient medicine auditing, new-born baby and mother identification, legitimate drug control, etc. These developments are expected to be completed in early 2006.

5. Findings and discussion

We find several important issues arising from this case, including issues involving development strategy, device management, data management, and value generation. We discuss them sequentially as follows.

5.1 Development strategy

Introducing an emerging technology into any organization is challenging, not to mention introducing it into a hospital. Medical institutions impose a form of professional bureaucracy, i.e. a medical staff acting with a considerable level of autonomy. Qualified technology vendors and consulting firms may help, but the limited number of successful RFID business cases [7] bears witness to the difficulty. RFID is an IT artifact, but it is not appropriate to relegate an RFID project either to an IT department or a business unit. Rush [26], based on his experience, asserts that people from IT development and business units should work together but focus on different responsibilities, e.g., one on building infrastructure and the other on driving applications. A team effort is called for, and establishing a mechanism that can really involve different kinds of expertise and generate synergies is necessary. The LBMS project was brand-new, without precedent. Furthermore, as a demonstration project, it was expected to exhibit innovativeness and applicability. To achieve the objectives, TMUH used a collaborative strategy aimed at bringing together TMUH, industry, and academia to work closely as partners. Division of labor among the three parties was clear; each focused on its field of specialization. Each party, too, had strong incentives for devotion to the project: the hospital was eager to find a powerful solution to contain SARS and improve its medical services via RFID within a year. Lion Information Inc. was intent on succeeding as a new business, and naturally was trying its best. Members of the advisory group, especially the professors, were interested in the emerging technology and mindful of making academic contributions, mostly algorithms, to help solve advanced technological problems. The coordinating instruments—regular meetings and capable project coordinators—were successful in fostering partner relationships.

Resistance from medical staff, especially physicians, has been mentioned as a major inhibitor for hospitals trying to implement IT (e.g. [6, 31]). The hospital involved relevant medical staff in the project. Although top management strongly supported this project, the opinions from medical staff were especially valued because medical staff have decisive power over decisions to adopt RFID in their medical processes. This is the peculiar and important characteristic of hospitals and should be taken into consideration in the first place when implementing IT in a hospital. This experience, respecting domain knowledge in application areas, is also applicable in industry.

5.2 Device management

The basic purposes of RFID are data collection and transmission. Incomplete or unreliable reads cause problems in subsequent data processing and the generation of information for decision making. The purpose of device management is to collect and transmit reads that are as complete and clean as possible. Since RFID uses radio waves and is tagged to the moveable person or object, it inevitably is affected by its physical environment and the person(s) or object(s) tagged. The following issues or factors may affect the quality of reads and need to be taken into account: what or who are to be tagged (that is, what are the characteristics and behavior of tag-bearers), what data is to be collected, how often must tags and readers

collect and transmit data and how often does that data need to be considered, what is the physical environment/layout, what are the possible movements of tagged person(s) or object(s), what are the functionalities of RFID hardware (readers, tags and field generators), and what should be the tradeoff or balance between accuracy requirements and money invested (that is, more readers, i.e. more investment, can produce more accurate data, but more readers cost more.)

In hospitals, many pieces of medical equipment make use of radio waves. Should any interference occur, the lives of patients could be endangered. RFID uses radio waves and, although in the range of its operating frequency is restricted to free ISM (industrial, scientific, medical) bands, these frequencies too can be a source of interference and can interfere with RFID devices [32]. Thus, frequency spectrum management is especially important [3].

Also in a hospital there are many compartments, rooms and partitions, with many walls and doors. These may affect the service range of RFID devices because building layouts and materials can interfere with radio waves. One informant said that the listed range of the devices often cannot be achieved in the field, and the actual covering range should be measured one by one in the real settings to determine the portfolio and locations of readers and field generators. Balance between accuracy requirements and investment costs is another concern. In this project, in order to have more accurate reads over moving patients and objects, the hospital chose an active RFID solution that is much more expensive than passive ones. A survey conducted by Spyglass Consulting Group in 2005 [5] reports that healthcare organizations in the UK prefer active RFID solutions. This implies that cost is not so influential in the decision-making of RFID adoption for healthcare organizations. However, TMUH still substituted less-expensive field generators for some readers without lowering their requirement of accuracy. The configurations of different types of field generators—normal, floor, or area—were different based on their designated role in different locations.

The design of the tag must consider the characteristics and behavior of tagged persons or objects. In our case, the possibility of the patient's tearing off his or her RFID wristband or hospital employees taking away the tag from waste bags were considered, and an alarm design was added to signal when the wristband is torn off or the tag is removed without permission. As our study found, the design and deployment of RFID devices are highly environment and context dependent, and should be adjusted and tuned to fit real situations.

5.3 Data management

We also explored RFID data management as a critical issue [2, 24], finding two major challenges: intermittent and unreliable reads, and high-volume data generated in a very short time [27]. Good device management can reduce intermittent and unreliable reads, but it is neither possible nor necessary to eliminate problems completely for two reasons—technological constraints (e.g. radio waves are easily interfered with) and cost/benefit considerations. The seriousness of the problems is only a matter of degree. In addition to the device management approach, software solutions, i.e. developing algorithms to compensate for missing or incomplete reads, was used in this project and worked well. The algorithms were developed from the concept of cellular phone positioning. The location and the path of the moving tagged person or object can be calculated, based on the signal strength of the moving tag sensed by different readers and the reads from correlated landmark tags, even when some reads are missing.

As for handling high volume data, in the beginning this was not considered an issue worthy of attention because it was felt that the new dedicated database would be large enough. However, within minutes of the system starting to work, the amounts of data received and stored became so huge that the system had to be shut down to avoid damage. Several meetings were held in a bid to solve the problem. Finally, a solution was implemented: rules were set for data filtering and transmitting. These rules were based on the kinds of data to be collected—that is to say the location of the data and other information relevant to information management and medical processes. Except when time thresholds for data transmission were basic and simple, only data meeting certain criteria were allowed to be transmitted and processed. For example, under the new rules, only if a change in the body temperature of the tagged patient exceeded a preset degree, e.g. 0.5 degrees Celsius, would the data be transmitted from reader to database for further tracking; otherwise no transmission would occur. Rules were also set to regulate data transmission between different devices or systems, e.g. between tags and readers, between field generators and readers, between readers and databases, and between databases and event detection systems. Rules were also introduced to decide whether data should be stored or not. In addition, TMUH developed middleware to link the LBMS system and healthcare information system for integration purposes. In general, we found that data management in hospitals, if tied to medical knowledge and practices, can substantially reduce the volume of data to be handled, while generating meaningful information for decision making.

5.4 Value generation

Of what value is RFID? How do we evaluate the return on an investment in RFID technology? These questions are often seen in IT investment decisions, but the answers are neither simple nor conclusive because of different environmental, managerial and organizational issues in different organizations, and lack of a clear causal relationship between IT and business performance (e.g.

[9]). In addition, the nature of the IT recognized by the focal organization is also critical. Some investments are made in IT infrastructure; some are made for applications. The two different types of investment generate different values across different time scales. IT infrastructure provides shared and long-term organizational IT resources that constitute a foundation for present and future business applications [13]. The benefits of IT infrastructure investments are indirect and long-term [25]. In contrast, applications generate direct and immediate value. However, many applications need to be based on an appropriate infrastructure.

Whether an RFID investment is a part of an organizational IT infrastructure or just another application affects how RFID is evaluated and its potential value to organizations. Rush [26] strongly asserts that RFID is essentially an infrastructure technology because it allows companies to capture data about objects and individuals moving in the real world. He argues that for RFID, the return on investment (ROI) is found in the applications, not the infrastructure. Infrastructure collects, transmits and stores data; while applications, derived from business needs, leverage these data to generate value.

In our case, although the hospital invested in RFID to contain SARS, seemingly an RFID application, in fact, an RFID infrastructure was built. Devices were deployed hospital wide; RFID networks and systems were integrated with existing hospital information systems; a platform was developed to synthesize data collected from RFID and other sources such as patient medical records. The excellent SARS containment capability that was developed derived from the infrastructure. Furthermore, it was the infrastructure that enabled the hospital optimistically to announce several new RFID application development projects the following year.

The hospital, because of its past aggressiveness in investing in IT to improve efficiency and medical services and its excellent IT capability, was able to recognize the huge potential value of RFID. Further encouraged by Government policies and the Government's subsidy, the hospital was willing to make infrastructure investments through applications even though the projected ROI was not clear. In contrast to TMUH, most other hospitals conducting RFID projects have focused on single, or only a few, applications in certain department(s) or areas. This has been normal because RFID in hospitals is still in an emerging stage, because knowledge about the technology and its applicability in the medical domain is still limited, because few or no successful business cases can be consulted, and because ROIs are so doubtful. Nevertheless, if the value of RFID is to be reaped in the future, it must be kept in mind that RFID is a part of IT infrastructure, not simply another application.

RFID is not a silver bullet. Melville et al. [20] assert that the value of an IT investment is realized through the business process. Changes are needed to incorporate IT in that process. Rappold [24] argues that organizations have to think carefully how to change their business processes to reap the benefits of RFID. In our case, RFID substitutes for some manpower in periodical temperature taking and location data collecting. The system, based on the preset rules and the data, is able to detect events, such as fever cases and breaking into restricted areas, and to inform competent persons of events automatically. Through such continuous monitoring, patients can benefit from better care and therefore improved safety. Efficiency and effectiveness are both achieved. At TMUH, relevant medical processes were changed to incorporate RFID. The medical staff in charge of infectious control no longer needs periodically to take the temperature of infected or possibly infected patients. Infection control has shifted from nurses in each ward to a central unit. As a consequence, fewer hospital personnel are needed. In another benefit, the risk of infection has been reduced for staff. Nurses and physicians highly appreciate this benefit, as does the management of TMUH. Perceiving the usefulness of RFID, some medical professionals from other departments are starting to ask for RFID experimentation in fields including precious equipment tracking, in-patient medicine auditing, in-hospital monitoring of psychotics, newborn and mother identification, and legitimate drug control. Professional staff in a hospital exert high hegemony and autonomy in their medical specializations, and only as they learn of the possible relevance and usefulness of RFID can the applications of RFID accelerate and therefore generate more value [11]. In addition, RFID applications must consider the characteristics of the culture of the organization. In this case, TMUH is not likely to tag their physicians and staff except for specific situations, e.g. infectious control, because it considers physicians and staff to have a right to privacy.

As mentioned above, not all benefits are tangible and can be estimated or expressed in monetary figures. An informant said that although RFID can improve efficiency, the main objectives are to reduce medical errors and improve patient safety. Medical errors are very extensive and expensive nowadays [28], and preventing them not only improves patient safety, but also reduces the risk of the hospital, physicians, nurses and other staff being exposed to lawsuits. This precious value may further encourage hospitals and hospital staff to adopt RFID.

To provide a concise picture of our findings and their possible impacts in the hospital setting and in a broader context of RFID implementation, we summarize the key lessons and their impacts in Table 1.

Table 1. Lessons and their possible impacts

Lessons	Impact in the hospital setting	Impact in a broader context of RFID implementation
- Consider RFID as a part of IT infrastructure	- Rely on internal RFID infrastructure readiness. - Self-directed need-driven applications.	- Rely on the external environment's readiness of RFID infrastructure. - External demand-driven/ mandatory applications.
- Use Team approach for RFID implementation	- Form an effective project team involving members from the vendor, hospital's medical staff and IT unit and consultants. - Foster partnership relationships. - Good project management	- Form an effective project team involving members from the vendor, the organization's business and IT unit and consultants. - Negotiate & collaborate among the value system. - Good project management
- Device management is highly environment and context dependent.	- Active RFID solution is more appropriate for hospitals. - Frequency spectrum management is vital. - Combination of tag with sensor provides better care for patients. - Cost is not the major factor.	- The type of RFID solution depends on the whole value system. - Cost is the major factors, especially the cost of tags.
- Data management needs to be combined with business practice and knowledge.	- Use of data is clearly defined by applications.	- Use of data is not so clear and still depends on creative thinking.
- Change is needed.	- Carefully review and redesign the internal process and the organization. - Motivating medical staff is important.	- The change of the whole value system is vital.
- Value appropriation	- Beneficial to patients, medical staff and the hospital.	- Depends on the bargaining power & creative applications among the participants of the value system.

6. CONCLUSIONS

RFID in healthcare, although in its infancy, may have great potential to reduce operating costs and improve medical services and patient safety. The experience of manufacturers and retail marketers in implementing RFID can be consulted, but it cannot be transferred to hospitals without modification. The success of an RFID project depends on its strategy, the implementation process, the characteristics of the technology, the organizational context, and the stakeholders, who certainly include physicians and nurses. The value of a new technology is rooted in business, not in the technology itself. Our case shows how RFID was deployed to meet the needs and practice of medical services in one hospital. A collaborative development strategy can successfully create synergies such as those achieved among TMUH, Lion Information Inc., and the advisory group. The involvement and participation of medical staff is also critical. The success of RFID in hospitals requires a team effort.

We learn from this case that RFID does have the potential to contribute to operating efficiency, good medical service and patient safety. Benefits and value derive from the infrastructure. RFID should be considered as a part of IT infrastructure, and the value of RFID is delivered through its applications in business. RFID as infrastructure provides a real option for the hospital. Device and data management are critical in building the infrastructure and the applications. In addition to the technology itself, the physical environment, the interference with radio waves, business practices, domain knowledge, the behavioral side of the persons to be tagged,

the movement of tagged objects and people, cost/benefit considerations, etc., all need to be considered.

RFID may have the potential to revolutionize hospital medical practices, but it cannot deliver value to a hospital by itself automatically. Hospitals have to think how RFID might help, and what forms of it might help, before making any decision about it. Perhaps the value of RFID might not be clear; a launch-and-learn approach might then be best. RFID requires some changes in the organization if the organization is to cope with it; and it causes changes in the organization and process. Hospitals must be prepared to accept such change. A hospital may find itself completely different after adopting the technology. There are privacy issues associated with RFID as well, although they are not discussed in this study because, under Taiwan's Communicable Disease Control Act, SARS patients and suspected SARS patients must accept mandatory isolation care by competent authorities.

Although our findings are derived from a single hospital case, they are of significant value for other hospitals. However, several important issues remain to be studied to better understand RFID in hospitals. Possible research questions include: what factors affect a hospital's decision to adopt RFID? What factors facilitate or inhibit adoption of RFID within the hospital, especially managerial and organizational factors? How do patients react to RFID? What is the diffusion path of RFID among hospitals? How does RFID influence the structure of the hospital and medical services? Does RFID change relationships among the hospital, patients and medical staff, and if so, how? How does medical staff react to RFID, and are there any differences in the reactions of various departments? What factors cause the differences? How does RFID affect decision making behavior and what is its influence on decision quality and business performance?

7. References

[1] Aarts, J., Doorewaard, H., and Berg, M., "Understanding implementation: the case of a computerized physician order entry system in a large Dutch university medical center," *Journal of the American Medical Informatics Association*, vol. 11, no. 3, 2004, pp. 207-216.

[2] Angeles, R., "RFID Technology: supply-chain applications and implementations issues," *Information Systems Management*, vol. 22, no. 1, 2005, pp. 51-65.

[3] Anonymous, Singapore Fights SARS with RFID, in RFID Journal. June 4, 2003,

[4] Anonymous, RFID in the hospital, in RFID Gazette. July 15, 2004,

[5] Anonymous, Spyglass Consulting finds weak ROI for passive RFID solutions in healthcare. 2005, Spyglass Consulting Group:

[6] Ash, J.S., Gorman, P.N., Lavelle, M., Payne, T.H., Massaro, T.A., Frantz, G.L., and Lyman, J.L., "A cross-site qualitative study of physician order entry," *Journal of the American Medical Informatics Association* vol. 10, no. 2, 2003, pp. 188-200.

[7] Bacheldor, B., RFID pain now, rewards to come, in InformationWeek. March 28, 2005,

[8] Brewin, B., RFID gets FDA push. November 15, 2004, FCW.COM:

[9] Chan, Y.E., "IT value: the great divide between qualitative and quantitative and individual and organizational measures," *Journal of Management Information Systems*, vol. 16, no. 4, 2000, pp. 167-208.

[10] Collins, J., Hospital Gets Ultra-Wideband RFID, in RFID Journal. August 19, 2004.

[11] Davis, F.D., "User acceptance of information technology: system characteristics, user perceptions and behavioral impacts," *International Journal of Man-Machine Studies*, vol. 38, no. 3, 1993, pp. 475 - 487

[12] DoIT, *Final Report of Location-Based Medicare Applications*, Department of Industrial Technology, Ministry of Economic affairs, ROC, 2004.

[13] Duncan, N.B., "Capturing flexibility of information technology infrastructure: a study of resource characteristics and their measure," *Journal of Management Information Systems*, vol. 12, no. 2, 1995, pp. 37-57.

[14] Ericson, J., RFID for Hospital Care, in Line 56, the E-Business Executive Daily. July 23, 2004,

[15] Fanberg, H., "The RFID Revolution," *Marketing Health Services*, vol. 24, no. 3, 2004, pp. 43-44.

[16] Glabman, M., Room for Tracking RFID, in Materials Management Magazine. 2004 Health Forum, Inc.:

[17] Hersh, W., "Editorials: Health care information technology progress and barriers," *Journal of American Medical Association (JAMA)*, vol. 292, no. 18, 2004, pp. 2273-2274.

[18] Janz, B.D., Pitts, M.G., and Otondo, R.F., "Information systems and health care II: Back to the future with RFID: lessons learned - some old, some new," *Comunication of the Association for Information Systems*, vol. 15, 2005, pp. 132-148.

[19] Karkkainen, M., "Increasing efficiency in the supply chain for short shelf life goods using RFID tagging," *International Journal of Retail & Distribution Management.*, vol. 31, no. 10, 2003, pp. 529-536.

[20] Melville, N., Kraemer, K., and Gurbaxani, V., "Review: Information technology and organizational performance: an integrative model of IT business value," *MIS Quarterly*, vol. 28, no. 2, 2004, pp. 283-322.

[21] Murphey, M.F. and Kay, J.D.S., "Patient identification: problems and potential solutions," *Vox Sanguinis*, vol. 87, no. s2, 2004, pp. s197-s202.

[22] Pare, G., "Implementing clinical information systems: a multiple-case study within a US hospital," *Health Services Management Research*, vol. 15, no. 2, 2002, pp. 71-92.

[23] Quaadgras, A., "Who joins the platform? The case of the RFID business ecosystem," in *Proceedings of 38th Hawaii International Conference on System Sciences*, Hawaii, USA, 2005.

[24] Rappold, J., "The risks of RFID," *Industrial Engineer*, vol. 35, no. 11, 2003, pp. 37-38.

[25] Renkema, T.J.W., *The IT Value Quest: How to Capture the Business Value of IT-Based Infrastructure*, New York, NY: John Wiley and Sons, 2000.

[26] Rush, T., Think Infrastructure, in RFID Journal. August 1, 2005,

[27] Sarma, S.E., "Integrating RFID," *ACM Queue*, vol. 2, no. 7, 2004, pp. 50-57.

[28] Sensmeier, J., "Transform workflow through selective implementation," *Nursing Management*, vol. 35, no. 12, 2004, pp. 46-51.

[29] Smaros, J. and Holmstrom, J., "Viewpoint: reaching the consumer through grocery VMI," *International Journal of Retail & Distribution Management.*, vol. 28, no. 2, 2000, pp. 55-61.
[30] Southon, F.C.G., Sauer, C., and Dampney, C.N.G.K., "Information Technology in complex health services: organizational impediments to successful technology transfer and diffusion," *Journal of the Americam Medical Informatics Association*, vol. 4, no. 2, 1997, pp. 114-124.
[31] Spil, T.A.M., Schuring, R.W., and Michel-Verkerke, M.B., "Electronic prescription system: do the professionals USE IT?," *International Journal of Healthcare Technology Management*, vol. 6, no. 1, 2004, pp. 32-55.
[32] Srivastava, B., "Radio frequency ID technology: The next revolution in SCM " *Business Horizons* vol. 47, no. 6, 2004, pp. 60-68.
[33] Thompson, C.A., "Radio frequency tags for identifying legitimate drug products discussed by tech industry," *American Journal of Health-System Pharmacy*, vol. 16, no. 14, 2004, pp. 1430-1431.
[34] Yang, G. and Jarvenpaa, S.L., "Trust and radio frequency identification (RFID) adoption within an alliance," in *Proceedings of 38th Hawaii International Conference on System Sciences*, Hawaii, USA, 2005.
[35] Yin, R.K., *Case study research: design and methods*, 3rd ed., Thousand Oaks, California: Sage Publication, Inc., 2003.