# RTLS-based Ubiquitous Healthcare Management System Design and Implementation

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Abstract:

The healthcare system in the United States has been identified as one of the most “complex systems” and has suffered from ineffective logistics management, patient safety concerns and escalating costs. Real Time Location Systems (RTLS), an application based on ubiquitous computing, is recognized as a new application that will increase the visibility and operational efficiency of clinical and administrative workflows in the healthcare setting. In this paper, we propose a hybrid framework to implement RTLS in hospitals according to the theory of Information System Design Theory, Lean Management and Task-Technology Fit. This paper also presents performance matrixes to evaluate key technologies and criteria to set the resolution level for tracking objects. Business rules are designed for mining the valuable information from collected real-time data. The findings of this paper will facilitate the integration of RTLS into the clinical environment to reduce cost, optimize standard operation processes and improve dynamic medical services. A case study in a Veterans Affairs Medical Center is presented.

## 1. Introduction:

Healthcare is considered the fastest growing business and largest service industry in the world (Purbey et al.2007). Thus, to cope with this expansion, the healthcare industry must change its traditional operations and deploy a new information system to manage unpredictable processes and supply accurate responses in time (Li et al. 2008). At the same time, many hospital facilities are currently challenged by increasing financial pressure, patient and staff safety concerns and ineffective medical supply management. Some surgeries have to be delayed due to stock-outs or lost assets (Unnithan et al.2008), which can lead to the lower satisfaction level by patients and family members due to an increase in waiting time or length of stay. Many of these problems share a common cause – a lack of ‘visibility’ into the real-time location, status, and condition of patients, staff, medical equipment, and other mobile assets. This requires hospitals to deploy a new integrated system to visualize physical objects with corresponding clinic processes at the right time and location.

‘Ubiquitous computing’ was developed by Weiser (1991) to compose a vision where computing power becomes invisibly integrated into the world around us and accessed through intelligent interfaces, which is also called the ‘Internet of Things,’ from its original linking and sharing of computers and documents to currently connecting with personnel. With the exploitation and exploration of technology innovation, it is possible to create a context-aware environment where hardware and software components can seamlessly and spontaneously interoperate to supply services regardless of the unique requirements of the environment (Saha. et al. 2003).Many fields within businesses and institutions have deployed the ubiquitous computing technologies to develop context-aware services, varying from small intelligent spaces to large virtual enterprises (Esposito et al. 2007). Radio-frequency Identification (RFID) is one of the key enabling technologies behind the vision of the 'Internet of Things' and has been identified as 'the next evolutionary step in Automatic Identification Data Capture (AIDC) technology' (Lu et al, 2006). Since RFID tags use radio waves to identify, track, and trace individual objects accurately and automatically in real time, the capability of capturing data triggers the enormous attention and expectation that RFID technology can improve supply chain visibility, operation efficiency, and asset management (Ngai et al., 2007).

Healthcare is believed to be 'the next home for RFID' (Tzeng et al., 2007). As Fisher and Monahan(2008) stated, RFID is an emerging technology which is quickly becoming the standard for hospitals to track valuable assets, identify and locate patients, and manage medical personnel. There is great potential for improving the quality of medical services and increasing the productivity of value-added operations (Kuo et al., 2008). Consequently, the integrated information system 'Real-time Locating System (RTLS)' is selected as an extremely promising system to improve safety, quality, and the overall value of healthcare to address a wide array of issues in the medical industry.

However, implementing RTLS in a healthcare setting is considered to be challenging and complex, which has the potential for considerable costs. To date, many healthcare facilities have only implemented small-scale trials or installations. While there have been a fair amount of academic papers that discuss the types of the applications currently implemented with RTLS technology, there have been few academic publications focusing on the system design and implementation process in the healthcare sector.

This research is centered upon a strategic plan by the Veterans Healthcare Administration (VHA) to deploy RTLS technology across their medical centers. The VHA plans to deploy a single RTLS platform for all facilities. Currently, two Veterans Integrated Service Networks (VISNs) have been selected as test sites and will be trying multiple technologies against similar use cases or applications.

In the paper, we propose a strategy for an RTLS-based Ubiquitous Healthcare Management System (UHMS) design and implementation, which will facilitate the integration of RTLS into different clinical environments for cost reduction, process optimization and clinical service improvement. The rest of this paper is organized as follows: a) a brief overview of previous RFID (RTLS) designs and implementations in healthcare; b) an analysis of the challenges in deploying RTLS in a hospital, c) a description of the proposed methodology to design and develop a UHMS, d) an implementation of an RTLS-based system in a hospital and e) concluding remarks on the study and future research.

## 2. Previous study in RTLS implementation

With the exploding growth of RTLS applications in asset management and patient tracking, the need to define a methodology for the prototype of ubiquitous healthcare management system (UHMS), and guide a road map for the implementation, has aroused academic attention. However, there are few published articles related to the development of an information system design theory for an RTLS-based healthcare management system. A brief review of literature is presented below.

'Action research' is an iterative process, with researchers and practitioners acting together, diagnosing problems, actively intervening to achieve enhancement and reflective learning (Susman, 1983). Unnithani et al. (2008) investigated an action research framework for a pilot implementation of RFID in a large hospital, involving the cycles of situation diagnosis, action planning, action taking, evaluating and specifying learning. Wu et al. (2008) discussed a number of challenges that have hampered the adoption of RFID in organizations, including technical settings, standard settings, lack of infrastructure, high costs, and migration problems. Curtin et al. (2007 ) explored a research agenda to address a series of broad research questions related to how

RFID technology (1) was developed, adopted, and implemented by organizations; (2) was used, supported, and evolved within organizations and alliances; and (3) has impacted individuals, business processes, organizations, and markets. The difficulty and cost to control the real-time data from tagging and tracking was also noted. Based on participant observation and interviews with hospital staff members and industry consultants, Fisher et al. (2008) found that organizational factors contributed to the success or failure of the RFID systems in hospitals and suggested taking into account privacy concerns and the increased workload for hospital staff, especially during the implementation process. In the research by Ngai et al. (2009), a prototype of the RFID-based healthcare management system was built and implemented in a quasi-real world setting. By describing four components of Information System Design Theory (Kernel theories, meta-requirements, meta-design, and design method), several RFID-enabled processes, such as patient identification, location tracking, and drug inventory management, were analyzed and designed. Ting et al. (2009) composed 11 steps in the preparation, implementation, and maintenance stages of constructing a RFID project in a medical organization. Ting conducted a case study to illustrate the 23 critical success factors that should be taken into consideration in the development framework.

## 3. The challenges in deploying RTLS in a hospital

Although researchers and practitioners have provided useful insights for successful deployment, the research on designing and implementing an RTLS-enabled system in the healthcare industry is still in its infancy. Some studies (such as Ting et al.2009) suggest that the first step for implementation is to visually represent the current state processes via a set of prevailing process mapping methods. However, few papers pointed out the necessity of eliminating non-value-added activities based on the methodology of lean management. Duplicated or unnecessary work flows should be discarded or simplified in order to optimize the standard operation process and reduce tracking complexity before system implementation. Meanwhile, the design proposed by Ngai et al. (2009) has not covered all of the flows running in the daily operational management in a hospital and the potential adoption field, such as process engineering flow (reusable equipment cleaning in Supply Process Distribution (SPD)). In addition, business rules should be composed to analyze the real-time data and mine the significant information from corresponding tracking objects. Furthermore, preliminary steps of implementation, such as technology evaluation, tracking objects selection, and resolution level setting, have not been discussed deeply in previous studies. Finally, few researchers have demonstrated the importance of engrossing RTLS in the facilities' culture for the successful deployment of a new technology in the traditional working place.

## 4. Hybrid design and implementation framework for RTLS adoption in hospitals

Information Systems Design Theories (ISDTs) were defined by Walls et al. (1992) to be a prescriptive theory to integrate normative and descriptive aspects into design paths for designing information systems with more effective approaches. Based on designing principles and managing the effective development practice, ISDTs are considered as the guideline for adopters since they increase development reliability and the likelihood of success (Markus et al. 2002).
Ngai et al. (2009) demonstrated the product design and process design for RFID-based healthcare system according to ISDTs. Our research continues to explore the design and implementation methodology by combining ISDT with lean management and the concept of Task-Technology Fit for defining a comprehensive action plan.

Before implementation, project managers should consider the following questions: What is the compatibility of the solution with the existing environment and healthcare informatics system? What are the risk factors associated with using new or newer technology? Can the existing IT capability handle the data storm retrieved from RTLS? How accurate are tracking results? Compared to other technical solutions, how applicable is the RTLS approach to implement in hospitals? Is the potential ROI in an acceptable range?

The answer to these questions should clarify four basic concepts, which are 'why, where, when and how' to implement RTLS. The questions in detail could be described as follows: 1) Why should we choose an RTLS system? 2) Which applications and process are best improved or automated via an RTLS system? 3) When is a suitable time to implement it in practice? and 4) How can a facility best adopt the technology into their culture and daily practice? (Banks et al. 2007).

ISDTs define a design process in two aspects: 'Design Product' and 'Design Process', which includes the components 'Kernel Theories', 'Meta-Requirements', 'Meta-Design', 'Design Method', and 'Testable Design Hypotheses' (Walls et al. 1992). According to ISDTs, the proposed framework for designing UHMS to address the research areas is presented below in Figure 1:

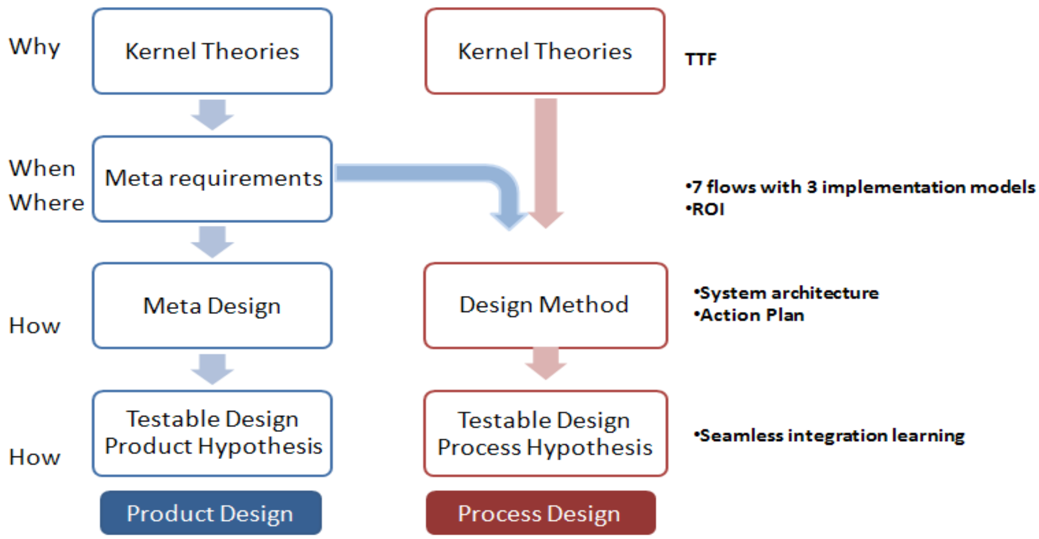


Figure 1: Framework for Designing UHMS

### 4.1.Why: Task-Technology Fit (TTF)

The Task-Technology Fit model proposed by Goodhue et al. (1995) is used to examine the impact of "fit" between task characteristics and technology characteristics on individuals. In order to explore the adoption of a new hospital information system, the concept of task-technology fit is applied to offer a suitable starting point as an adoption method of Kernel theories. By and large, the question 'why' to implement RTLS in a hospital will be addressed by a rather loose interpretation of TTF. Figure 2 depicts key components of the conceptual TTF model:

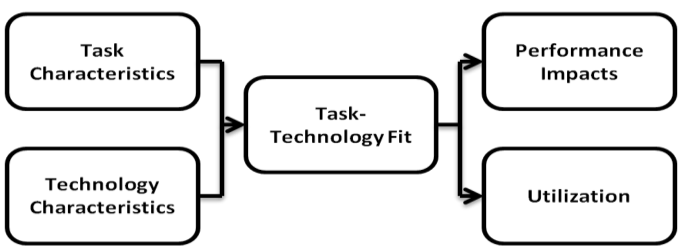


Figure 2: Key Components of the Conceptual TTF Model

The original TTF model provides some foundational factors to evaluate the adoption of technologies in completing tasks. Thus, we could borrow some of those factors for identifying important factors contributing to the adoption of RTLS in healthcare organizations. Considering the advantages of tracking the location and real-time information supplied from RTLS, the empirically testable prediction related to adopt RTLS for healthcare management improvement is summarized in Figure 3:

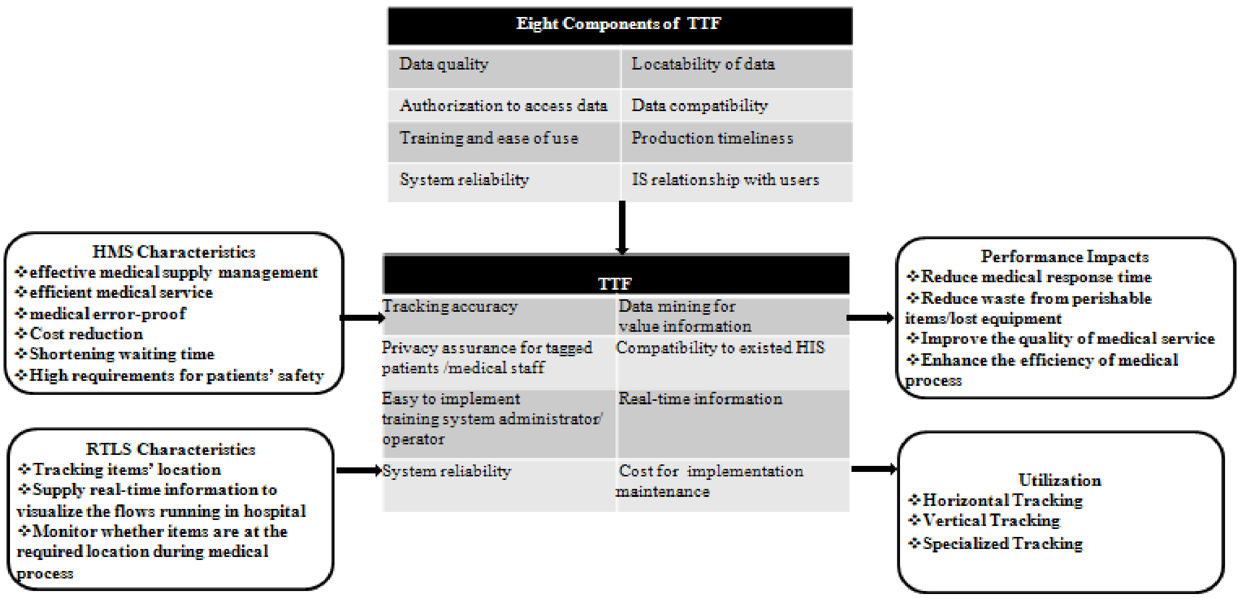


Figure 3: TTF Analysis to Adopt RTLS for Healthcare Management

### 4.2.Where: Meta Requirements

Meta requirements describe the class of goals to which the theory applies (Walls et al. 1992). These requirements are used to analyze the objectives or potential adoption of RTLS in a hospital. Based on lean management methodology, healthcare management has been subdivided to monitor and facilitate the seven flows running in the daily operation: the flow of supply, equipment, information, patient, clinician, medication, and engineering (such as cleaning reusable equipments). The initial deployment should focus on assets, people, and work flows which will deliver the highest return on investment and can be used as a foundation for future RTLS growth and system wide implementation. Thus, the primary problems involved with the time-sensitive and location-sensitive flows should be tackled first in order to have measurable outcomes.

In the past few years, RTLS technology providers have developed horizontal solutions for tracking assets and vertical solutions for monitoring work flows in manufacturing, warehouse management and retailer. However, healthcare is considered too unique to target since there are different types of specialized applications, such as standard operation process for cleaning reusable equipments. In order to optimize the seven flows running in the daily operations in a hospital, three of tracking models will be adopted to create the RTLS-based healthcare management system. The prototype with seven flows for UHMS is shown in Figure 4.

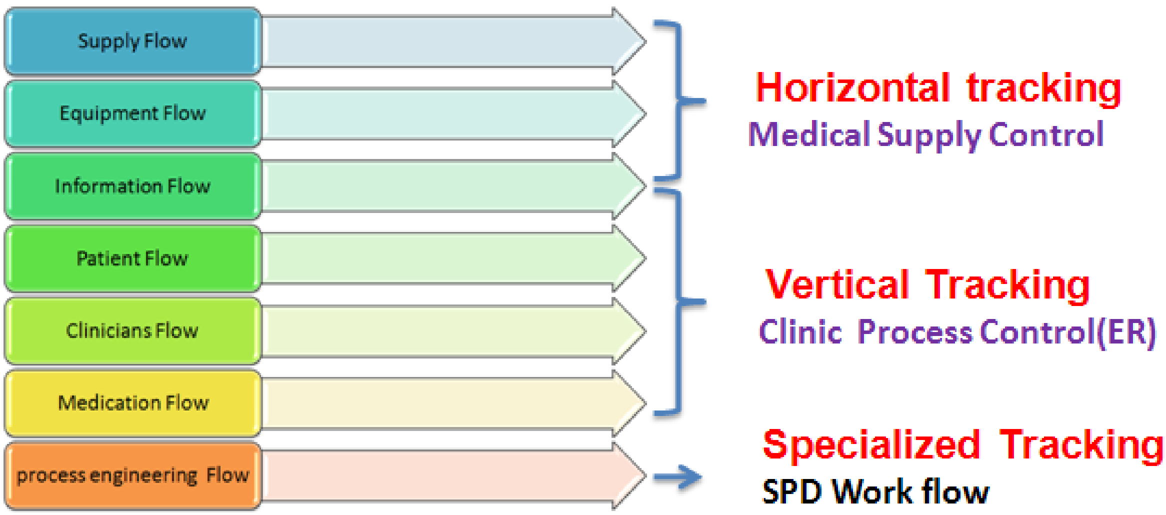


Figure 4: Prototype with Seven Flows for UHMS

### 4.2.1. Horizontal tracking model for medical supply control

Management of medical and surgical supplies is one of the targeted areas of early implementation when considering ROI in a hospital setting. Hospitals lose a considerable amount of money each year due to unexpected low stock of needed supplies, inaccurate on-hand inventory levels, and undetected expiration of supplies. Consequently, some medical treatments have to be delayed or cancelled due to the shortage or unavailability of required assets. Therefore, it is crucial to improve the visibility of medical supply management.

Meanwhile, the accurate location information of assets in a timely manner could decrease labor costs associated with searching misplaced items and reduce the revenue due to asset unavailability or duplication of purchases. This location tracking data could optimize the flows of supply, equipment, and information, and facilitate the horizontal management through multi-level inventories. Management of supplies in clinical areas such as the Cardiac Catheterization

Lab (CCL) or the Operating Room can be considered as early adoption areas since they typically have the most expensive supplies and the highest consumption rate.

### 4.2.2. Vertical tracking model for clinic process control

Significant problems as noted by Medicare's quality control indicate lengthy wait times and risks for medical errors as two of the top concerns in the industry. Among the seven flows, improving the quality and efficiency of medical service requires better organization of four flows, which are information flow, patient flow, clinician flow, and medication flow. Vertical management, which is designed to track objects according to the timeline of process operation, can be used to analyze and manage patients' location and status in the healthcare delivery process. The Emergency Room (ER) can be considered one of the most complicated and busiest areas in a hospital, where patients must receive adequate treatment in the shortest possible time. Considering the time-sensitive services in the ER, RTLS technology could be implemented as a solution to reduce waiting time and eliminate errors in clinical services.

### 4.2.3. Specialized tracking model for SPD work flow control

When considering patient safety, one can look at the cleaning process for reusable medical equipment (RME). This process is often complex and variable, which is dependent on the manufacturer and model of the device. Healthcare facilities often utilize Standard Operating Procedures (SOP's) that are based on Manufacturer's Instructions to guide staffs in SPD to complete the cleaning process thoroughly and consistently each time. To ensure the sterilization processes in proper operations, the specialized tracking model is in demand to monitor the work flows according to SOPs. Advanced autoclave tags could withstand rigorous sterilization processes including ultrasonic cleaning, high pressure liquid sterilization and steam autoclaving.
Consequently, autoclave tags with RTLS solution could allow hospitals to improve staff efficiency, automate SPD management and optimize RME reprocessing work flow.

## 4.3.When: Return on Investment

Before taking action to deploy the system, the Return on Investment (ROI) should be estimated. This estimation helps decide whether it is a good time to select this approach since the price points are coming down while technology is continuing to innovate. Estimating ROI analysis requires an understanding of the required investment for the project and a prediction of benefits that will be derived from RTLS implementation. The cost components for RTLS implementation are listed in Table 1:

| Cost Components for RTLS Implementation | |
|---|---|
| **Main Hardware cost** | RFID tags/ readers |
| | servers/client-end computor |
| | network swithes |
| | wireless access points/ signal amplifier |
| | other accessory equipments(such as PDA) |
| **Software Cost** | database |
| | data analysis package |
| | user interface system |
| | maintance fee |
| | updating fee& Frequency |
| **Integration** | hardware connection to existed HIS |
| | software integration |
| | customization cost for specific application |
| **Labor Cost** | training for internal staff |
| | new employees(System administrator) |
| | process analyst |
| | Support from other party(RFID experts, consultants) |
| **Installation Services** | setting up or update the network |
| | design the topology of RTLS infrastructure |
| | hardware installation, such as tags. Readers |
| | hardware/ software maintainance and management |
| | testing the performance of system after implementation |
| **Business Process Reengineering** | business process optimization |
| | new additional options with real-time information |

Table 1: The Cost Components for RTLS Implementation

As a key solution of Automatic Identification Data Capture (AIDC) technology, RFID could easily identify and track the location of items, which will release labor from the inefficient manual operations. When RTLS has been implemented in the healthcare industry, hospital should anticipate the expected benefits, which may happen to be quantitative data, from cost reduction, improve service performance improvement and increase revenue. These three key drivers for benefits are summarized in Table 2:

| Three Key Drivers for Benefits | |
|---|---|
| **Cost Reduction** | reduce required labor force /time |
| | reduce the medical supply shortage rate, emergent order, expiration waste and inventory level |
| | reduce the missing assets/rental rate of equipments |
| | reduce paper-based documentation |
| **Service Improvement** | increase capability of medical error-proof |
| | reduce the patients' revisit rate |
| | increase working efficiency |
| | increase patients' effective treatment time |
| **Revenue Increasement** | increase the amount of patients served |
| | increase the capability to serve patients from other hospitals |
| | speed up the revenue-capture rate |
| | increase the utilization rate of equipments |

Table 2: Three Key Drivers for Benefits from RTLS Implementation

### 4.4. How: Meta Design---→ logic Architectural system

In this section, the researcher will design an architecture framework of the RTLS-based UHMS, which consists of seamless control in the three main adoption areas. The logic of the architectural system and functions of each flow are described as follows in Figure 5. The architecture framework of the UHMS is consisted of seven flows (Information Flow, Patient Flow, Clinicians Flow, Medication flow, Supply flow, Equipment Flow, Process Engineering Flow). The new designs of each flow based on RTLS are also described below:

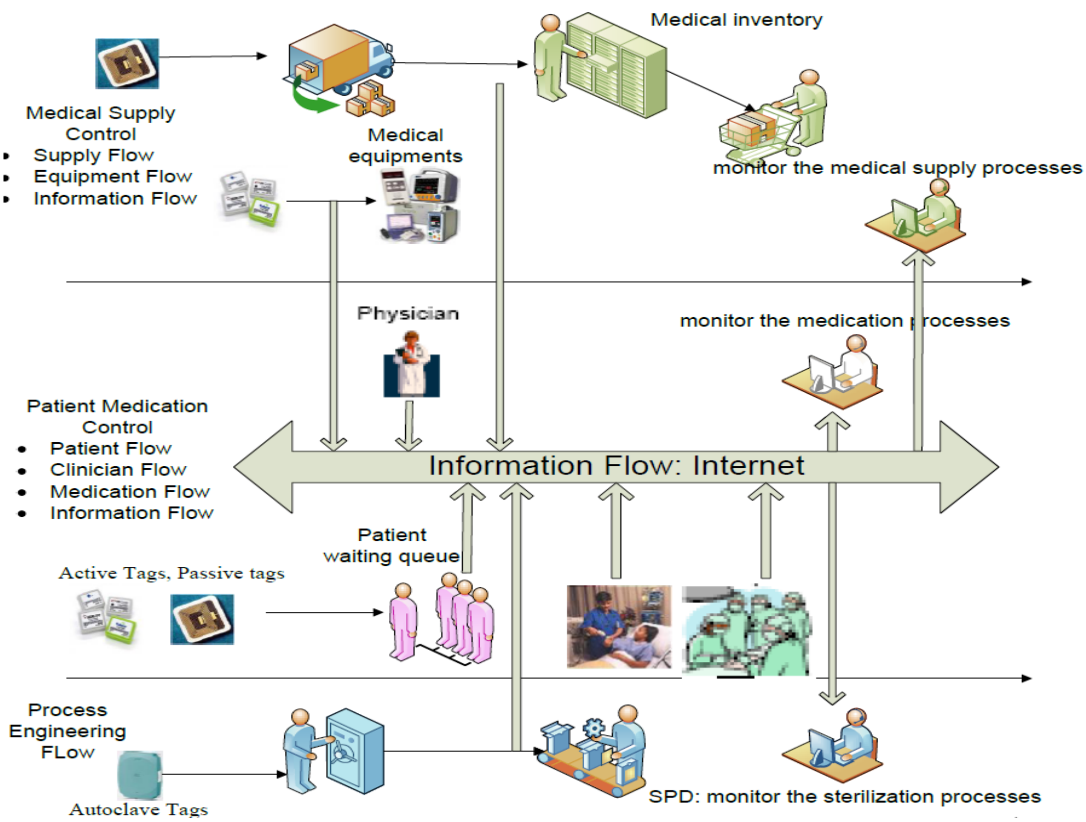


Figure 5: The Logic of the Architectural System

### 4.4.1. Information Flow

RFID wristband will be issued to every patient at the registration step and will be worn patients during the entire hospitalization period. Some important patient information (such as name, patient ID, drug allergies, clinicians on-duty) will be stored in the RFID wristband in order to identify patients accurately. The status of process for delivering healthcare and diagnosis results will be transmitted efficiently based on electronic files. This could eliminate the risk of medical errors and release medical personnel from manual entries for all required data and paper reports.

### 4.4.2. Patient Flow

During the clinical process, patients always move to different locations for diagnosis, such as blood testing and X-ray examination. Sometimes the clinical processes have to be delayed due to the absence of patients, for example, patients do not come to their appointment ; they leave the hospital against medical advice; clinicians can't find the patient in their hospital room. Consequently, clinicians need to spend time searching for them or rescheduling the treatment.

This unexpected change will slow down the original process and involve some non-value added operations. The rate of ‘patient’s leaving against medical advice and without being seen by a provider’ is one of the key factors to consider when evaluating the performance of clinical services. Based on the middleware integrated in RTLS, a reminder alarm will be sent to corresponding clinicians to notify when patients leave unexpectedly. Meanwhile, RTLS could monitor the procedures that patients are receiving, such as the status of process and the staff members that are providing services. This could help the quality management department to record each step of the clinical process and improve the quality control of medical treatments.

#### 4.4.3. Clinician Flow

Normally, a group of clinicians, such as physicians, nurses, and technicians, cooperate to serve patients for specific medical treatments. In order to classify clinicians into different groups and identify them easily as shown on the management portal, unique color-coded RFID badges combined with an ID number could be issued to each group of clinicians. Once the location of clinicians is tracked in this system, the length of valuable time they spend treating patients could be easily estimated, which might be used as objective evidence to demonstrate the performance of clinicians. In addition, an advanced function could be designed in RTLS middleware to better assign clinicians to specific patients nearby based on their location and the particular service they could supply.

#### 4.4.4. Medication Flow

Delivering the right medicine to the right patient at the right time is crucial for patient safety and effective medical diagnosis. When small RFID labels are tagged on each drug container for a unique patient as well as the original containers from the pharmaceutical factory, the location of the medicine could be roughly tracked. Some primary information, such as quantity, inventory level, and expiration date could be written on the RFID labels, which could facilitate automatic reminders for removing expired and recalled product items from the inventory shelves.

#### 4.4.5. Supply Flow

In supply chain management, there are three flows running in logistics operations: Information Flow, Material Flow and Money Flow. RTLS as an advanced automatic data capture system could facilitate the information flow, sharing information during the whole logistic management process. The benefits of RTLS implementation in perishable medical supplies are shown in Figure 6:

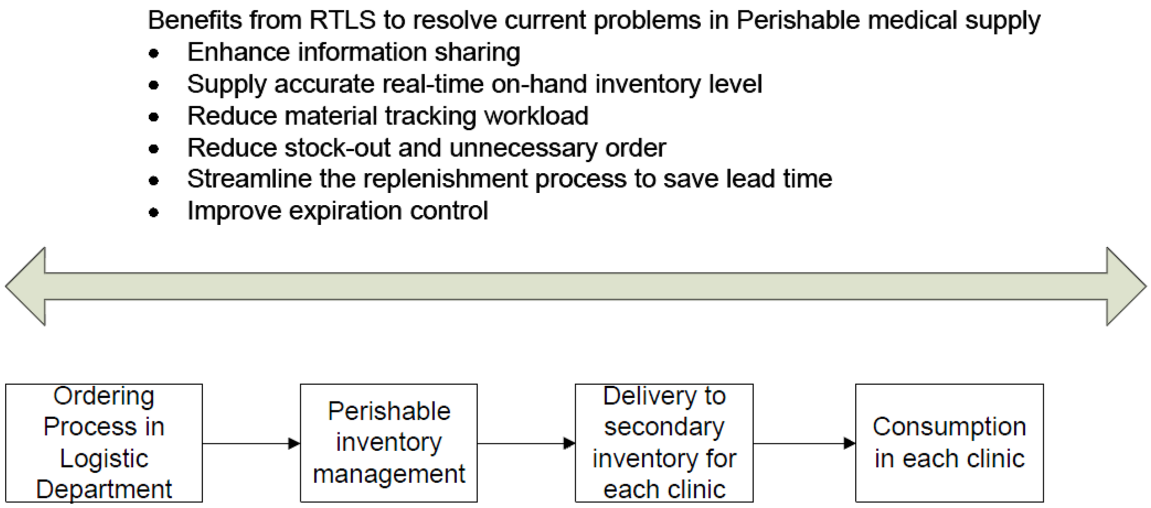


Figure 6: Benefits from RTLS Implementation In Perishable Medical Supply

#### 4.4.6. Equipment Flow

Misplaced or lost equipment can sometimes postpone medical treatment. When this happens, the logistics department must rent equipment from nearby hospitals. Attaching RFID tags to the equipment makes it easier to track their location and status, such as ‘available to serve’ or ‘in-use’. Consequently, the time need to physical search for it will be dramatically reduced, and the preparation process for surgery or medical diagnosis is also improved. Furthermore, an alert could be triggered if equipment is moved without clinicians’ permission. This could eliminate the loss from stolen equipment.

#### 4.4.7. Process Engineering Flow

For this section, we will mainly focus on SPD workflow reengineering based on the deployment of RTLS. By implanting autoclave tags, the location of reusable equipment during the cleaning process is tracked and verified to avoid skipping steps; the temperature and pressure are monitored following standard operation process (SOP) rules; and the length of time for each cleaning step is recorded to ensure an adequate sterilization period. Meanwhile, Real-time visibility ensures that critical washing machines are available when needed, thereby increasing working efficiency, shortening SPD preparation time and increasing throughput. In addition, automated SPD management of RME equipment in multiple locations is continually maintained, enabling better planning and scheduling of reprocessing operations. Based on the location information, RTLS could identify the status of RME equipment in the cleaning and sterilization process, such as wait-in-queue, work-in-process and finished. This will eliminate duplicating operations when some RME equipment has already completed certain steps.

## 5 Implementing an RTLS-based system in a hospital

Although RTLS is an outstanding technology which can enhance healthcare system efficiency and automation, actual implementation of the technology can result in substandard and ineffective systems without a comprehensive pre-study that involves site visitation, an understanding of the technology, and rigorous implementation plans. The phase of 'design method' in ISDTs will be described in the following section.

### 5.1. Process mapping and optimization prior to RTLS procurement

To support an optimal RTLS deployment, a graphic representation and written assessment study of the current state of work flows should be provided. This section will outline the key processes that are relevant to RTLS applications and/or key process performance metric variations, work standards and requirements, and the individuals involved. It is important to categorize similar work flows into unique groups. This could simplify process mapping processes and identify work flow patterns in order to reduce the complexity level for implementation. Based on lean management methodology, non-value-added activities should be eliminated to optimize standard operation processes and reduce cycle time. Finally, the suggested areas for automation utilizing RTLS technology and potential qualitative/quantitative measurements for improvement should be provided. A case study from a catheterization lab in one VA facility is shown below in Figure 7. The current steps which could be 'improved' by RTLS and non-value-added steps should be deleted are also highlighted.

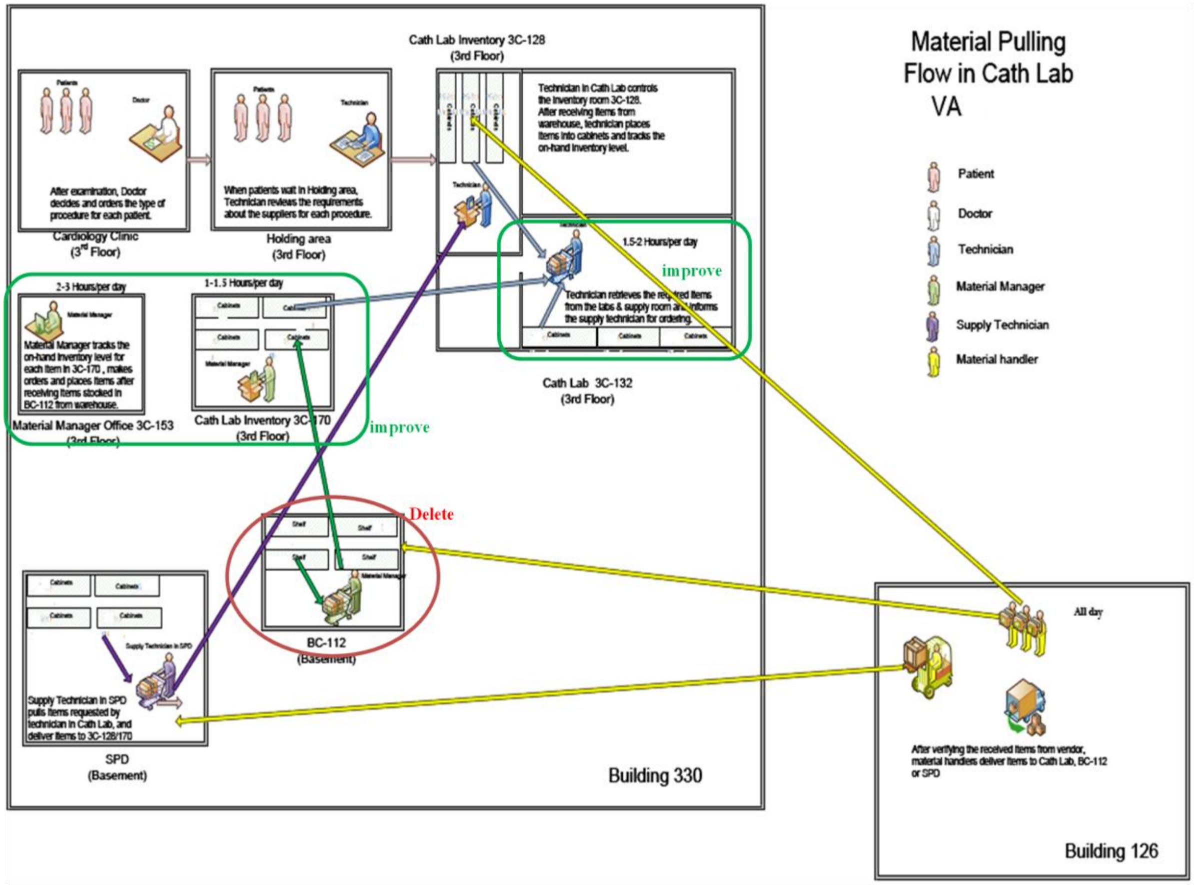


Figure 7: Process Mapping and Optimization from a CCL in One VA Facility

### 5.2.Evaluating Technology and Vendor Performance

Typically, an RTLS system consists of several components, including tags, readers, and antennas. The tags are used to store the unique identification information of tagged objects; the readers are responsible for detecting and communicating with tags to extract information through the antennas coupled to them. Numerous types of RTLS technologies are emerging to support Service, Business and Support functions, such as Wi-Fi, Zigbee, UWB, Infrared, and active and passive RFID systems. However, no one form of RTLS technology can satisfy all requirements. Different resolution levels, costs to deploy the hardware and software, and interference from other medical and support equipment with RTLS are some of the primary obstacles. Consequently, the selection and evaluation of suitable solutions to meet specific objectives is essential to the success of an RTLS implementation. In our research, 12 factors have been identified to evaluate the strengths and weaknesses of each type of technology, shown in Table 3:

| Technology Evaluation | | | | | | |
|---|---|---|---|---|---|---|
| | Passive RFID | Active RFID | Wi-Fi | Zigbee | IR | UWB |
| Adopter Environment | indoor | indoor | indoor/outdoor | indoor | indoor | indoor |
| Cost | low | high | medium- high | low-medium | low-medium | high |
| Signal Frequency | 0.125–0.1342, 0.140–0.1485, 13.56, 840–960 MHz | | 2.4GHz | 915 MHz (USA),2.4GHz | 300-10000GHz | 3.1-10.6 GHz |
| Signal Coverage | low | medium | medium-high | low | low-medium | low |
| Resolution Level | room level | room-zone level | zone-building | room-precision | room | precision |
| Accuracy | 1M-10M | | 1M-10M(more) | 5M-8M | 8M-10M | 0.1M-0.5M |
| East to extend more functions | not available | | available | not available | | |
| Date Rate | 0-10Mbit/s | | 10Mbit/s<, <100Mbit/s | 0.01Mbit/s<, <0.5Mbit/s | <40 Mbit/s | 100Mbit/s<,<1000Mbit/s |
| Battery Consumption | no | low | high | low | medium | high |
| Resistance to Interference | medium | | high | Medium | low | high |
| Information Encryption | yes | | yes | yes | no | yes |
| Metal/Water Content | not suitable | suitable | | | | |

Table 3: 12 Factors for Technology Evaluation

High tracking accuracy requires higher technology and maintenance costs. Among these 12 factors, the Resolution Level for tracked objects is a key factor to choose technology solution and design architecture. Seven primary characteristics of tracking objects are suggested to define the resolution level, shown in Table 4:

| Resolution Level Setting | |
|---|---|
| Characteristics of tracking objects | Resolution Level Setting |
| The medical items with high priority | Precision level |
| The medical items with Low priority | Room Level |
| Large medical equipments | Room-zone Level |
| Personnel | Room-zone Level |
| Reusable equipments for surgery | Precision level |
| Medicine | Precision level |
| sample for lab (blood) | Precision level |

Table 4: Resolution Level Setting

With the wide-spread adoption of RFID technology, numerous vendors are anxious to join in this new market. Based on feedback from previous implementation sites and the facility-specific requirements identified in the evaluation, a Performance Matrix for vendor selection is shown in Table 5:

| Performance Parameters for RTLS selection | |
|---|---|
| **Category** | **parameter** |
| Function requirements | locating error rate |
| | real-time information(data update frequency) |
| | scope of signal detection |
| Handware | tag:<br>easy to ware/operate<br>small size/ low weight<br>long battery life<br>strength of signal |
| | integration of third-party devices |
| | additional hardware installation |
| Software | adaptive to existed database |
| | friendly user interface |
| | easy to configurate the system |
| | supplied software function |
| | frenqucy to update system |
| Business Rule | event definition |
| | data mining |
| Cost | price for hardware/software |
| | hire additional personnel to operate/monitor |
| | maintenance costs |
| | update cost |
| Service support | system warrenty scope/period |

Table 5: Performance Matrix for vendor selection

### 5.3. Selection of tagged objects

In a healthcare setting, there are numerous complex processes that involve the movement and relationship between equipment, staff, patients, and supplies. Considering the cost of hardware and the data processing capability of middleware, it is crucial to analyze the criteria to prioritize the tracked objects when considering the ROI a facility will initially receive. As an example, when considering which medical supplies to track in a CCL, we interviewed staff members, developed eight factors and suggested rules as listed in Table 6 below:

| Selection of Tagged Objects | |
|---|---|
| **Factors** | **Suggested criterion** |
| Price | item with price more than $ 100 for active tags (based on budget) |
| Consumption rate | fast-moving item |
| Easy to order | item with specific characteristics / long production time |
| Expiration date | item with short life time |
| Level of perishable risk | item with high risk for safety if it's perished |
| Moving frequency | item / personnel moves frequently between multi-locations |
| Priority of responsibility in medical treatment | medical staff who has high responsibility to serve patients |
| Severity of disease | patients who are at high severity level for life safety |

Table 6: Eight Factors and Suggested Rules for Selection of Tagged Objects

### 5.4.Business event definition and objectives

Although RTLS can successfully track the location of assets and personnel in real time, RTLS can also provide support for other business processes. To assist with identifying these business cases, designers must provide a means to document the potential event resolutions within each RTLS application. A complex clinical path could be represented as a chronological sequence of events. Each event occurs at an instant time and marks a change of state in the operation. Based on the Discrete-Time Methods for the analysis of event composed by Allison (1982), there are two alternative approaches. One is to assume an underlying continuous-time distribution and then estimate the model's parameters by methods that take into account the discrete character of the data. The other approach is to simply assume that events can occur only at the discrete intervals measured in the data and then apply discrete-time models using logistic methods. Our model is designed based on the latter approach. Based on the analysis of important steps, the whole process will be divided into sequential events and phases. For each event, an assigned milestone is used to define the beginning and ending point for an important event. Consequently, the objectives for each event and the aspects of elimination and improvement should be clarified. For example, the performance of a healthcare delivery process in an ER from one VA facility could be measured by these discrete event points with non/value added analysis by red/ green color as shown in Figure 8.

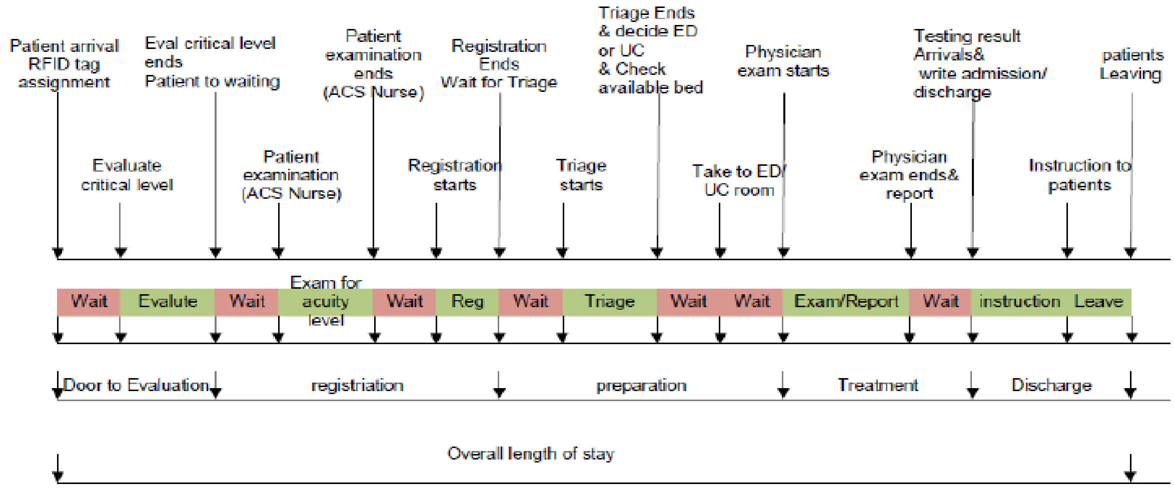


Figure 8: Discrete Event analysis for medical process in ER

Meanwhile, only the information about Location (equipment, patient) is insufficient to assist medical staff in decision-making. For example, a technician is looking for an available wheelchair, requiring information about the location and occupied status of other patients synchronously. Business rules are designed for mining the valuable information from collected real-time data and creating links to combine two corresponding tracking objects. These rules are also called the rules engine. There are two primary components to set up a business rule for each event:

Conditions: the requirements which must be met in order for the rule to be applied.

Action: the action which should be taken when this condition is met.

An example of condition is the locations of a wheelchair and patient are identified at the exact same time. An example of an action is the wheelchair is occupied and not ready to serve others.

### 5.5.Getting the Right Cultural Emphasis at the Right Time for RTLS

Tapp, et al (2003) discussed four primary reasons that ERP implementations fail. They are (1) inadequate education/training, (2) poor leadership from top management, (3) resistance to change, and (4) unrealistic expectations. Individuals are the key enablers in creating the right culture to adopt the new technology at the right time.

The three "value disciplines" to guide IS implementation successfully are product leadership, customer intimacy and operational excellence. In an early adopter field, it is critical for a project manager to press forward with "product leadership" but to do so with "customer intimacy" so that the project manager can learn what constitutes a full solution that will produce a compelling ROI. This requires the adopter's technical and business partners to work closely with each customer to identify the business processes that can be eliminated, automated, or otherwise improved through the introduction of the newly proposed technology.

The education and training of end users and the implementation group will play an important role in designing realistic expectations for benefits gained from new technology. The education could help everyone understand the aims and action plans to adopt the system, update and communicate with stakeholders. End-users are sometimes resistant to change, which is perhaps the greatest obstacle holding hospitals back from deploying new technology.

Operational excellence drives doing the same things faster, cheaper, and better—which is good only when you are sure that you are doing the right things in the first place. This requires establishing an excellent solution team with key technology experts who lead the design of the system infrastructure, project managers who own the business process, user representatives from adopter, IT technology members, and vendor members.

**5.6. Testable design hypotheses**

Basic Function testing will evaluate the fundamental performance of the RTLS system under normal operating situations after implementing it in early adoption and implementation applications. Several key factors should be considered during the testing phase, shown in Table 7:

| Key Factors to Test Fundamental Performance of RTLS | |
|---|---|
| Signal overage scope | Locating accuracy |
| Error rate | System compatibility |
| Data processing capability | User interface |

Table 7: key factors for basic function testing

Pressure testing is addressed to verify system reliability under extreme situations when the key components or operations are out of control. Specific experiments are designed to test the performance if tags/readers have large density, hardware fails, or software collapses. Finally, the implementation team should provide documentation of end-state and assessment of RTLS implementation within initial implementation areas and expand the deployment process by estimating the strategy value and reengineering previous business processes.

## 6 Concluding remarks:

According to the theory of Information System Design Theory (IDST), lean management and task-technology fit (TTF), this paper presents a hybrid design and implementation framework to implement RTLS in a hospital. The contributions of this research are the infrastructure for 7 flows with horizontal, vertical and specialized tracking models and its implementation prototype. This system infrastructure has proved to be extremely comprehensive to address four groups of questions (‘why, where, when, and how’) when implementing RTLS in a hospital. We also provide the technology selection criterion as a primary step in the design framework and explore the methodology for Revolution Level Setting and Tracked Object Selection. This study has demonstrated an action plan based on the proposed architecture. Process mapping and optimizing current process could reduce the complexity of implementation. To evaluate the technology and vendor performance, we collected the feedback from previous pilot sites and summarize here the key factors. Business rule setting is recognized as one of the primary steps to retrieve real-time data more efficiently to mine valuable information. We believe the culture creation could reduce user resistance to adopt new information systems in their traditional work style. Evaluation of system performance after implementation is also discussed. It is hoped that a deep understanding of the design and development of RTLS in the healthcare sector will provide guidance for the successful implementation.

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