A study of RFID application impacts on medical safety

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Abstract: With the international reform in medical management systems gaining ground worldwide, hospital management has gradually begun to shift its focus from providing expensive medical treatment to improving medical service quality and patient safety. In this study, we discuss the application of Radio Frequency Identification (RFID) and data integrating technology with the medical service, and examine whether or not this technology can enhance medical safety. We also discuss the possible benefits following the application of the RFID system. The findings show that the application of RFID to hospitals can actually generate benefits, which can be further divided into operational structure benefits, users' structure benefits, and organisational and environmental benefits. However, not all these benefits can achieve medical safety. Among them, only the operator and environmental benefits can play such roles. Nevertheless, the application of RFID can bring hospitals towards the integration of technology benefits and improved medical safety.

Keywords: Radio Frequency Identification; RFID; medical safety; operational structure benefit; users' structure benefit; organisational and environmental benefit.

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1 Introduction

Since 1995, when Taiwan first implemented the health insurance system for its citizens, it has been more convenient for people to become hospitalised. On the other hand, medical disputes have increased each year. According to statistics from the Medical Accident Appraisal Team under the Taiwan Health Department, clients requesting medical accident appraisals each year have increased from 147 in 1987 to 406 in 2001. The reasons identified include the following: unsatisfactory medical service (24%), surgery involvement (15%), misdiagnosis and deferment of hospitalisation (11%), and misuse of

medicine (9%). Moreover, global medical accident investigations also demonstrated that among acute in-patient cases, approximately 3% to 16.6% had encountered mistreatment. Researchers believe that 30% to 50% of such events could have been prevented or avoided (Consortium Hospital Medical Quality Appraisal Commission, 2003).[1] By taking effective steps towards the prevention of poor treatment in medical procedures, medical disputes and medical risks would be reduced and as a result, medical service quality and patient safety would be guaranteed (Varshney, 2006; Anderson *et al.*, 2007; Chao *et al.*, 2007).

Various hospitals in Taiwan have relevant management standard processes – patients arrive at the operating room, the doctor carries out the surgical procedure and the relevant staff members maintain the data. However, under the present artificial medical workflow, there exists a high incidence of error and low efficiency attributed to human limitations.[2] Unlike the general manufacturing industry, hospital practice is closely related to a person's life and health. With the lives of people at stake, there is no room for even the slightest error. In relation to this, intensifying management on high-risk service flows in hospitals (*e.g.*, the operating room) is an effective and critical way for hospitals to create safe medical service environments, protect patient safety and promote quality medical service levels. It is also the same objective which the medical industry should endeavour to achieve.

The Radio Frequency Identification (RFID) systems transmit recognised data by utilising radio waves; the automatic recognition and capture of information are among its advantages. However, RFID can only be performed effectively with the cooperation of relevant industries, including the assistance of consultant firms for software development and system integration. Therefore, the present demand for RFID is imperious, but despite this, RFID is still not widely adopted in Taiwan's hospitals. There are few studies researching the benefits of RFID and it is still unknown if it can indeed enhance hospital management benefits, reduce human error, guarantee patient safety and indicate usable hospital resources in real time when it is added to the hospital workflow.

In this paper, therefore, we intend to contribute to the literature by demonstrating the RFID system's benefits, its introduction and development process in hospitals and to integrate related information regarding science and technology application data. It is hoped that our research can act as an example for medical industries to accelerate RFID development, improve medical service and provide patients with safeguards.

2 Literature review

2.1 RFID's characteristics and its practical application in the medical industry

The RFID system is one of the standard systems used for automatic identification or recognition (auto identification; Auto ID). By using radio waves to transmit recognised data and complete identity and content recognition, this system can carry out data exchange, object tracing, classification and statistical analysis more quickly and without spatial limitations. Apart from its basic fast recognition feature, the RFID technology has other features, such as:

- radio reading – it directly reads information and inputs this into databases through RFID Readers

- large reading quantity – it allows the processing of many tags at one time and records the treated conditions on the tags for future reading
- mobile reading – it allows reading at high-speed movement
- ease of miniaturisation and diversification – it possesses characteristics that fit different applications, thereby providing a broad scope of application with a tendency for gradual expansion
- environment resistance – it is unlike the traditional ID data dominated by the bar code or the manufacturer's number, which does not resist dirt, needs a long time to be recognised under inclement weather and from which data cannot be continuously traced. In comparison, RFID is heat-, water- and impact-resistant; in fact, the tag can be maintained for more than ten years and can accept writing for more than hundreds of thousands and even million of times
- repeated usability – since it stores electronic data, RFID can be rewritten repeatedly
- penetrability – even if enveloped with nonmetal or opaque materials such as paper, lumber or plastic, RFID can process information, except when wrapped with material of metallic quality
- large data memory capacity – it can accommodate increasing volume capacity, therefore, RFID information will not be limited to the capacity of a bar code (Cheng *et al.*, 2007). Owing to its advantages of automatically recognising and capturing information, facilitating the safe reading of much data at one time and its ability to be used repeatedly, RFID demonstrates remarkable application potential.

Healthcare is very different in many industrial activities. Xiao (2005) specified two characteristics of healthcare that make the deployment of Information and Communication Technology (ICT) challenging. One is that healthcare is a prime example of collaborative work. It is increasingly delivered by highly specialised personnel with frequent handoffs. The other is that healthcare work is often nonroutine. Healthcare is also relative to patient safety. Therefore, the implementation of RFID will be a necessary step in tracing each patient in any nonroutine situation, in providing hands-off summary information, avoiding human negligence and accidents in terms of handling information and even fitting in with the principle of 'automation as far as possible' (Xunxiang, 2004; Kushniruk *et al.*, 2005; Chao *et al.*, 2007).

At present, RFID technology has been applied to clinical nursing with the use of microchips, which receive radio signals from a patient's electronic tag. These tags send unique ID codes to sensors installed at every position or care point in a hospital for the staff to recognise. At present, RFID chips have been designed to have various portable types, such as wrist belts, paper sticker labels and so on. Their applications are enumerated as follows (Zeyun, 2004):

- For hospital management and integration with a hospital's information system: the information sent by RFID can be integrated with electronic medical records in a clinical nursing environment, the computerised doctor's referral system and the medicine information system.

- For medical supplies management systems: RFID can be applied to general medical supplies management, *e.g.*, supplies keeping management, medicine stockroom management, medicine validity period monitors and so on.
- For convenient disease condition control and management: the main advantage of RFID electronic volume tags is the convenience it gives hospitals in controlling disease conditions (especially highly infectious diseases such as Severe Acute Respiratory Syndrome (SARS) and Mad Cow Disease). RFID can also be used for patient management in areas where life is most at risk, such as in the intensive care unit or emergency room (Chen *et al.*, 2007).
- For the application of RFID implant-type chips to patients: the number on the RFID chip can also be used for network access of a patient's electronic medical record. Since only authorised persons can access real-time data, the security and privacy of the patient's record are fully guaranteed.
- For patient health self-management: an RFID chip in a health card could contain the complete medical record of a patient. Any doctor, pharmacist or other nursing staff could access this key health information at real time.

2.2 The appraisal pattern of information systems

In general, appraisals from Information Systems (IS) focus on increased commercial benefits following the systems' use (*e.g.*, increase in turnovers). However, Aladwani (2002) proposed the following two major methods regarding IS benefit appraisal.

2.2.1 Appraising the benefits of IS from the sociological viewpoint

The benefits appraisal pattern puts an emphasis on the behavioural characteristics of IS users. In this pattern, groups and organisations act as a background and the contributions made by the IS operation serve as the factors for appraising performance.

2.2.2 Appraising the benefits of IS from the technical viewpoint

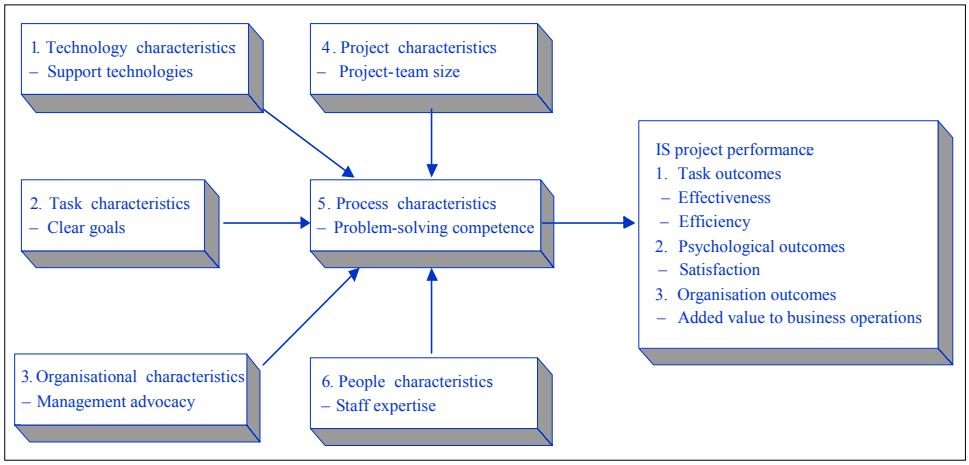
This benefit appraisal pattern focuses on the achievements and contributions of the IS. It neglects the users' behavioural characteristics and the changes in the social and organisational environment. In his integrated model of IS project benefits (Figure 1), Aladwani (2002) proposed six major structure characteristic factors (technology, task, organisation, project-team, process and expertise) to explain the influence of IS project benefits (IS work, user cognition and organisation value). He also arrived at three important conclusions on IS benefits:

1 that the IS project benefit is the multiconstruction of structures

2 that the achievement of high IS project benefits should be based on the six major structures

3 that the variables used for studying IS benefits have a close correlation to those used for studying the IS, the project members and the project management.

Figure 1 The integrated model of IS project benefits (see online version for colours)



In his research, Aladwani (2002) pointed out that the IS performance indicator is the most important foundation for measuring IS, which can be carried out from three main aspects:

1 the effectiveness of the IS in promoting work and work efficiency

2 the increased benefit to IS users, such as user satisfaction with the improvements of work processes

3 the organisation's benefit through additional commercial value (added value).

In our research, we took Aladwani's model as a construction basis for measuring the benefits of RFID as used in hospitals.

Referring to the data from relevant academic literature, we collected the possible benefits of using RFID and classified them according to Aladwani's appraisal model, which has three structures: operational, user and environmental (Table 1).

Table 1 The benefits of RFID according to three major structures

Structure	*Explanation of the benefits (based on the literature)*	*Sources of information*
Operational benefits	Increased patient recognition	Ling, 2004; Chengguo, 2004; Chenghua, 2004; Xunxiang, 2004; Zeyun, 2004
	Reduction of mistakes	Ling, 2004; Chengguo, 2004; Chenghua, 2004; Xunxiang, 2004; Zeyun, 2004; Chongchi, 1995; Davidson and Chismar, 1999; Haicheng *et al.*, 2002; Qijun, 2000
	Statistical information produced	Chongchi, 1995; Qijun, 2000; Huangsheng, 2002
	Reduced preparation time (supports the work of the medical staff)	Xingjin, 2001; Chongchi, 1995
	More effective data processing	Xingjin, 2001; Chongchi, 1995

Table 1 The benefits of RFID according to three major structures (continued)

Structure	*Explanation of the benefits (based on the literature)*	*Sources of information*
Operational benefits	Improved work efficiency among medical care personnel and the administrator, thereby saving human resources	Haicheng *et al.*, 2002; Xingjin, 2001
	Reduced costs due to improper treatment	Shelson and Richard, 1999; Haicheng *et al.*, 2002
	Can be considered as warning signals to surgeons with regard to relevant procedural matters	Joe, 1993; Qijun, 2000
	Increased accuracy of doctors' advice	Davidson and Chismar, 1999
	Integrated hospital service network	Qingwen, 2000
	Real-time condition of patients is provided	Huangsheng, 2002
	Effective management and application of medical resources	Proposed by the case study
	Work schedules and time frame analysis of medical personnel provided, which helps calculate cost and efficiency	Proposed by the case study
Users' benefits	Real-time access to key health information	Ciying, 2004; Haicheng *et al.*, 2002
	Increased information regarding patients hospitalised and transferred	Haicheng *et al.*, 2002
	Faster and more convenient method for patient enquiries	Haicheng *et al.*, 2002; Xingjin, 2001
	Enhanced tracking of patient services, thereby increasing rate of return	Haicheng *et al.*, 2002; Huangsheng, 2002; Qijun, 2000
	Increased convenience in the hospitalisation process and shortened hospitalisation period	Xingjin, 2001
	Improved safety	Haicheng *et al.*, 2002
	Reduced hospital stay	Terry, 1999
Organisational and environmental benefits	Improved establishment of national medical information (which gives the impetus for the development of the Emergency Operation Center (EOC) policy)	Chongchi, 1995
	Hospital publicity	Xingjin, 2001; Haicheng *et al.*, 2002
	Integrated medical industry services	Qingwen, 2000
	Promotion of electronic case history development as standard practice	Xingjin, 2001
	Improved internal communication within hospitals and enhanced service capabilities	Self, 2002
	Operational process can be regarded as a reference point for improved workflow	Huangsheng, 2002
	Expanded scope of medical service, faster first aid treatment and increased business income	Youlin, 2004
	More efficient management of waste materials and biopsy materials	Youlin, 2004

3 Research method and design

3.1 Case study

The case study is the most widely adopted research technique in qualitative research. In-depth interviews focus on quality, while the general investigation focuses on quantity. By using conversation as the focal point of the interview process, the in-depth interview allows for a better flow of opinions between the interviewers and interviewees. That is, instead of pinning down the established thoughts of interviewees, the in-depth interview discovers these thoughts through interaction, experience and effective communication. According to these main points, we designed the interview plan as shown in Table 2.

Table 2 Interview question design

Rounds of the interview	*Interview question*	*Objective and/or reason for the questions*
Round 1 interview	For how long, when and where have you used RFID?	To learn about the time of application of RFID in the hospital
	What are the conditions of manpower allocation in your department?	To help the researcher gain more knowledge about the sample
	Why was RFID introduced?	To gain information regarding the hospital's motives for the introduction of RFID, which will help enhance the data gathered regarding the motives and objectives in adopting RFID
	How was it introduced? What hardware system was employed?	To learn about the method of RFID application
	What were the benefits after the introduction of RFID?	To discuss and determine the research variables
	What were the limitations and problems in the introduction of RFID?	To learn about the limitations of the application of RFID
Round 2 interview	When are data gathered with the application of RFID?	To check whether or not the sample has enough operating room capacity to apply RFID, and if so, to gather data regarding the room, scheduling system and generation of the RFID code
	What is the purpose of using the data gathered from RFID?	Better tools for physicians, caring staff, patients, instruments and materials
	With a schedule system in place, do physicians, caring staff, patients, instruments and materials have a 'log in' step to complete when they enter the operating room?	To find out if enhancements to the scheduling system are employed by the physicians, caring staff and patients
	How does the system send warning signals when it detects an unconfirmed RFID?	To find out if enhancements like sound alarms are needed for the effective application of RFID
	Is there a confirmation mechanism when physicians, caring staff, patients, instruments and materials are all set for a procedure? What is the method of confirmation? Is it a step-by-step process?	Request reconfirming one another's identity; broadcast the matters concerning operations; request confirming the operation position; reconfirm relevant instruments and materials

Table 2 Interview question design (continued)

Rounds of the interview	*Interview question*	*Objective and/or reason for the questions*
Round 2 interview	Under what circumstances are operations permitted?	Compare the different conditions during pre-operation and post-operation
	Are the start and end times of a procedure recorded?	To find out if the data regarding patient wait, registration, procedure time, recovery time and discharge time are recorded with RFID
	Has this relevant information been integrated into the hospital management system?	To learn about the conditions following RFID integration
Round 3 interview	Explain operation schedules	To know more about the status of the hospital following RFID application
	Explain various procedures to patients	
	Explain the workflow in an operating room	
	Explain the correlation between RFID and the operation process	
	Apart from the mentioned RFID applications, where else do you think can it be used and what benefits can it bring?	To learn about the possible application of RFID in other fields

3.2 The survey

As mentioned earlier, since RFID has not been widely introduced in Taiwan and only a few scholars and experts have studied its benefits, the adopted method for disseminating the questionnaire survey might be questioned by other researchers. Thus, we limited our research to Taiwan's 531 regional general hospitals (21 medical centres, 80 regional-level hospitals and 430 district hospitals) and relevant information-using units (including doctors, nurses and related management units). All the respondents are involved in medical institutions; thus, we believe that the findings from the questionnaire survey demonstrate the representativeness of the current medical service conditions in Taiwan.

The study questionnaire was designed based on the literature, the earlier results of interviews and the revised research framework. The measurement standards of the questionnaire adopted a five-point Likert scale. The respondents who completed the questionnaires selected their answers according to their understanding of RFID's benefits. Each item in the questionnaire was carefully examined in order to increase the questionnaire's credibility, validity and appropriateness in terms of the questions asked, as well as to avoid ambiguity, maximise the function of every question and make every question clear for each of the respondents. Any inappropriate item which might cause confusion to the interviewees was revised.

3.3 Research framework and variables

According to literature discussions and many expert recommendations, we first established our research framework (Figure 2), appraised the hospital benefits on the basis of three major structures (operational, user, and organisational and environmental) and finally verified the impact of these benefits on medical security. Since this research will use the variables which result from factor analysis as independent variables, we

propose research hypotheses regarding the three major structures before carrying out data analysis. H1, H2 and H3, respectively, represent our hypotheses on the operational structure, user structure and organisational and environmental structure of medical safety (further detailed in Table 3).

Figure 2 RFID benefit appraisal basic research framework (see online version for colours)

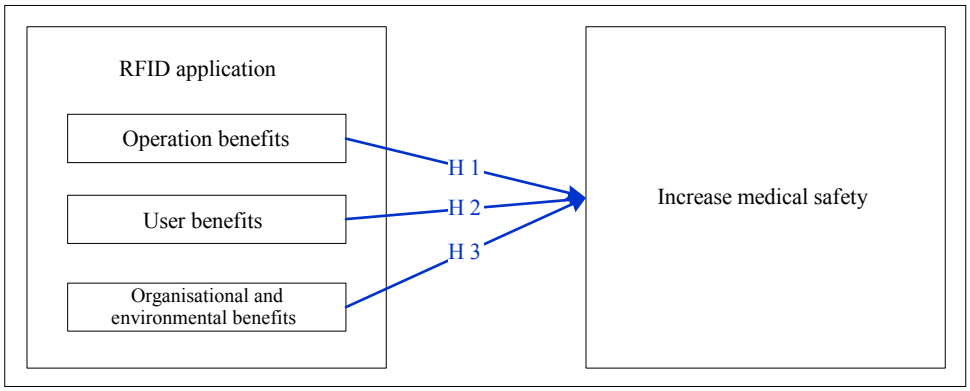


Table 3 Classifications and explanations of RFID benefit appraisal based on the research variables

Research constructs	*Research variables*	*Operational definitions and explanations of benefits*
Operational benefits	Increase patients' reorganisation (including newborns)	Carry out the traditional way of work comparison by means of 'three reading and five comparing,' reduce the mistakes caused by the immediate action of the medical staff, warn the possibility of leading to mistakes, timely improvement of patients' security
	Reduce mistakes	Take various measures to recognise whether or not doctors and patients enter the wrong operating room, which can help medical staff save time in recording and help reduce mistakes
	Produce statistical information	The use of condition data for the operation room and the whole process of patients coming to the hospital (get hospitalised, register, undergo operation and recover)
	Reduce the working time involved in preparation	Recognise the relevant flow of information and prepare materials (as support for medical staff's work)
	Effective data processing	Problems of low efficiency and wrong inputting exist in artificial inputting
		Integrate RFID with the hospital IS to reduce repeated KEY-IN window flows
	Improve the work efficiency of medical care personnel and administrators, saving manpower	Automatically obtain information on patients' physical well-being and make patients' information transparent
	Reduce the cost arising from improper treatment	Reduce the costs resulting from medical disputes

Table 3 Classifications and explanations of RFID benefit appraisal based on the research variables (continued)

Research constructs	*Research variables*	*Operational definitions and explanations of benefits*
Operational benefits	Warn surgeons about relevant matters concerning operations	Display relevant operation information through RFID when a patient is brought to the operating room
	Increase the accuracy of doctors' advice	Display relevant information through RFID when a patient is brought to the operating room (serves as a reference for related medical care for the personnel and the pharmacist)
	Integrate hospital interior service chains	Disseminate patients' information though the hospital IS, which will facilitate easier internal communication
	Provide the real-time condition of patients and medical care	When the signals sent by the RFID are received by the reader, the medical staff can learn about the patients' conditions immediately, thereby saving time
		Infectious diseases can be controlled from spreading by selective isolation
	Provide working-time analysis to medical personnel	Integrate medical service information and help calculate costs and benefits
	Effective management and application of medical resources (including medicines)	With the advantages of tracing articles, RFID can be used in logistics management to learn the correct quantity of articles in stock at real time and monitor the keeper, as well as the quantity, location and validity period for medicines
Research hypothesis	H1: The benefits from the application of RFID on the operational structure have a remarkable significance in the improvement of hospital safety	
Users' benefits (satisfaction)	Real-time access to key health information	Put the RFID chip on the 'health card' and the chip can record a patient's complete medical information
	Increase information about patients' hospitalisation and transfer	Since the condition of the operating room as well as that of the patients is clear, inquiring of the data through a system linking RFID and the web before patients get hospitalised is made convenient
	Speed, convenience and accuracy involved in providing patients with the data they need	If information desks are set up, patients will be able to obtain related data (disease condition bulletin system)
	Present the diagnosis and initial caring service and increase patient satisfaction	Patients and medical staff can quickly inquire about the disease in terms of its different stages (condition bulletin system). RFID can automatically report relevant physiological data which will allow doctors to assess the physiological condition of patients, analyse complications if there are any and make a correct diagnosis
	Higher safety	Patients would be convinced by high-technology medical instruments which they can see for themselves
	Increase the convenience involved in the hospitalisation process	As the condition of patients becomes clear, the waiting time can be shortened. Medical service is no longer limited to hospital or clinic rooms because of the help of the internet and radio communication detection devices such as RFID
	Reduce the days of hospitalisation	The hospitalisation time can be reduced because of fewer mistakes (if there are mistakes, then reprocessing is needed)

Table 3 Classifications and explanations of RFID benefit appraisal based on the research variables (continued)

Research constructs	*Research variables*	*Operational definitions and explanations of benefits*
Research hypothesis	H2: The benefits from the application of RFID on the user structure have a remarkable significance in the improvement of hospital safety	
Organisational and environmental benefits	Improve the establishment of a national medical information network (give the impetus for the development of the EOC policy)	Incorporating the quick feedback mechanism of RFID with the hospital management IS will establish close links with the national medical institution information network
	Boost hospital image	With high-technology medical instruments which the patients themselves can see in the hospital, they would feel a greater sense of safety and trust towards the hospital, which can in turn promote the image of the hospital
	Integrate the upper and lower industries of the medical profession	The upper medical industries are the medicine and instrument manufacturing industries, while the lower medical industry refers to hospitals. Their cooperation via RFID may push hospital management to new heights
	Impel the development of the policy on electronic maintenance of patient case histories	If the encryption of RFID can be upgraded to ensure safety, then the necessity of electronic maintenance of patients' case histories would be increased, which allows the integration of first aid, preventive medicine and long-term care, as well as the generation of more benefits
	Improve internal communication in the hospital and enhance the service capability of the hospital	Setting up hospital-wide monitoring and emergency centres results in the provision of real-time warnings and dealing with emergency situations through radio communication. Because the information about the disease condition of patients and recourse can be obtained quickly and accurately, there will be efficient external consultation and internal communication
	The complete operation may be the reference for improving workflow	Analysis of the information on patients getting hospitalised and their waiting time
	Expand the medical service scope, speed up first-aid treatment and increase business income (long-term care)	Hospital resources can be shared with neighbouring district care homes. Medical personnel in hospitals may, in turn, provide care to people nearby (with focus on providing long-term care and quality medical service in order to lessen the burden of staff working at care homes)
		Make quick responses to first aid calls
		Through RFID's fast feedback mechanism and hospital IS, the medical institution can work closely with the community, allowing a more efficient use of medical resources
	The efficiency of management through the disposal of hospital wastes and other materials	Trace the transfer route of hospital wastes and other materials to ensure their proper disposal
Research hypothesis	H3: The benefits from the application of RFID on the organisational and environmental structure have a remarkable significance in the improvement of hospital safety	

4 Case study analysis and discussion

4.1 Understanding the practical application conditions of RFID in the hospital

By the results of the in-depth interviews and data collection, we learned the practical applications of RFID in the case hospital. The case hospital has implemented RFID for many years, and the main applications include temperature control, position control and the management of operation room. For operation benefits, RFID can help case hospital mitigate medical errors, reduce working time and cost from improper treatment. On the other hand, RFID can not only assist doctor to access patients' information in real-time, but take some benefits for patients such as speed, convenience and accuracy in the treating process.

4.2 Verifying if the research variables collected from the literature discussions really have correlations with the benefits produced by RFID

- The main controlling interface regarding temperature and position corresponds to the seventh question on operational structure benefits.
- Temperature, an exceptional controlling information, corresponds to the 16th question on users' structure benefits.
- The system warning about a doctor entering the wrong operating room corresponds to the second question on operational structure benefits.
- The information about patients being admitted to the operating room and pictures 4 to 7, the patients' operation position and case history recognition, correspond to the first question on operational structure benefits.
- The provision for family members to watch the operation process corresponds to the 14th question on users' structure benefits.
- The integration of hospital and home care (expanding the service scope) corresponds to the 27th question on social and environmental structure benefits.
- The integration of medical resources (*i.e.*, ambulance and medical care personnel) corresponds to the 13th question on operational structure benefits.
- The integration of the medical IS (simplified administrative work) corresponds to the sixth question on operational structure benefits.
- The system sketch map of RFID in the operating room corresponds to the 22nd question on organisational and environmental structure benefits.
- The 12th and 13th questions on operational structure and the 27th and 28th questions on organisational structure are topics obtained from individual interviews.

4.3 The benefits brought about by RFID which have correlations with Aladwani's benefit model involving the three major structures (operational, users', organisational and environmental) which can be adopted for RFID benefit appraisal

From the results regarding RFID benefits on different structures, we learned that these benefits have close correlations with Aladwani's benefit model. By explaining the three major objectives by means of individual analysis, we prove that the individual interviews considerably support our research framework, specifically through the verification and collection of research variables.

5 Survey data analysis and discussion

5.1 Descriptive data presentation

In this research, we mailed a total of 630 questionnaires to the respondents and retrieved 194 questionnaires, or a return rate of 30.79%. Subtracting for six invalid questionnaires which were incomplete or inappropriately filled out, there were 188 valid questionnaires (21 medical centres, 76 regional-level hospitals and 90 district hospitals), with an actual return rate of 29.84%. From the 188 valid questionnaires provided in the topic 'RFID application condition', we discovered that 42 hospitals have implemented RFID (22.34%), 60 hospitals have assessed RFID (31.92%) and 86 hospitals have indicated it impossible to use (45.75%). Most interviewees answered the questionnaires according to their cognition of the literature and their analysis based on their work experiences. In terms of 'work seniority', 72.88% of the interviewees have worked for more than six years (seniors) and in terms of 'educational status', 70.22% of them held a Bachelor's degree. Furthermore, 77.66% of the respondents were identified as our research objects in the questionnaire survey.

Although many of them had not employed RFID in reality, the respondents' opinions sufficiently represented the current viewpoints of the medical industry. Since opinion is said to affect action directly, we believe that the findings of our research serve as an important reference for the introduction of RFID in hospitals. In addition, from the result of the statistical significance test, we can conclude that, at present, there is a high potential expectation for RFID introduction in the medical industry. Moreover, we believe that the lesser the application, the higher is the research value. In our questionnaire survey, 92 interviewees showed interest in the research findings while 22 proposed their opinions.

The questionnaires were designed according to a five-point Likert scale, in which the 30 questions were divided into four major classifications in order to weigh the cognition degree of the supervisors and medical users on the benefits which can be derived from the RFID system. Because the 30 questions are about the benefits of RFID, the different weights represent the agreement of responders for each item. The more weight an item gets, the more benefit is recognised for RFID and vice versa. The statistical data analysis showed that the average scores were distributed between 3.18 and 4.43, indicating that the application of RFID could definitely bring various benefits to hospitals.

5.2 Reliability and validity analysis

According to the data regarding duty, education status and work seniority of the respondents, we adopted an independent sample to verify and compare the differences between the questionnaire answers received during the normal period and those received during the follow-up period in order to measure the error of unreturned questionnaires and ensure that all the received questionnaires have sufficient matrix representativeness. With a significance level of 0.05, we obtained the results as shown in Table 4. The findings indicate that the p-value was higher than 0.05, proving that there is no significant difference in the individual basic data variables between different receiving periods. Therefore, we believe that the unreturned questionnaires would not affect the validity of the research findings. In other words, the samples received have sufficient matrix representativeness.

Table 4 Individual sample *t* verification

	Verification values		*Significance*	
Individual data	*Assume variables are equal*	*Not assume variables are equal*	*Assume variables are equal*	*Not assume variables are equal*
Duty	1.156	1.165	P = 0.249	0.246
Education status	1.444	1.517	P = 0.150	0.131
Working seniority	1.571	1.540	P = 0.118	0.126

In this study, we designed the first draft of our questionnaire according to the literature discussions. We invited experts to review it and then carried out a preliminary survey to ensure the clarity of the questions and enhance the overall content validity. Further, we adopted factor analysis to weigh the construct validity of the questionnaire. First, we conducted principal component analysis, which required the gathering of the variables of each structure, and according to factor loading, we classified them into several primary factor groups. After this, we renamed the groups based on their characteristics. The benchmark for choosing the factors was an eigenvalue higher than 1, which allows variables to have proper difference validity. In the factor axis rotation method, the maximum Varimax Rotation of the orthogonal axis rotation is commonly adopted to obtain the minimum and the maximum variable differences between the factors after axis rotation and other factor loadings. All factors were chosen at the significance level of $\alpha = 0.05$, with the sample size ranging from 150 to 200 and the factor loading above 0.45. In this research, the variables which have a factor loading higher than 0.45 were included in each factor group. The results are shown in Table 5.

Before proceeding with the basic hypothesis examination and multiple regression analysis, we first conducted a validity analysis of the variables. Table 6 presents the validity analysis results, in which the Cronbach's α values are all greater than 0.6, confirming that all the new factor validity values conformed to the standard and, hence, the next analysis was carried out.

Table 5 Factor analysis

		Factor variables						
Constructs	*Questions*	*X1*	*X2*	*X3*	*X4*	*X5*	*X6*	*Y*
1	V01	.746						
	V02	.828						
	V03	.649						
	V08	.669						
	V09	.601						
	V05	.538						
	V04		.534					
	V06		.668					
	V07		.481					
	V10		.772					
	V11			.792				
	V12			.666				
	V13			.707				
2	V14				.805			
	V15				.820			
	V16				.728			
	V17					.682		
	V18					.840		
	V19					.532		
	V20					.550		
3	V21						.636	
	V22						.768	
	V23						.698	
	V24						.643	
	V25						.681	
	V26						.789	
	V27						.735	
	V28						.743	
4	V29							.903
	V30							.903

Table 6 Validity examination

Factors	*Constructs*	*Rename*	*Cronbach's α*	*Index number*
X1	1	Veracity of the operational structure	0.842	6
X2	1	Data processing efficiency of the operational structure	0.743	4
X3	1	Resource control and management of the operational structure	0.696	3
X4	2	Information transparency involved in users' operation	0.750	3
X5	2	Satisfaction with medical services in users' structure	0.656	4
X6	3	Integration of medical information and expansion of service scope	0.859	8
Y	4	Impact on medical safety	0.772	2
All	All		0.939	30

5.3 Basic hypothesis verification and multiple regression analysis

In adopting multiple regression analysis, we must verify whether or not the variables conform to the basic hypothesis (variable normality hypothesis verification and independent variable nonmulticollinearity hypothesis verification) in order to ensure that the analysis results are free from errors.

Table 7 Adjusted normality hypothesis verification

		Skewness			*Kurtosis*		
Variable	*Number*	*Statistic*	*S.D.*	*Zs*	*Statistic*	*S.D.*	*Zk*
X1	188	–.201	.177	–1.125	–.192	.353	–0.537
X2	188	–.226	.177	–1.265	.137	.353	0.383
X3	188	–.091	.177	–0.509	–.238	.353	–0.666
X4	188	–.156	.177	–0.873	–.135	.353	–0.377
X5	188	.126	.177	0.705	.244	.353	0.682
X6	188	.028	.177	0.156	.075	.353	0.209
Y	188	.031	.177	0.173	.058	.353	0.162

Notes: Variable explanations:

X1: operation veracity of the operational structure after calculating the square root.

X2: data processing efficiency of the operational structure.

X3: resources control and management of the operational structure.

X4: information transparency in users' operation.

X5: satisfaction with medical service on users' structure after calculating the square root.

X6: integration of medical information and expansion of service scope.

Y: impact on medical safety.

5.3.1 Normality hypothesis verification

The verification results showed that the X1 and X5 variables do not conform to the normality hypothesis principle (their Z values were higher than |±1.96|). Meanwhile, other Z values were all lower than |±1.96|. Therefore, we conducted data conversion by calculating the square root of X1 and X5. After recalculating, the skewness Z values and kurtosis Z values were found to be lower than |±1.96| as shown in Table 7. Under the significance level of 0.05, the variable data distributions conformed to the normality hypothesis.

Table 8 Pearson correlation coefficient verification

Variable	*X1*	*X2*	*X3*	*X4*	*X5*	*X6*
X1	1					
X2	.619**	1				
X3	.521**	.544**	1			
X4	.618**	.587**	.506**	1		
X5	.758**	.811**	.652**	.606**	1	
X6	.590**	.552**	.608**	.658**	.648**	1

Note: **P < 0.01.

5.3.3 Multiple regression analysis

The regression model Equation (1) used in this research is shown below:

$$Y = \alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + \varepsilon \quad (1)$$

First, we conducted ANOVA on the variables to determine whether or not the model is remarkable. Then, we identified if there was a significant correlation between the independent variable and the dependent variable. The ANOVA results are shown in Table 9.

Table 9 ANOVA results

Model	*Quadratic sum*	*Degree of freedom*	*Average quadratic sum*	*F verification*	*Significance*
Regression	31.537	6	5.256	40.029	.000(a)
Residual error	23.767	181	.131		
Summation	55.303	187			

As shown in Table 9, with $p < 0.05$ and the F value = 40.029, it is indicated that there is a significant correlation between the independent variable and the dependent variable. After verifying the significance of the model, we verified the significant correlations of every structure and individual variable with the dependent variable by using multiple regression analysis (Table 10).

Table 10 Multiple regression analysis

Construct	*Dependent variable*	*Non-standardisation coefficient* *B estimate value*	*Standardisation coefficient* *Beta distribution*	*t*	*Significance*
1	(Constant)	.371	–	1.512	.132
	X1	.307	.305	3.874	.000**
	X2	.135	.126	1.481	.140
	X3	.328	.334	4.907	.000**
2	X4	–2.750E-02	–.030	–.422	.674
	X5	–4.182E-02	–.039	–.356	.722
3	X6	.223	.209	2.820	.005**

Notes: Variable explanations:

X1: operation veracity of the operational structure.

X2: data processing efficiency of the operational structure.

X3: resources control and management of the operational structure.

X4: information transparency in users' operation.

X5: satisfaction with medical service in users' structure.

X6: integration of medical information and expansion of service scope

**$p < 0.01$.

The results shown in the regression analysis coefficient table represent that the independent variables X1 (operation veracity), X3 (resources control and management) and X6 (integration of medical information and expansion of service scope) have a significant correlation with the dependent variable Y (impact on hospital safety), in which X1 and X3 are rechosen as the new variables of the operational structure and X6 is a new variable in the organisational and environmental structure. However, all the new variables on the second structure (users' structure) have no significant correlation with the dependent variable. Since X2 in the first structure (data processing efficiency) has no significant correlation with the dependant variable, we carried out a regression analysis on the first structure alone, as shown in Model (2) below:

$$Y = \alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \varepsilon. \quad (2)$$

The result (Table 11) of the ANOVA showed that $p < 0.05$ and the F value = 75.040, indicating that in this model, the correlations between the independent variable and the dependent variable are significant and that the benefits produced from the first structure can considerably improve hospital safety.

Table 11 ANOVA on the operation construct

Model	*Quadratic sum*	*Degree of freedom*	*Average quadratic sum*	*F verification*	*Significance*
Regression	30.431	3	10.144	75.040	.000(a)
Residual error	24.872	184	.135		
Summation	55.303	187			

From the result (Table 10) of the multiple regression ANOVA, we could find that all the application benefits of RFID might promote medical safety. At the same time, the multiple regression analysis coefficient table (Table 11) also clearly exhibits that each of its structures and variables have a significant correlation with hospital safety. Since the application of RFID is still in its infancy in Taiwan, its price, security and technology are still in question. For this reason, some of its benefits are not yet recognised. However, we believe that with the gradual introduction of RFID, the research findings will be improved.

According to the data analysis results obtained from the questionnaires, the average scores in the measurement tables were distributed within the range of 3.18 and 4.43, showing that the application of RFID might bring great benefits to hospitals (the measured average scores were distributed between 3.18 and 4.43). In addition, the regression analysis results indicated that the integral model (RFID's whole application benefit) can help hospitals improve in terms of medical security. In terms of individual cases, the benefit has been found to correlate with medical security.

Although some of the questionnaire items have high average scores in the narrative statistics measurement, they have no remarkable significance with medical safety in the regression analysis. Based on this, we note the correlation between benefit and safety. After analysing the data, we discovered that RFID can definitely generate benefits, but not all benefits can promote hospital safety. We also note that the respondents' familiarity with RFID has a great influence on the results. The regression analysis result is shown in Table 12.

Table 12 Research hypothesis verification result

Hypotheses	*Supported*
H1: The operational structure benefits after using RFID have a remarkable impact on improving hospital safety.	Yes
H1a: The operation veracity benefits (X1) on the operational structure have a remarkable impact on improving hospital safety.	Yes
H1b: The data processing efficiency benefits (X2) on the operational structure have a remarkable impact on improving hospital safety.	No
H1c: The benefits (X3) produced from resource control and management on the operational structure have a remarkable impact on improving hospital safety.	Yes
H2: Users' structure benefits after using RFID have a remarkable impact on improving hospital safety.	No
H2a: Information transparency benefits (X4) on users' operation have a remarkable impact on improving hospital safety.	No
H2b: The benefits (X5) produced from satisfaction with medical service on users' structure have a remarkable impact on improving hospital safety.	No
H3: Organisational and environmental structure benefits after using RFID have a remarkable impact on improving hospital safety.	Yes
H3a: The benefits (X6) produced from integrating medical information and expanding the service scope have a remarkable impact on improving hospital safety.	Yes

6 Conclusions and suggestions

It is necessary for information organisations and other entities to study carefully the project innovation investment involved in RFID because its application involves many information technologies and information management flows. Only by combining various users' expertise and the actual function demands of different departments can a highly functional system be designed. A successful system does not only promote medical quality, but also improves cooperation among various departments and intensifies staff solidarity.

The introduction of advanced information science and technology in medical industries should focus not only on cost, but also on the safety of patients, which is considered the most important factor (the highest principle). Moreover, the hospital should provide support for the introduction of information science and technology, which can effectively promote medical service safety. At present, however, medical industries are still looking into the introduction of RFID because a sufficient number of studies and success application demonstrations regarding the application benefits of the system is still lacking. In addition, under the policy of health insurance for all, Taiwan's hospitals have to take a conservative stance on expense disbursement in order to maintain normal operations. From the individual case analysis, we can clearly note the practical benefits of RFID, such as automatically obtaining physiological information, integrating rest homes, expanding the medical service scope, intensifying the recognition of patients in the operating room, reducing mistakes, sending warnings when emergency situations occur and promptly displaying disease information to relevant people.

From the narrative statistics in the questionnaire survey, almost all respondents agreed that the introduction of RFID would improve the recognition of patients, effectively prevent various mistakes, help promote work efficiency and strategically collect management information. Moreover, the data regression analysis also proved that RFID can promote medical service safety.

In summary, some medical disputes, such as misdiagnosis by a hospital and the misuse of medicine, have increased annually. Such errors threaten patient safety. Unlike the general industry, hospitals are directly related to patient life and health. With such vital reasons, hospitals should implement advanced technologies such as RFID to mitigate these types of medical risks. By the use of RFID technology, a hospital's operation will lead to the increased accuracy of a doctor's advice and reduce mistakes such as the misuse of medicine. RFID can indeed make considerable contributions to hospital management and medical service security. In the abstract of this paper, we mentioned that with the international reform in medical management systems, hospital managements have gradually begun to improve in several aspects – from medical expense control to the improvement of medical service quality and patient safety. Obviously, medical safety will inevitably be an important factor for hospitals as they improve their management policies in the future.

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Notes

1 Consortium Hospital Medical Quality Appraisal Commission, http://www.Tjcha.Org.Tw/, called CHMQAC in this article.

2 According to a 1999 report on medical error by the Institute of Medicine of the USA (IOM), there are approximately 98 000 people who die from medical error every year in the USA (Institute of Medicine, 1999). This report aroused attention towards the medical service process and pointed out that medical service is no longer a service of infallibilities and zero risk because of human limitations.