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Eric WT Ngai
Hong Kong Polytechnic University, mswtngai@polyu.edu.hk

F FC Suk
Hong Kong Polytechnic University, msfred@polyu.edu.hk

C C. Ng
Hong Kong Polytechnic University

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Ngai, E. W. T., Department of Management and Marketing , The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, PR China, mswtngai@polyu.edu.hk

Suk, F, F. C., Department of Management and Marketing , The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, PR China, msfred@polyu.edu.hk

Ng, C. C., Department of Management and Marketing , The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, PR China.

Abstract

This study is a design science research which describes the design of a radio frequency identification (RFID) based Healthcare Management System (RHMS) for the healthcare industry. In this study, a prototype RHMS has been designed and developed. The evaluations results validate the practical viability of the proposed architecture. We have described an Information System Design Theory for the RHMS which can form a basis for further research. We hope that the lessons learned from this study help support and further the efforts of academicians, researchers and practitioners in RFID based healthcare management system research.

Keywords: Radio frequency identification (RFID), healthcare management system, information system design theory

1 INTRODUCTION

A radio frequency identification (RFID) is a recent innovative technology that is considered to be the next wave of the IT revolution (Tzeng et al. 2007). The emergence of RFID has been drastically affecting a number of industries (Curtin et al. 2007). It has been adopted in industries like logistics (Ngai et al. 2007a, Ngai et al. 2007b), manufacturing (Swedberg 2006), food safety management (McMeekin et al. 2006; Kelepouris et al. 2007), and transportation (Caputo et al. 2003). There are, however, relatively few academic publications related to the application of RFID in the healthcare. Thus, in this study, we leverage the potential of RFID as a key enabler to examine how it can help the delivery of higher business benefits and the provision of effective support for the transformation of health practices in the healthcare domain.

The development of an information systems design theory (ISDT) for a RFID-based Healthcare Management System (RHMS) is important due to the limited nature of theoretical guidance for the design and development of RHMS in the healthcare industry. In this research, we propose architecture for the development of an RHMS which help in strengthening patient and use of medication safety, improving pharmaceutical inventory operations and controls, enhancing patients' identification and their in-hospital location tracking processes for the healthcare sector. The system architecture is generic in that it is relevant to a spectrum of different operating environments. The second phase of this research details the development of a prototype termed RHMS, under the design science in IS research guidelines. The prototype is an instantiation of the architecture and is tailored for healthcare application. ISDT provides guidance to developers and sets an agenda for academic research (Markus et al. 2002). An empirical evaluation through an implementation of RHMS in a quasi-real world setting validates directly the prototype and in the process the key architectural features that address user flexibility and system dynamics.

The rest of the paper is organized as follows. In the next section, we present a brief literature review on RFID study in the healthcare industry. Then, we describe our design and development of an RHMS prototype using an ISDT approach. Finally, concluding remarks of the study are made and a research agenda is proposed.

2 PAST LITERATURE ON RFID STUDY IN THE HEALTHCARE INDUSTRY

RFID is an exciting area for research due to its relative novelty and exploding growth (Ngai, et al. 2008). This technology allows the wireless storage and automatic retrieval of data and provides a significant improvement on identification, tracking, and stocking of objects as compared to barcode technology. However, there are limited published articles related to RFID study in the health care industry. A briefly reviews of literature are provided as follows:

Østbye et al. (2003) evaluated an infrared/RFID equipment-tracking system in a tertiary care hospital to determine whether it can increase equipment utilization, increase appropriate charge capture, and decrease personnel time spent looking for equipment. With the system available, they observed increased utilization of infusion pumps but not of beds or sequential compression devices. Nursing staff and system users had positive impressions of the system and its potential. Tracking systems can successfully locate hospital equipment and may improve utilization.

Cavalleri et al. (2004) presented a prototype of using wearable RIFD device for automated staff and patient identification and tracking. They indicated that the RFID transponders (e.g. 13.56Mhz and 125Khz tags) were low-cost and ease of use, however, most of them were not feasible to be adopted for in-hospital patient identification as the reader station unit produced a significant amount of electromagnetic energy which were hardly compliant with European standards for health care

environments. Their prototype showed that its electromagnetic emissions were compliant with US and European standards. In addition, it also provided a long distance range of patients' tracking up to a few meters. Security features for the quality control of transmitted data and device authentication were also implemented.

Li et al. (2004) adopted RFID and mobile technology to implement a mobile healthcare service system for positioning and identifying persons and objects both for inside and outside hospital. The system demonstrated that patient's location and bio-information could be collected using RFID devices ubiquitously crossing geographic barriers. In particular, for the case of the sudden occurrence of any unknown epidemiology of disease like Severe Acute Respiratov Syndrome (SARS) in 2003, the system could effectively reduce the affected numbers of medical professionals and strengthen the infection control process among infectious patients.

Janz et al. (2005) showed an RFID application used by the emergency department of a hospital. They reported that data collected from tagged patients could improve medical processes, decision-making, and resource management. However, as compared to their experience from manufacturing and retail for using RFID technology, as in the healthcare environment, it involved patients, physicians, medical know-how and practices, and organizational issues, it was more challenging to develop the RFID-based application for the tagging people.

Fisher and Monahan (2008) indicated that many hospitals have begun to adopt RFID applications to track inventory, identify patients, and manage personnel. In particular, RFID innovation has been used to track medical equipment to minimize time of searching, verify patient identification to avoid medical error and collect data on workflow to find inefficiencies in current hospital operations. However, they found that hospital staff, especially nurses, expressed concern about the surveillance potential of these tracking technologies.

Although the prior literature showing some signs of research and advancement in the study of RFID in healthcare industry, there is lack of a design science research into design and development of RFID system in general, and RHMS, in particular. Good understanding of RFID system design and use is still in an emerging state both in practice and in academia as RFID is an emerging technology (Ngai, et al., 2007). The plug-in ready for use have not become commercially available. A more fundamental issue is the lack of theory to guide the design and development. Hence, there is a need to address this problem.

3 A FRAMEWORK FOR DESIGN AND DEVELOPMENT AN RHMS

Information Systems Design Theories (ISDTs), defined by Walls et al. (1992), are prescriptive theories which integrates normative and descriptive theories into design paths intended to produce more effective information systems. The nature of ISDTs is articulated using Dubin's concept of theory building and Simon's idea of a science of the artificial. For practitioners ISDTs are beneficial because they increase development reliability and the likelihood of success by providing principles and the range of effective development practices to a more manageable set (Markus, et al, 2002). Therefore, an ISDT provides theory-based guidance about how to design and support a particular type of information system, in this study, RHMS.

3.1 An Information Systems Design Theory for RFID-based Healthcare Management System

In this section, we present the ISDT for RHMS by describing each of the components as explicated by Walls et al. (1992) namely, kernel theories, meta-requirements, meta-design, design method and testable hypotheses.

3.1.1 Kernel Theories

The theory underlying an IS design theory (referred to as "kernel theory") may be an academic theory or a practitioner theory-in-use. Kernel theory enables formulation of empirically testable predictions relating the design theory to outcomes like system - requirement fit (Markus et al., 2002). Development of an ISDT for RHMS requires a kernel theory which provides a basis for dealing with system development. Prototyping as a system development methodology by putting together a working model i.e. a prototype in order to test various aspects of a design, illustrate ideas or features and gather early user feedback from the evaluation.

By building a prototype system, various issues arise and can be addressed. For instance, new concepts of user interface design can be evaluated. Prototypes can be used to clear up a variety of problems, learn about the concepts, framework, and design through the system building process. The developers gain insights into the application area and into the users' work tasks and the problems they face.

3.1.2 Meta-requirements

It describes a class of goals to which the theory applies (Walls et al., 1992). Herbst and Karagiannis (2000) indicated that business-process knowledge could typically be acquired by interviewing personnel in the relevant business domain. These interviews enabled us to understand the current processes and operations in the healthcare environments. They also provided significant insights for us to re-think some of the existing healthcare practices that can be beneficial after business process re-engineering. In this study, we focus on several RFID-enabled processes as follows:

- *Patient Identification Process*

Patients in the hospital are required to carry a RFID wristband which stores patient's personal data such as a registration ID, name, age, admission date, medical history, etc. Nurses can use the handheld RFID readers with antennas to read the patient wristbands to accurately examine their identities, medical histories, doctor-in-charges, current drug charts and usages, etc. In case of emergency, this piece of accurate patient information can help physicians and nurses make decision to give right and responsive medications to save patients' lives.

- *Patient Location Tracking Process*

Every patient is given an RFID wristband after admission. The wristband is an RFID tag. Patients' locations are tracked by constantly reading the tag information from their wristbands using the readers equipped with antennas which are placed at strategic locations inside the hospital. Even in a dimmed lighting environment, patients and those are waiting for treatments in a large ward can be located and identified in an effective manner.

- *Patient Medication and Monitoring Process*

To reduce medication dispensing and usage errors, drugs are tagged with RFID labels. Nurses can use the handheld RFID readers to read the labels to examine the medication details before dispensing to the patients. In addition, to improve the five "rights" of medication safety, patients' wristbands which contains the drug charts, medical history, last drug usage time, etc. can be retrieved by the readers and further verify the match medications to the patients. Having taken the drugs, the patients' next medication details and drug charts will be updated onto their tagged wristbands. Readers with antennas located inside the hospital ward will read regularly the patients' wristbands to monitor if they closely follow the instructions of drug charts to receive the proper medication treatment accordingly. This kind of proactive and automatic medication usage monitoring process can enhance medication

safety and ease nurses workload of manual monitoring. Privacy and security are intensively discussed issues. Proposed measures include the destruction or deactivation of tags or encryption of data.

- *Drug Inventory Management Process*

To improve the efficiency and accuracy of drug inventory, automatic processes on tracking the inventory level, expired and recall products are feasible for the drug products being tagged with RFID labels. When the drugs are moving in and out of the pharmacy dispensing room, their quantities stored inside their tags are retrieved by the RFID readers and updated their inventory levels into the system.

Having acquired knowledge of the business processes and learned the operational environment in the healthcare industry, we analyzed their business needs to define the specific, unambiguous, and testable requirements. After discussing the business requirements with the key stakeholders, we summarized their key functional requirements for a RHMS. These requirements are shown in Table 1.

Stakeholders	Requirements for a RHMS in a Hospital
Patients	• To provide high-quality caring services • To strengthen the five "rights" of medication safety
Physicians & Nurses	• To provide an accurate way for patients' identifications • To track precise patient locations throughout hospital • To provide an effective way to strengthen the five "rights" of medication safety • To enable an automatic process to monitor the usage of patients' medication • To facilitate electronically searching for drug details
Pharmacists	• To automate pharmaceutical inventory tracking • To facilitate locating and removing expiry and recall medication products from the inventory • To provide real-time reports of medication inventory level • To reduce inventory cost and out-of-stock risk • To enable responsive inventory replenishment
Medical Executives	• To eliminate unnecessary manual processes and operations • To strengthen controls to improve patient and medication safety • To automate daily operations to lessen the workload and pressure of hospital staff • To reduce inventory cost by optimizing their inventory levels
System Owner	• To provide user friendly interfaces • To provide accurate, ease of access and up-to-date information like drug details and patient locations • To design an infrastructure with high interoperability with existing legacy applications

Table 1 Requirements from key stakeholders

3.1.3 Meta-Design Features

In this section, we design an artifact - RHMS system architecture which is generic in that it permits a flexible modification. We embark on the discussion of the specific architectural components as follows:

Figure 1 shows an overview of the architectural framework of the system. It comprises five layers.

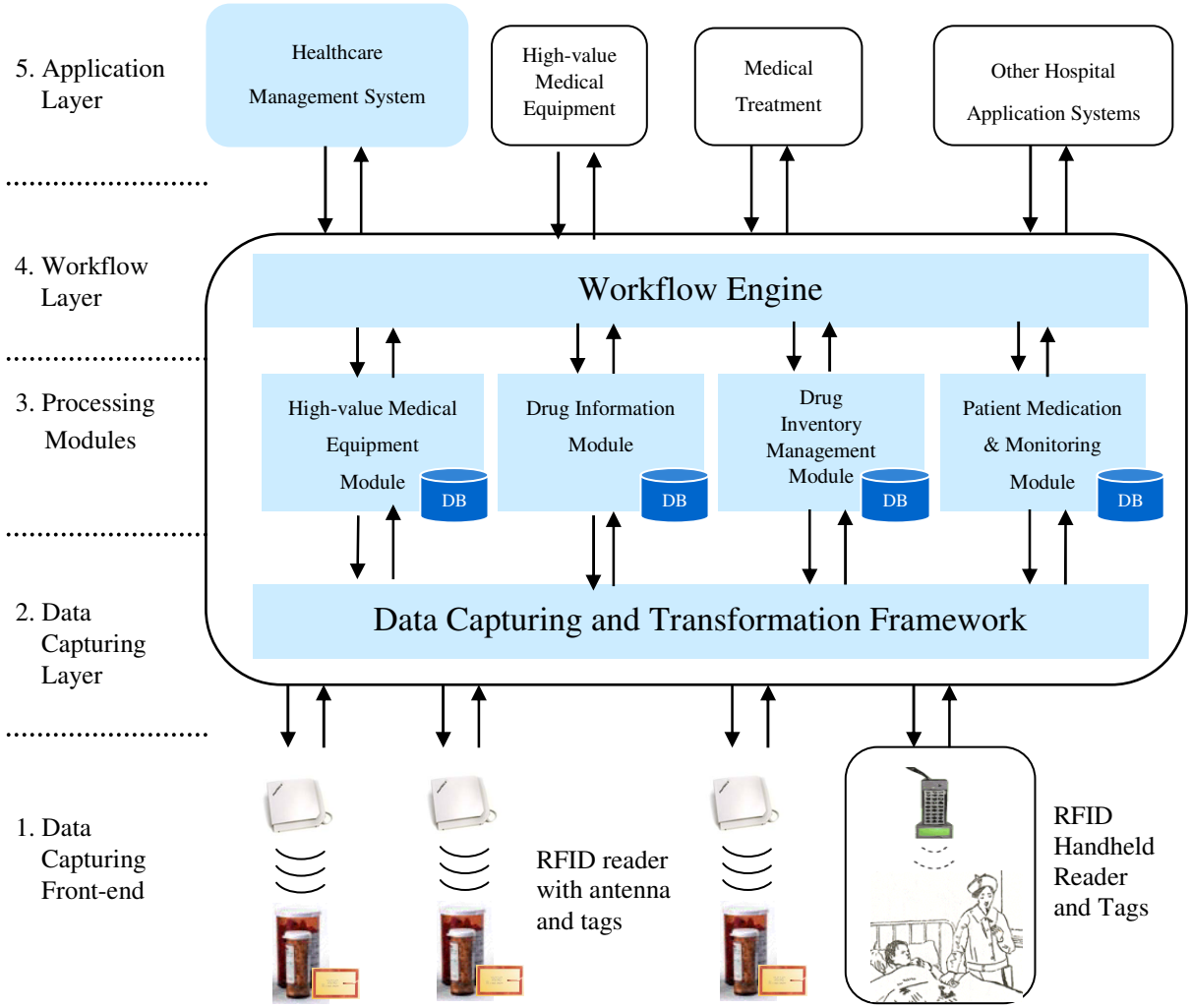

Figure. 1 *Architectural overview of the HMS system.*

- *Data-Capturing Front-End System*

The first layer provides the RFID data-capturing front-end system. It contains three components: transponders, readers, and antennas. When patients are admitted to a hospital, they are required to carry a wristband (a transponder card). Each patient wristband is embedded with an RFID tag which stores patient's basic data such as a registration ID, name, age, doctor-in-charge, admission date, etc. Nurses can use the handheld readers to read the patient wristbands to accurately identify and match the right medications to the patients. To improve pharmaceutical inventory management, each pharmaceutical product is affixed with an RFID tag, which contains the drug ID, name, expiry date, quantity, etc. This arrangement allows an automatic and real-time inventory level checking of the pharmaceutical products inside the pharmacy dispensing room.

- *Data-capturing Interface*

The RFID tag and the in-house hospital system share different data formats and standards, thus an interface is essential to enable communication between them. This interface converts the tag information into data that are readable in the system components in the upper levels, and vice versa.

- *Processing Modules*

The captured data are stored and managed by a set of relational databases. Specifically, four databases are designed for managing the patient information, drug information, drug inventory management, patient medication respectively. These data repositories provide the essential information to drive the workflow engine to run various applications. Data in the databases are extracted and updated by various applications in the upper levels.

- *Workflow Engine*

This layer is used to manage, coordinate, and integrate the processes and flows of data between processing modules and application layer. A middleware interface is built for the applications to retrieve and update data from/to the respective databases in the processing modules. The middleware has defined a set of business rules and logics that govern the proper flow of data stream processed by various application systems.

- *Application Layer*

Application layer provides a user-friendly graphical interface for the hospital staff to use the application functions. As the workflow engine has enabled a set of standard application program interfaces (API) which allow different applications and databases to communicate effectively with each other, a new application like HMS can thus integrate easily with the existing legacy systems, such as the human resources management system and medicine treatment system, to achieve higher application interoperability.

System architecture

System architecture development is the initial process of identifying the subsystems and establishing a framework among subsystem controls and communications (Sommerville 2007). The system architecture provides an encompassing and integrated environment for both logical design and physical implementation (Tung and Keim 1992). The mapping between the system and business processes is used to guide the application development and ensure integration takes place in the right way. It defines the functionalities of the components and describes how they communicate with each other.

An overview of the system architecture is shown in Figure 2. The figure depicts an RHMS consisting of several key components: (i) the RFID reader, (ii) terminals, (iii) application and database servers, (iv) patient wristband, and (v) tagged drug items. All of them are linked up through a wireless network (WLAN).

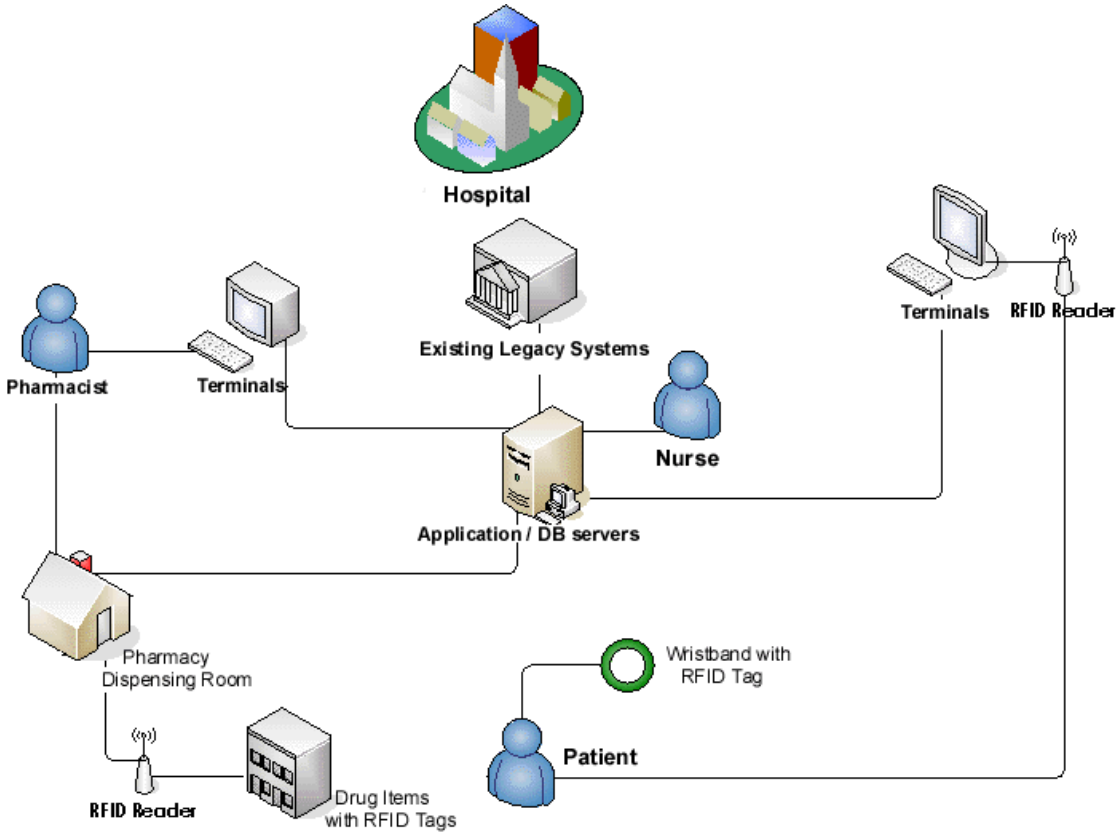

Figure. 2 Architecture of the RHMS

We describe each of the key components below.

RFID Reader: RFID readers were placed at fixed positions inside the hospital and connected to several antennas to monitor patient drug usage, detect the patient locations and track pharmaceutical inventories.

Terminals. Though a user-friendly browser interface, hospital staff could access the internal application systems. Some terminals were equipped with handheld RFID readers. Hospital staff could use them to read and write tagging information from the patients' wristbands or drug items.

Application/Database Servers. As a pilot, application and database were placed in a single machine box. From architectural prospective, they could be installed in separate machines. Application server contained web and java containers where web pages and java-based programs could be run over there. Database server mainly included four relational databases: patient information database, drug information database, drug inventory database and patient medication monitoring database. These databases were accessed through the Java Database Connectivity (JDBC) gateway to execute the queries.

Patient Wristband. This was an RFID transponder (a passive RFID tag). Every patient was given a wristband after admission. The wristband was used for patients' identification purposes in the hospital. Some readers, which were equipped with antennas and placed at strategic locations inside the hospital, constantly read the tag information from the patients' wristbands in order to track their locations. The wristband also contained patients' medical histories, drug charts, doctor-in-charges, etc. Nurses could examine the patient medical records before giving the medications to the patients.

Tagged Drug Items. A tiny passive RFID tagged label was embedded into each drug product item. The tag information could be either read or written by an RFID reader to retrieve and update the products' information such as quantity and inventory levels when they were moved in/out from the pharmacy

dispensing room. These tagged items also facilitated automatically flagging for removal of expiry and recall product items from the inventory shelves.

3.1.4 Design method

Design method describes the procedures for artifact construction (Walls et al., 1992). Prototyping as a system development methodology by putting together a working model that is a quick way to demonstrate a solution to a problem. In the system implementation stage, a prototype was built in order to test various aspects of a design, illustrate ideas or features and gather early user feedback from the evaluation (Sommerville 2007). We developed the RHMS system according to our architectural and system design. HyperText Markup Language (HTML), JavaServer Pages (JSP) and Javascript, and Macromedia Flash programming languages were selected for the development of web-based interfaces, as they were portable and compatible with most web browsers. In addition, we used Java and Java Servlets for developing modules in the middle tier, such as session tracking and flow redirecting, because most of the current application servers like Tomcat widely support these kinds of Java components. Finally, a structured query language (SQL) was used for writing statements and queries in the rational database management (RDBMS) system.

3.1.5 Evaluation

Having developed the system prototype, we conducted testing and evaluation processes to ensure that the prototype conformed to its specifications and met the business needs at this stage. A set of formal tests, including module tests, integration tests, functionality tests, and performance tests were performed to show that the prototype was free of bugs and errors. In addition, we examined the prototype by inviting domain experts to evaluate it. Gasching et al. (1983) noted that evaluation by domain experts is effective to help determine the accuracy of the embedded knowledge in the prototype. We employed a user questionnaire to document responses to the system testing. To obtain comprehensive feedback, 45 potential users were invited to participate in the evaluation. At the evaluation session, the system prototype was demonstrated and feedback was solicited through discussion and an evaluation form. The results of the prototype evaluation were satisfactory and supported the contention that the RHMS system performed its functions as expected. Three physicians, four nurses and two pharmacists, domain experts, who have RFID knowledge and were invited to evaluate the prototype. A formal questionnaire containing both closed and open-ended questions was designed and consisted of two sections: i) effectiveness of the RHMS prototype, and ii) usability of the prototype system. The potential users were asked to use a 5-point scale (1 = strongly disagree, 3 = undecided, and 5 = strongly agree) to rate the two main aspects of the RHMS prototype: its effectiveness and its usability. The results of the questionnaire analysis showed that the potential users rated the system highly on the above two aspects, with a mean score of least 3.9 on a 5-point scale. Based on the results of the evaluation, the prototype was seen to be a promising system for improving an overall medical management and operational efficiency in the healthcare.

3.1.6 Testable hypotheses for RHMS

The final component is a set of testable design process hypotheses which can be used to verify whether the meta-design satisfies the meta-requirements. Many of these hypotheses have to do with the feasibility of building such a system which others address the effectiveness of the design product (Walls, et al., 1992). We can test whether the RHMS built based on the proposed architecture will be more flexible, open and customizable, and whether the level of adoption of a system built with this ISDT will be greater than other approaches.

4 A RESEARCH AGENDA

It is proposed that this research would follow up by a case study approach because of the following reasons (Benbasat et al., 1987):

- We can study the RHMS in a natural setting, learn about the state of art, and generate theories from practice.
- The case method allows the researcher to understand the nature and complexity of the processes currently taking place. A goal of the developing the proposed RHMS were to:
  - improve the pharmaceutical dispensing management to reduce potential dispensing errors and thus enhance the safety of medication use;
  - automate pharmaceutical inventory operations and controls to keep a close monitoring and real-time reporting of inventory levels;
  - strengthen the patients' identification and location tracking processes in a hospital to enhance patient safety; and
  - provide a differentiated caring service quality in a hospital through the use of innovation.

As there has been a lack of empirical studies on this approach, it is possible to pose a range of hypotheses that can be empirically tested. It would be an interesting topic of research to see whether:

- the RHMS will provide better service quality in a hospital,
- the RHMS built based on the proposed architecture will be more flexible, open and customizable, and
- the level of adoption of a system built with this ISDT will be greater than other approaches.

5 CONCLUDING REMARKS

This paper presents using an Information Systems Design Theory (ISDT) for the design and development of an RFID-based HMS prototype. In this study, we have demonstrated a prototype system based on the proposed architecture and the ISDT approach. In order to validate the conceptual design of the prototype, it was extensively tested and evaluated by the potential user that the system can deliver significant results to strengthen patient and use of medication safety, improve pharmaceutical inventory operations and controls, enhance patients' identification and their in-hospital location tracking processes in the healthcare industry. The user evaluation demonstrated the practical viability of the proposed architecture. Use of this ISDT provides "an IS underlying RHMS that is more flexible, customizable and close to the needs of its specific organization" (Jones, et al., 2003). We believe the developed prototype using ISDT approach would be a useful one and would provide a workable means to help hospitals to gain a better understanding of the design and development of RHMS.

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