RFID TECHNOLOGY SELECTION AND ECONOMIC JUSTIFICATION FOR HEALTHCARE ASSET TRACKING

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ABSTRACT

RFID Technology Selection and Economic Justification for Healthcare Asset Tracking

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Although Radio Frequency Identification (RFID) and Real-Time Location System (RTLS) technologies for inventory tracking have been growing in popularity, the healthcare industry has been reluctant to adopt these technologies. One of the primary reasons for this lack of enthusiasm has been the risk associated with electromagnetic interference between RFID/RTLS systems and medical equipment functionality. The other reason has been the substantial cost and complexity of implementing RFID/RTLS in healthcare organizations.

In this study, we show that there are several ways to safely install RFID/RTLS systems to improve the inventory management processes of hospitals and clinics. We then analyze the inventory shrinkage (loss and theft) data of the Veterans Health Administration VISN 10 (the Veterans Integrated Service Network of Ohio) using a mathematical model to estimate the annual shrinkage. Finally, we develop an economic cost/benefit analysis database system in Microsoft Access that can be used to calculate the breakeven point of RFID/RTLS implementations, as well as calculate the expected reduction in inventory-related operating costs. This system can be adapted for cost/benefit analyses in similar inventory-intensive environments.

Keywords: RFID, RTLS, healthcare, shrinkage, economic model

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1 Introduction

1.1 Research Motivation

Radio frequency identification (RFID) and Real Time Location Systems (RTLS) are rapidly growing sets of technologies aimed at tracking and recording the presence of entities. RFID/RTLS popularity and implementation rates increased significantly a decade ago due to supply chain mandates issued by Wal-Mart, the U.S. Department of Defense (DoD), Target, and other major supply-chain companies and entities. The usefulness of RFID/RTLS lies in the ability of such systems to economically track objects through a warehouse or supply chain using radio waves at high speeds [1]. Because items are tracked using radio waves, tracking does not require line-of-sight (LOS). The main alternative to RFID/RTLS is barcode scanning, which requires LOS, thus short read range (typically only up to 1') [2]. In contrast, RFID/RTLS systems used for inventory tracking and management have reading distances ranging from several inches to several hundred feet, depending on the specific RFID/RTLS technology. In fact, GPS (Global Positioning Systems) that have read ranges of several miles can also be considered RTLS [2]. The capability of RFID/RTLS to capture large amounts of identity and location data almost instantaneously makes these technologies powerful industrial tools, as they can improve inventory management using minimal levels of personnel and equipment [2].

In many industries, large amounts of inventory are unavoidable, and large inventory systems that lack an effective RTLS solution are susceptible to shrinkage (the loss of inventory due to theft or misplacement). Shrinkage cost can be substantial, thus companies and service organizations spend extraordinary amounts of money tracking and managing inventory. With RFID/RTLS, inventory can be tracked more efficiently, thus greatly reducing both shrinkage costs and labor costs. In many industries, the annual savings exceed the cost of implementing RFID/RTLS, resulting in a payback period as short as several months. The healthcare industry is no exception. The size of the healthcare industry combined with its well-documented costs and inefficiencies call for using RFID/RTLS technologies to reduce labor and inventory shrinkage cost [3], [4].

1.2 Purpose

Each year, hospitals and clinics lose significant amounts of money due to lost, stolen, and inefficiently allocated equipment, but refrain from implementing RFID/RTLS due to the fear of interference with critical healthcare equipment and the fixed cost associated with system development and installation. The purpose of this study is to develop the economic justification of using an RFID system to track inventory in a hospital without causing electromagnetic interference, or EMI, with any nearby piece of healthcare equipment. If the system is implemented in such a way that it avoids EMI, hospitals can be shown to benefit from an RFID system in both the accuracy of information and the speed at which it is collected. Hospitals will no longer be falling behind other sectors of industry in regards to inventory visibility.

1.3 Scope

Most hospitals have physicians, nurses, patients, and supporting staff. They also have expensive medical equipment, as well as a variety of ancillary equipment required to support hospital functionality. Many hospitals have similar inventory needs – equipment replenishment, calibration, and location tracking. This study develops a general economic justification model for RFID/RTLS for inventory tracking in hospitals. The model is customized for the types of equipment used in hospitals, but can also be modified for other types of organizations.

2 Background and Literature Review

2.1 How RFID Works

RFID is a system comprising a computer, a reader, antennas, and at least one RFID-tag. A picture of a generic RFID system is shown in Figure 1 below. The computer sends commands to the reader through a protocoled steam of data; typically through an Ethernet or a serial connection. These commands can be programmed for specific situations in using a low-level coding language, but most often the commands are drawn from a pre-set family of commands provided by the manufacturer. The types of commands fall into three different categories: read tags, write and kill tags, and adjust reader and antenna settings.

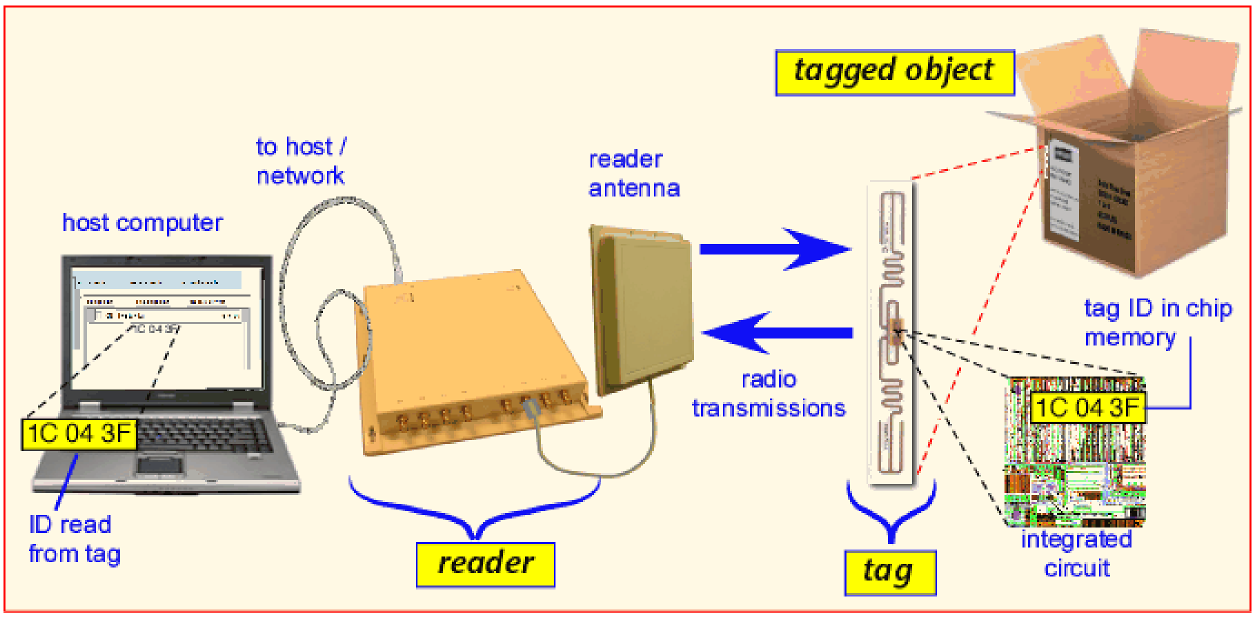

Figure 1: Generic RFID System Structure

Courtesy of PolyGAIT-The Cal Poly Center for Global Automatic Identification Technologies

There are three different types of tags: passive, semi-passive (or semi-active), and active. The difference among these tags depends on how much it uses an internal power source, a battery, to provide power to the tag. In a passive system, the sole power source for the tag is from the radio wave pulse generated by the reader's antenna(s). An active tag is one that is always broadcasting its information using a battery for its power. A reader antenna will pick up the information when it comes into range of the active tag. A semi-passive tag is similar to an active tag in that it broadcasts its information, but it waits until the reader antenna sends it a "wake-up" command. Once the tag is woken up, it will behave like an active tag until it returns to "sleep." Each of the different types of tags is shown below in Figure 2.

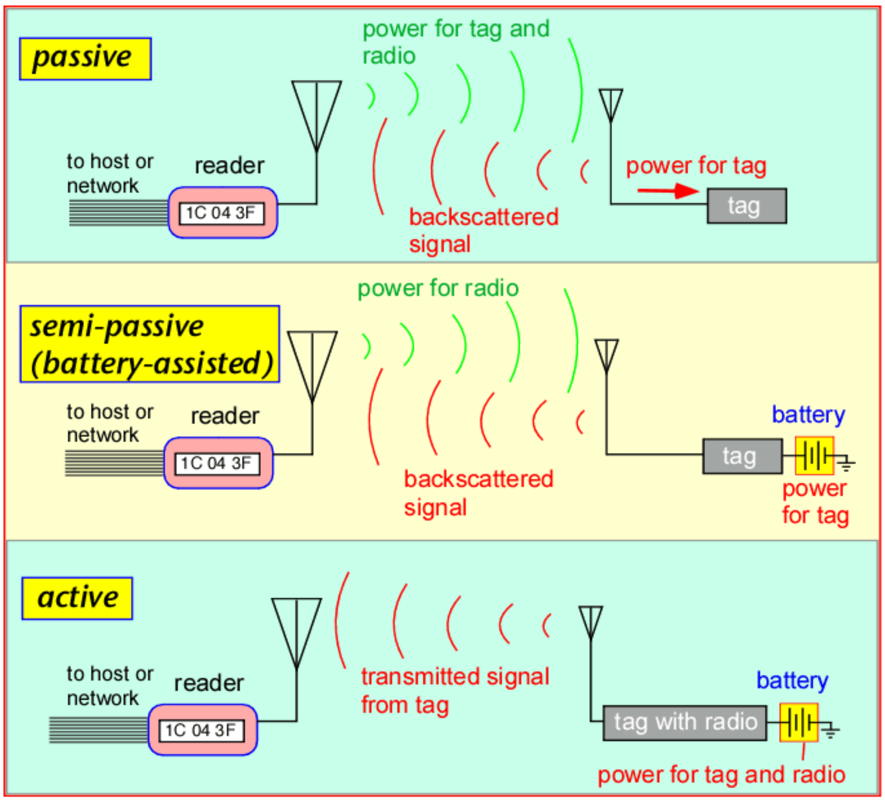

Figure 2: Tag Types

Courtesy of PolyGAIT-The Cal Poly Center for Global Automatic Identification Technologies

There are two different types of tags within the passive tag family: inductive and radiative as shown below in Figure 3. The differences lie in how the tag is powered and is aligned with the frequency of read.

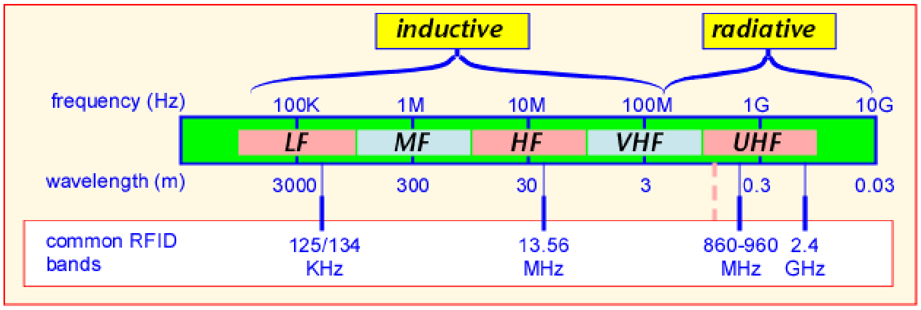

Figure 3: RFID Tag Frequencies

Courtesy of PolyGAIT-The Cal Poly Center for Global Automatic Identification Technologies

Inductive tags are used in the low and high frequency ranges, most commonly 125 KHz, 134 KHz, and 13.56 MHz. Most Radiative RFID tags work in the 860-960 MHz range or higher. There is a relationship between range, dense material penetration, and frequency. Generally speaking, the lower the frequency, the lower the range and the higher the material penetration obtained.

Shown in Figure 4 below isa typical passive radiative tag inlay consisting of an antenna, an IC, and a film substrate. Very often in supply-chain applications the inlays are "sandwiched" between two layers of paper with a sticker so they can be easily attached to objects that needs to be read.

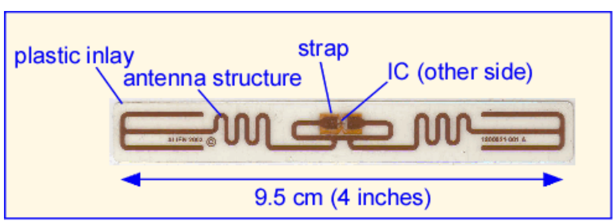

Figure 4: Tag structure

Courtesy of PolyGAIT-The Cal Poly Center for Global Automatic Identification Technologies

With the command from the computer, the reader sends out a pulse of radio waves through the antenna. If there is a compatible tag present within in the range of the waves, the radio waves will be absorbed into the tag's antenna, power the IC, read the identification number from the IC, and send back a pulse to the reader antenna containing its number. The reader then sends this number to the computer for further processing.

Ultra-high frequency (UHF) passive tags often have a 96-bit number in the form of a 24-character hexadecimal string called an electronic produce code (EPC). Similar to the UPC barcode standard, RFID tags have a standard which they follow in order to store various attributes about the product such as company, object class, and serial number. This format is useful because it allows for a structured, unique number for each tagged object. This number structure is controlled by the same organization that controls the barcode format: EPC Global/GS1. The format is shown below in Figure 5.

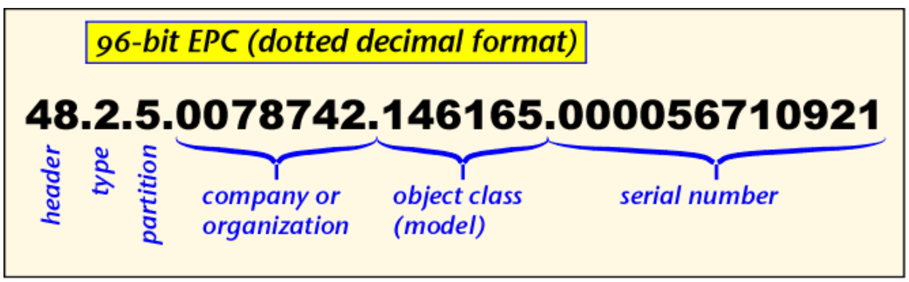

Figure 5: EPC Code Format

Courtesy of PolyGAIT-The Cal Poly Center for Global Automatic Identification Technologies

In nearly all cases, there will be a need to read multiple tags at once. In order to mitigate mixing the signals to and from the antennas, the reader and the tag will communicate with unique coded values for each tag. The unique coding process helps the reader to differentiate between various tags even when the backscattered signals are returned simultaneously. This process is shown below in Figure 6.

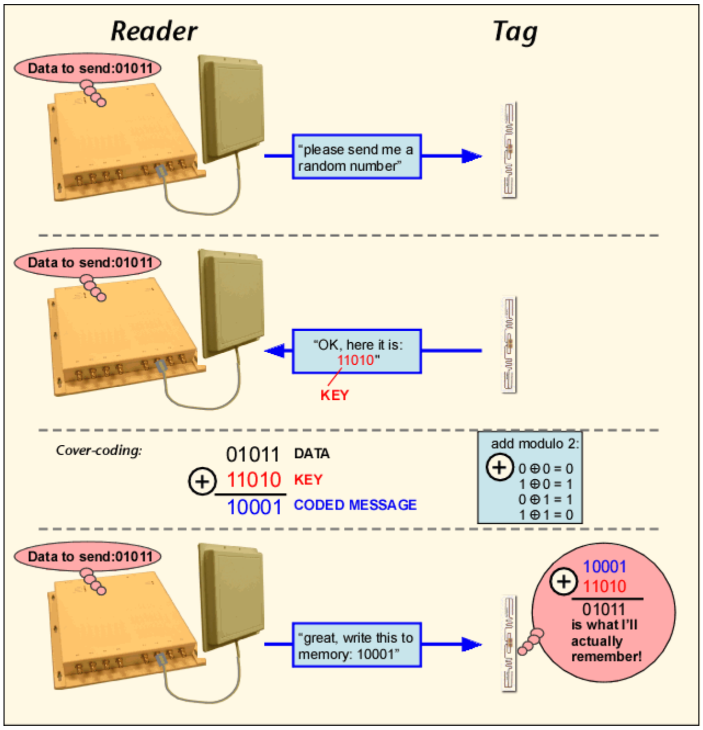

Figure 6: Coded Communication Between a Reader and a Tag

Courtesy of PolyGAIT-The Cal Poly Center for Global Automatic Identification Technologies

2.1.1 Primary Application of RFID/RTLS

RFID's primary benefit lies in its ability to gather data to provide visibility to a process. Many processes could benefit from real-time or batched data, but often the process of gathering the data is either too expensive or infeasible when done manually. RFID helps automate that process to provide data for, in many cases, a marginal additional operating cost. With this operational data, the process can be analyzed through a wide variety of different optimization methods including linear programming, simulation, time studies, statistical design of experiments, and many more. It also has significant advantages over manual data collection in both its ability to mitigate data entry error and speed of processing large batches of inventory in a single pass. There is no chance of false positives or typos, thus saving more time and giving more validity to the data.

RFID has alternative applications in other areas where there is no manual option available such as proximity-based security. In some systems, RFID can be part of a redundant identification system that can automatically log a user out of a system if they leave a “hot zone.” In high volume environments, RFID can be used to count objects moving at speeds too high for an operator to count by hand. This can be done in a limited fashion with a barcode system, but if RFID is used, it will be compliant for the other parts of the supply chain thus setting the framework for a world-class supply chain status. RFID systems also can be far more cost effective per item in the system. In a study done by Oztaysi et al., it was found that the cost of an RFID system of tracking and sorting posts and parcels was one third the cost of a barcoded system [5].

2.1.2 Frequency Band Regulations

The Federal Communications Commission (FCC), DoD, and The Special Committee on Radio Interference (CISPR) are the three agencies that provide electromagnetic compatibility (EMC) regulations for the United States. Table 1 below is given under Section 18 in the FCC’s regulations: a family of frequency bands called the Industrial, Scientific, and Medical (ISM) equipment standards defined for use around medical equipment. The specific band of interest for passive UHF RFID stretches from 902 MHz to 928 MHz in the United States. There are other bands that are used for RFID, such as the 2.4 GHz to 2.5 GHz band for UHF semi-passive or active tags used in RTLS.

ISM frequency	Tolerance
6.78 MHz	±15.0 kHz
13.56 MHz	±7.0 kHz
27.12 MHz	±163.0 kHz
40.68 MHz	±20.0 kHz
915 MHz	±13.0 MHz
2,450 MHz	±50.0 MHz
5,800 MHz	±75.0 MHz
24,125 MHz	±125.0 MHz
61.25 GHz	±250.0 MHz
122.50 GHz	±500.0 MHz
245.00 GHz	±1.0 GHz

Table 1: ISM Table of Frequencies from FCC Section 18 [6]

All RFID systems must be in full compliance with these standards. In order to be a robust system, compliance with other regulatory agencies around the world is essential. It is very difficult to have an effective worldwide system because very few of the regulatory agencies have overlapping RFID bands due to the fact that there is no global RFID frequency standard. Europe, for example, has its UHF ISM RFID band mapped from 865 MHz to 868 MHz. Compared to the United States, this is a fairly narrow band. Since there is no overlap, any system that needs to work in both the United States and in Europe must be able to switch between the two frequency ranges. Once other countries' standards are added, the system becomes even more complex.

2.2 Risks and Benefits of Implementing RFID/RTLS

Hospitals are uniquely stocked with expensive machines and pieces of equipment due to the functional requirements needed by their patients. Often times, these are manually counted and tracked, if they are counted at all. In many hospitals, personnel will go out and look for the machine when it is needed rather than consulting paperwork or a database tracking where the item could possibly be. Since the database is only as good as the information in it, the usefulness of manually entering an item's location is linked to how well the users log the applicable data.

In a simulation study done at Carmel Hospital [7], approximately $6,000 was spent annually on searching for IVAC systems when needed for a particular patient. The total IVAC systems inventory in this particular hospital's database was only 600 items. The average amount of equipment in a hospital is much greater, thus the cost of searching for equipment is very high and gives rise to the need for a dramatically better system. In addition, of the 600 IVAC units listed in the Carmel hospital database, about half could not be found at the time of the study. The sources and timing of shrinkage were unknown.

2.2.1 Potential Uses of RFID/RTLS in Hospitals

An RFID/RTLS can track equipment as it is moved through the hospital. It greatly reduces operational costs due to reduced labor cost and cost of lost equipment.

The use of RTLS systems is not limited to inventory. Hospitals are very complicated service-based organizations, and there is potential to use RFID for patients and/or personnel in order to improve the quality of service. In a study of surgical accuracy, it was shown that an RFID system can provide more accurate, legible, and clear instructions to help surgical teams provide the right care to patients where critical mistakes have occurred in the past [8].

Another benefit of the RTLS system is to fully track patients as they move through the system. In a system level study done by Cangialosi and Monaly, the RTLS system can be utilized in three ways: stationary readers on mobile equipment, mobile readers on stationary equipment, and mobile readers on mobile equipment. This system can be leveraged to track patients end to end during admission, examination, care, recovery, and discharge [9].

2.2.2 RFID EMI Potential

Despite the superior tracking results that an RFID/RTLS system provides, it still must be proven to be a safe system to use in a hospital. RFID devices, like cell phones, emit radio frequency (RF) waves. These waves carry the information sent by a device wirelessly at various frequencies. It is possible that the RF waves emitted could interfere with machines in the immediate vicinity. This phenomenon is termedelectromagnetic interference, or EMI. In one study, pacemakers and implantable cardiovascular defibrillators were exposed to RFID readers at multiple frequency levels resulting in incorrect pacing of the pacemakers and unnecessary delivery of shock from some defibrillators [10]. In order to ensure patient safety, research must be conducted to evaluate the effect of operating RFID in close proximity to medical devices. When a RF-enabled device is able to work around sensitive equipment without causing EMI, it is labeled as electro-magnetically compatible (EMC). In the hospital environment, any RTLS system must have EMC with all sensitive devices within range before it can be implemented [11].

2.2.3 RFID and Medical Equipment Proximity Testing

Due to EMC requirements, hospitals are behind other industries in implementing RTLS systems. In order to avoid a system failure, extensive testing must be done before implementing any RFID solution. This fact has led to a handful of studies being conducted to observe the effects of RFID EMI on various types of medical equipment. In one such study done by a research group at the University of Amsterdam, 34 incidents out of 123 tests were found [12]. Even though some of the incidents were categorized as “light” or “significant” rather than “hazardous”, it is still a cause for concern because the significant problems have the potential to turn into hazardous ones if the setting were to change. The Amsterdam study was conducted using a 124 kHz active system and an 868 MHz passive system. This study shows that EMI does exist in significant enough numbers to warrant thorough testing for every system implemented that may interfere with a patient's health. This testing was done in Europe under the European frequency bands; we have not found any research on the effects of RFID on medical equipment in the bands set forth by the FCC – the most commonly used in other industries being 902-928 MHz, 433 MHz, and 2.4-2.5 GHz.

According to another study, EMI from RTLS systems has a stronger link to the power rather than the frequency [13]. There were ten tests done with increasing power and proximity to sensitive infusion pumps. Once the power level reached a certain point, the pumps started to fail. Two out of ten of the tests caused failures. One of the conclusions of the study was that, when tagged, equipment prone to EMI is much more likely to fail than if it's not tagged, due to the RF emitting nature of a tag while being activated by a reader. The tests that caused failure were using the higher-powered Skyetek readers running at a maximum of 2.2W. The failures occurred at 10cm away from the infusion pumps. A lower powered Tracient reader was running at a 0.5W maximum, and there were no incidences of failure when there were only Tracient readers present even during the tests where there were 4 Tracient readers touching the tagged infusion pump. This result suggests that there may be a threshold of RF power that causes a failure in sensitive equipment.

There was another study done that tested equipment performance in the presence of tags and readers [14]. This study focused on the repeatability side of device reliability under potentially problematic RF conditions. 25 devices were tested at distances varying between 30 and 180cm. Each device was tested with two RFID systems, 32 times per system at each distance. A total of

320 evaluations were done per device resulting in 1,600 performance assessments overall. There were no EMI occurrences throughout the entire assessment.

2.3 Inventory Visibility

Lack of inventory visibility is major problem in the healthcare industry. Emergency departments (ED) have a very high turn rate on consumable inventory, therefore inventory counts are constantly changing. Precise knowledge of the location of inventory at all times is essential in these types of environments because every second counts when trying to save a patient's life. Added time searching for needed inventory or equipment extends the surgery time thus significantly increasing the cost to the hospital. Location and accurate inventory counts are decisive factors for effective inventory visibility. The types of resources in healthcare environments can be categorized using the following taxonomy: movable assets including consumable and reusable. Within the reusable assets, there are queuing and non-queuing types identified by whether or not a patient can wait for the asset to become free. Within non-queuing assets, there are fixed location, single location, and multi-location types each identified by how they move to interact with the patients as they travel through the hospital system [15].

Similar to the healthcare industry, the fresh produce industry has a significant time constraint on items in their supply chain. If produce takes too long to come from the grower to the grocery store, it will expire and not be sold. In a study by Panos and Freed [16], it was shown that RFID has the ability to dramatically reduce the time taken in supply chain quality checks. This same principle is applicable for objects with an expiration date or some level of urgency in a hospital as they move through from storage or waiting room to the doctors and out of the system.

2.3.1 Commercial Solutions for Inventory Visibility

RTLS systems are becoming increasingly complex as customers are demanding more out of an inventory visibility solution. Because of this, the industry is being pushed toward turn-key solutions where all of the hardware, software, and customer support are provided in one package.

There are many examples of RTLS solution providers. They are becoming increasing differentiated through unique feature offerings and end-to-end integration.

RTLS Solution Provider	Key Capability Offerings
AeroScout	Proprietary WiFi/GPS/passive/ultrasound tags, location based on TDOA and/or RSSI, asset/personnel/task tracking available
AirISTA	WiFi/WiMax/Active RFID/GPS platform, location based on TDOA and/or RSSI
Awarepoint	WiFi enabled, Awarenet's ZigBee based wireless mesh network standard
CenTrak	Hybrid system uses both Gen2IR and active RFID, WiFi, room and bed level accuracy
Ekahau	WiFi, uses asset and personnel tags, open API to connect to existing infrastructure, statistical signal strength monitoring
GE Healthcare	WiFi/UWB/infrared hybrid RTLS system
Radianse	Web interface, WiFi, RTLS using IR and 433 MHz RFID, asset and personnel tags available
TeleTracking	Infrared and Active RFID hybrid asset RTLS system
Westico	Facility map interface, WiFi or Westico's RTLS interface, support for passive tags and GPS, hardware independent

Table 2: Key Capability Offerings by a Sample of Providers

Many of the solutions currently offered commercially have a high installation cost. The cost of installation is proportional to the amount of inventory each hospital has. This can be a constraint in many situations. In a study done by Bozdag et al., four RTLS evaluation techniques were identified to help a hospital best choose a system that will meet its needs and constraints: economic, analytic, strategic, and phased techniques. Each has its strength, while the phased technique allows for the combination of two or more techniques [17].

In another study, a needs assessment was identified to help show whether or not an RTLS system should be implemented by performing a five phase approach. First, contact the local hospital and see if there are any plans on implementing remote technologies and identify which areas of the hospital will be affected, if any. Second, conduct a needs assessment if there is any question as to the potential of the technology. Third, design a prototype based on the results for a selected hospital unit as a case study. Fourth, evaluate the performance of and satisfaction from using the system in the unit. Fifth, based on the results of the study, determine whether or not to implement the system in a wider capacity [18]. Using this approach, the hospital can have a case study tailored to its own needs and environment before it adopt the system fully. This allows for the evaluation of system as well as providing an option for a phased installation approach.

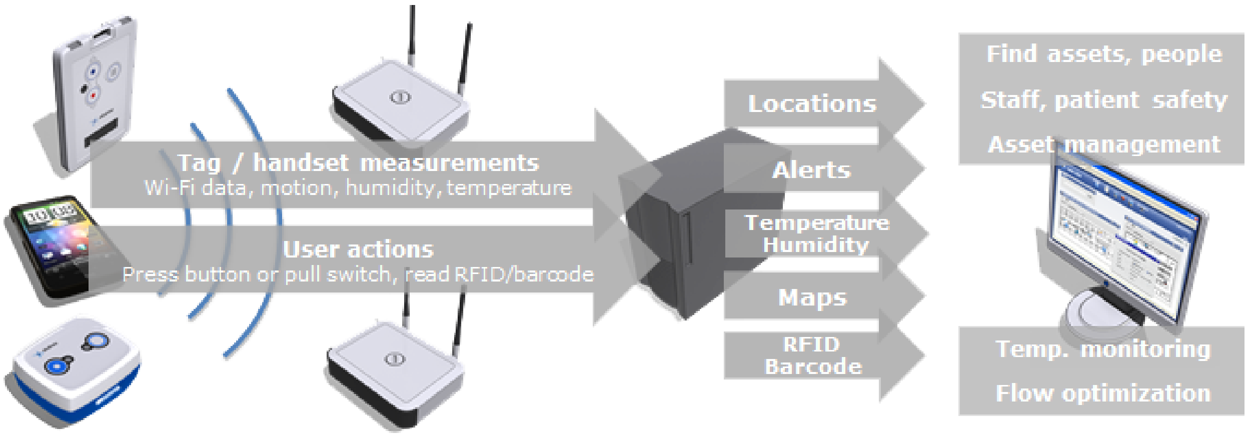

Figure 7: Ekahau Infrastructure

Courtesy of http://www.ekahau.com/

2.4 Hospital Inefficiencies

A healthcare facility is a primarily service-driven environment. Since 80% of resource input decisions are either made or controlled by physicians [19], the majority of costs come through inefficiencies in poor process performance or protocol. This shows that hospital efficiency relies less on what kind of illnesses its patients have and more on the practices of its physicians. These causes for inefficiency can be categorized three ways: poor procedures, system overload, and poor asset allocation. RTLS primarily affects the procedures and asset allocation.

2.4.1 Inefficiencies due to poor procedures

In a study done of 36 physicians in one hospital over six months, resource usage variation of up to 20 times was found for similar medical cases [19]. According to Chilingerian, "a substantial amount of money could be saved if every physician were as good as the most efficient or best practicing physician." Results from the study showed that physicians with heavier case load were more likely to be efficient. It was also found that specialization was another factor shown to increase physician efficiency. When a physician takes on a heavy case load of highly specialized, similar cases, he or she has the highest potential for case-load efficiency.

Case load inefficiencies are compounded when there is no clear process for patient asset allocation. If a patient requires a certain piece of monitoring equipment for their room and an available unit cannot be found, someone is sent searching for it. This stalls further action by doctors and decreases patient throughput.

Doctors and nurses are forced to spend a portion of their time keeping up with the paperwork required to effectively manage and organize patient records. Without this, the hospital would be chaotic. Despite the need, this is a non-value-added task. The more time a doctor or nurse is forced to do paperwork, the less time they are interacting with patients. A study was done into a context-aware system that can effectively pull patient records for doctors and nurses, that has the ability to interact and adapt based upon environmental variables. This system can significantly improve both accuracy and speed in working through the necessary paperwork to care for patients [20].

2.4.2 Inefficiencies due to overloading the system

In California, a study was done on the efficiency of hospitals [21]. It was found that the demand (doctors) has a negative correlation with efficiency while supply (hospital beds) has a positive correlation with efficiency. This means that when the number of doctors increases, the efficiency will drop. This study confirms results from the study done by Chilingerian, wherein he indicates that a heavier caseload will increase efficiency. Despite the efficiency boost, too much overload of a system will deteriorate other important metrics such as customer satisfaction and employee morale.

Customer satisfaction is measured in multiple ways including unnecessary anxiety and pain, negative emotions toward the staff, extended ambulance times due to ambulance diversion, patient's leave-without-being-seen (LWBS) rates, and increased vulnerability of waiting patients [22]. Each of these metrics can show a negative effect on a hospital ranging from slight satisfaction decrease to significant health complications and should be addressed appropriately.

2.4.3 Inefficiencies due to poor asset allocation

Misallocation and excessive use of hospital supplies have a significant chance to increase overall operating expenses. It was found that there was "statistically significant evidence of allocative inefficiency, which takes the form of *systematic* over-utilization of supplies and care graduates relative to care technicians and other personnel" [23]. Misallocation of hospital supplies, namely excessive use, has a significant chance to increase overall operating expenses. In the study done by Rodríguez-Álvarez et al, the misallocation of supplies increased the mean spending by 14%." This study points to either the lack of necessary assets in a hospital system, or the inability to effectively utilize existing assets. Identification of this misallocation is the first step in reducing the waste and increasing the overall efficiency of the hospital. Reduction of waste is not occurring naturally, however. "[Between 1980 and 1993], real per capita spending rose by 65% for all types of hospital care and more than 87% for all health services" [21]. This means that in 1993 hospitals were doing 65% of what they were doing in 1980 for the same amount of money. Waste is growing at an alarming rate. As with any other industry, much of this waste is passed on to the customer, which undoubtedly decreases customer satisfaction while increasing cost of treatment.

Increased costs are not the only factor that can decrease customer satisfaction. Poor allocation of assets can lead to higher wait times leaving the patient feeling neglected. While patients are in emergency departments (ED), they spend the majority of the time waiting on hospital staff. A study of 6 major hospitals shows that waiting for an x-ray examination, the first physician examination, or results of blood work makes up approximately half of the total waiting time for patients, which constitutes 51-63% of the total time in ED [24]. This wait time could be reduced with increased inventory visibility through use of an RFID/RTLS system thereby eliminating the need to search for a needed asset.

3 RFID Implementation in Hospitals

3.1 Source of Data

For any RFID testing method with resource constraints, simulation is an accurate and powerful option to identify possible bottlenecks, compare before and after implementation data, and to gain valuable visibility into the process. In order to develop data for the model used in this test, three simulation studies targeting both patients and equipment were used in two hospitals: Soroka Medical Center and Carmel Medical Center in Israel [25], [7]. After data was collected for the existing system and the proposed active and passive systems, economic decisions were made for these case studies. Using this data in a breakeven model analysis, a flexible model was created for hospitals that allows the investigation of the impact an RFID system would have on inventory challenges.

3.2 Model Structure

The proposed model gives the user the flexibility to change any of the parameters listed below in Table 3 by collecting the applicable information shown in the example survey in Appendix A: Hospital Survey and Questionnaire.

Parameter	Type
Cost of RFID Reader	System Variable
Cost of RFID Antenna	System Variable
Number of RFID Readers per Department	System Variable
Number of RFID Antennas per Department	System Variable
Cost of RFID System Software	System Variable
Cost of Annual Hardware/Software Maintenance	System Variable
Time to Check Inventory	User Input
Number of People that Check Inventory	User Input
Cost Per Person Per Hour to Check	User Input
Times Per Month Inventory is Checked	User Input
Probability of Lost Equipment	User Input
Quantity of Equipment	User Input
Cost of Equipment	User Input
Number of Departments	User Input

Table 3: List of Model Parameters

System variables are variables that have been generated based upon typical implementations that would take place in a hospital. User input variables are variables that the user would input based upon the current operating conditions. Most of these variable names are self-explanatory. The Probability of Lost Equipment is the percentage of shrinkage. See Appendix A for an example of how to gather this information. Using these parameters, the model automatically calculates the cost of the RFID/RTLS system and compares it to the cost of upkeep without the RFID/RTLS system in a breakeven model with data and associated graphs. The formula used for calculating the shrinkage cost is shown below in Equation 1.

$$\sum Quantity_i * Cost_i * Probability\ of\ Lost\ Equipment_i$$

$$For\ all\ i's\ where\ i\ is\ the\ piece\ of\ equipment$$

Equation 1: Shrinkage Cost

The time taken and money spent for a breakeven event to occur is calculated using Equation 2 and Equation 3, respectively.

$$Payback\ Month\ (BE_M) = \frac{(C_{Ant} * N_{Ant} + C_{Read} * N_{Read})N_{Dept} + C_{SW}}{S * N_{Dept} + (f * C_C * N_C * T)N_{Dept} - C_{Maint}}$$

Where: *BE_M=Breakeven Month*
C_{Ant}=Cost of RFID antennas ($)
C_{Read}=Cost of RFID readers ($)
C_{SW}=Cost of software ($)
C_C=Cost of labor per hour to check inventory ($/hr)
C_{Maint}=Cost of system maintenance per month
N_{Ant}=Number of RFID antennas per department
N_{Read}=Number of RFID readers per department
N_{Dept}=Number of departments
N_C=Number of employees who check on inventory
S=Shrinkage per month ($/mo)
f=Frequency of inventory upkeep checks per month
T=Time taken to check on inventory per person (hrs)

Equation 2: Breakeven Month

$$\boldsymbol{Breakeven\ Cost = N_{Dept}(C_{Ant} * N_{Ant} + C_{Read} * N_{Read}) + BE_M * C_{Maint} + C_{SW}}$$

Equation 3: Breakeven Cost

The number of departments directly drives the overall cost of an RTLS implementation by driving the overall cost of RFID modules (a reader and its antennas). Because of this, we found the number of departments to be the most sensitive variable in determining the final cost of implementation.

4 Shrinkage Analysis

The simulations were the source of the data used for this model in the prototyping stage. After a working model was built, real data (over 12,000 entries from multiple hospitals dating back to February of 1993) was collected from hospital databases associated with the Veterans Health Administration hospital network in Ohio Veterans Integrated Service Network (VISN) 10. The data collected had various fields describing hospital assets, including manufacturer, manufacturer equipment name, model, use status, type, asset value, disposition date, and equipment category.

4.1 Shrinkage Cost Estimation

Inventory items purchased over the course of 30 year ranged in purchase cost from $20 to nearly $2 million. The most expensive items on this list were certainly outliers, but still needed to be captured. The purchase cost of items reported as "Lost or Stolen" was used to calculate the shrinkage cost. We considered calculating the net present value for these assets, but decided instead to use the asset purchase cost as the asset value because many of the assets would have come down in value over time due to technological advancements.

4.2 Economic Breakeven Calculations

We then calculated the cost of inventory count and checking using the formula $(f * C_C * N_C * T)N_{Dept}$. On average, the result was relatively high due to the inclusion of doctors and nurses in addition to technical staff responsible for inventory control. The average shrinkage amounted to $3,500 per month per department for an average hospital size of 10 departments (see Figure 8 below). Calculating the payback period resulted in an average of 9.66 months for a passive RFID/RTLS solution and 6.45 months for an active RFID/RTLS solution.

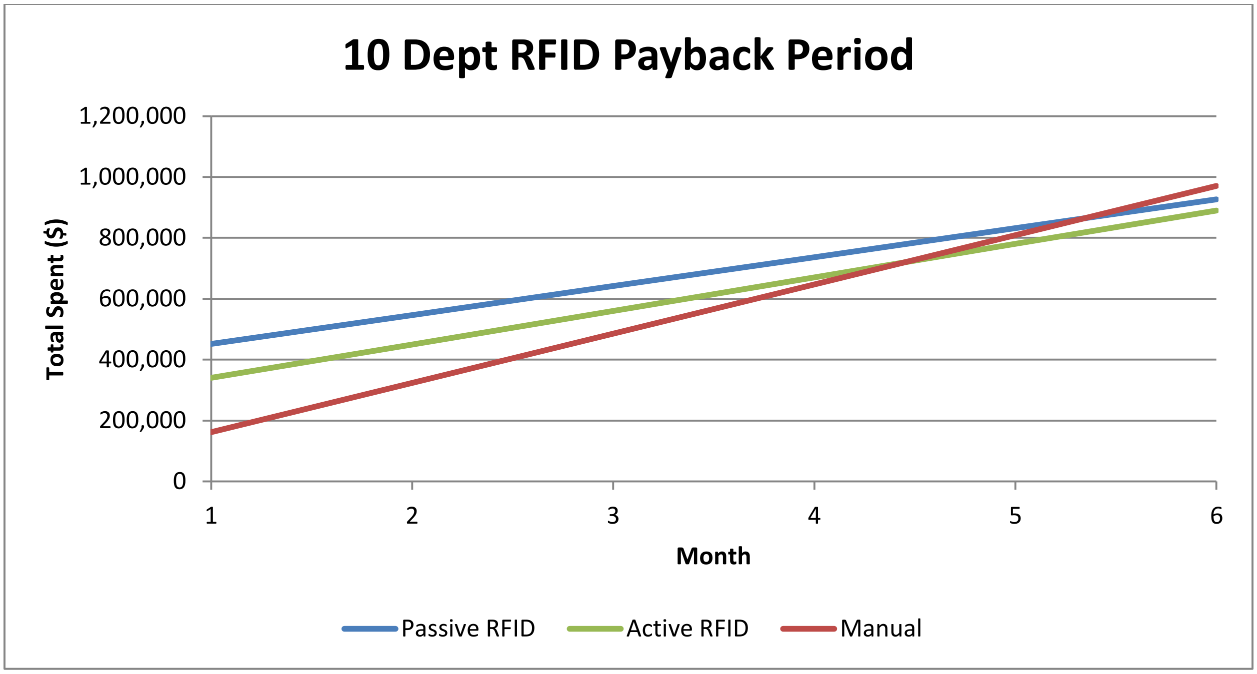

Figure 8: Payback Period for 10 Dept Hospital

In order to perform a sensitivity analysis, we expanded this concept to hospitals of multiple sizes. We took the calculated payback period of hospitals with 10, 30, 50, 70, and 90 departments and plotted the payback period of each for both passive and active systems shown below in Figure 9.

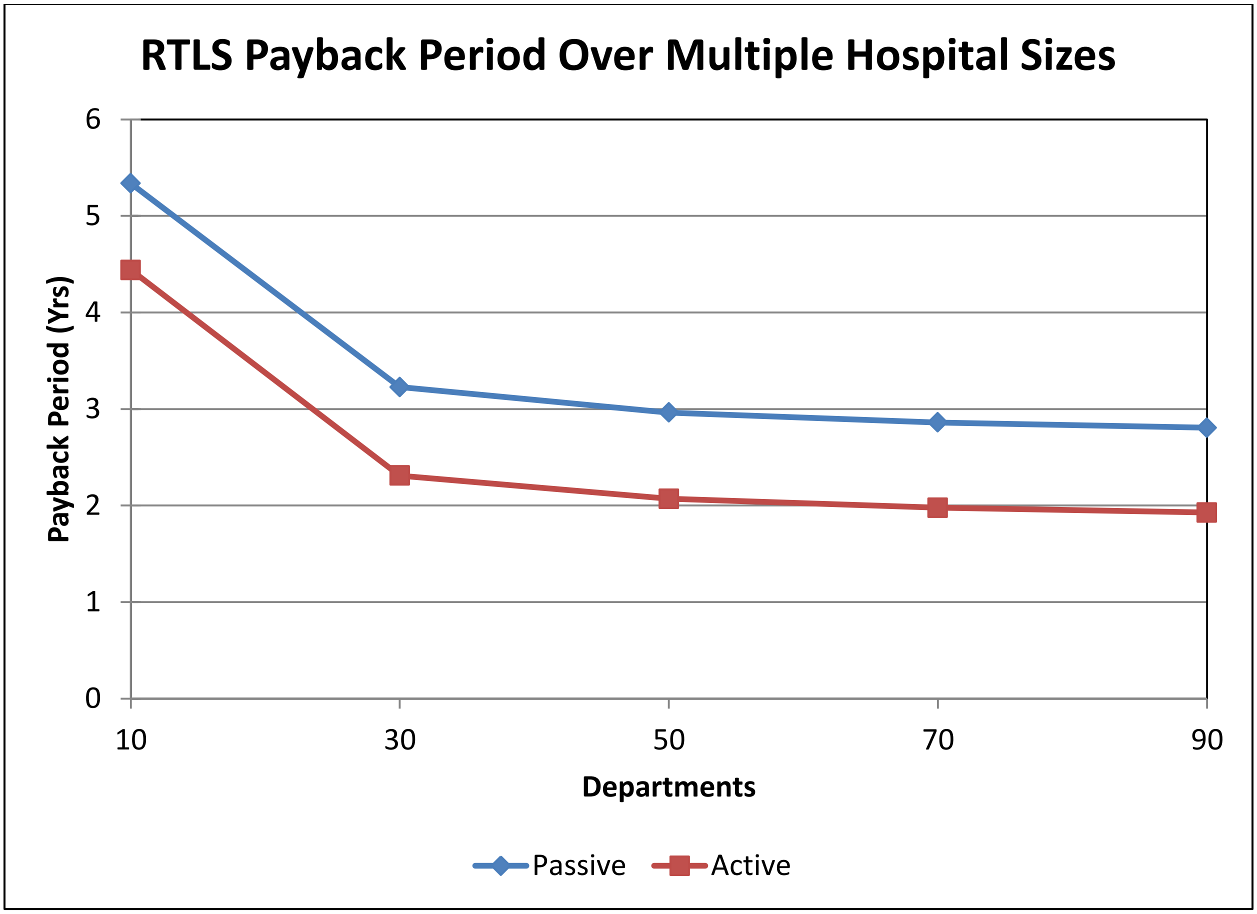

Figure 9: Payback Period – Equipment Type

4.3 Conclusions and Future Research

In this study we developed an economic justification system for using an RFID/RTLS system to track inventory in hospitals of various sizes, and other varying cost factors. We discussed the need to implement RFID/RTLS without causing electromagnetic interference with nearby instruments and equipment. Given a hospital's input regarding cost of shrinkage and inventory management, as well as size and required service level, the model we presented here can help drive good business decisions regarding RFID/RTLS implementation. From our experience and the findings derived from this model, RFID/RTLS shows a clear case of improving the process for most circumstances.

This paper can serve as a basis for further research in customizing cost/benefit analysis for the healthcare industry.

5 Appendix A: Hospital Survey and Questionnaire

Administration Interview

Courtesy Logan Hunt

1. Who is responsible for tracking large inventory (expensive items such as pacemakers, surgical probes, reusable assets, etc.)?
2. How often does this person(s) track large inventory?
3. Who is responsible for tracking small inventory (scissors, needles, inexpensive items)?

(if same as question 1 then leave blank)

4. How often does this person(s) track small inventory?
5. What is their salary/wage?
6. How does this person track inventory?
7. Do you currently have RFID or another tracking system for inventory?

If yes for question 7:

8. What assets do you track with this system?
9. What was the initial cost to install the system?
10. What is the recurring cost?
11. How satisfied are you with the system you are currently using?

(1 = dissatisfied 2=somewhat dissatisfied 3=neutral 4=somewhat satisfied 5=satisfied)

a. In tracking inventory:	1	2	3	4	5
b. Cost of maintaining system:	1	2	3	4	5
c. Tracking patients' time:	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5

d. Tracking doctors'/nurses time:

e. Time required to search for inventory:

12. If an item/asset is needed for immediate use on a patient, who typically searches for it (doctor, nurse, etc)?

13. Approximately what percentage of a doctor's time is spent searching for inventory while with a patient?

14. Approximately what percentage of a nurse's time is spent searching for inventory while with a patient?

15. What is the procedure following the discovery of missing inventory (either in use by someone else or out of supply)?

16. What type of assets is most often misplaced?

17. How often are inventory/supplies replenished in common patient rooms?

18. How often are inventory/supplies replenished in emergency rooms?

19. What is the priority of the following:

(Rank most important to least using numbers; 1 being the highest)

a. Tracking inventory (asset location):

b. Knowing what inventory items and supply status in each common patient's room:

c. Knowing what inventory items and supply status in each emergency room:

d. Minimizing time wasted between doctor and patient while searching for supplies:

20. On average, how often are supply rooms restocked?

21. What is the procedure for a patient when he/she checks in to when he/she checks out (includes treatment and billing)?

22. On average, how long during the weekdays do patients wait to start their appointments?

- ○ Less than 10 minutes
- ○ 10-30 minutes
- ○ Half hour to an hour
- ○ Over an hour

23. On average, how long during the weekends do patients wait to start their appointments?

- ○ Less than 10 minutes
- ○ 10-30 minutes
- ○ Half hour to an hour
- ○ Over an hour

24. How often are inventory/supplies replenished in common patient rooms?

- ○ Immediately
- ○ Every day
- ○ At least once a week
- ○ Once every 2 weeks
- ○ Once a month
- ○ I do not know

25. How often are inventory/supplies replenished in emergency rooms?

- ○ Immediately
- ○ Every day
- ○ At least once a week
- ○ Once every 2 weeks
- ○ Once a month
- ○ I do not know

26. During a patient's appointment, how much of your time is used to search for supplies or inventory?

- ○ Most of my time
- ○ Some of my time
- ○ Not much of my time
- ○ Not at all; someone else searches for it

27. How much of a patient's time during an appointment is wasted waiting for supplies?

- ○ Most of the patient's time
- ○ Some of the patient's time
- ○ Not much of the patient's time
- ○ None of the patient's time

28. How much time is used to search for supplies during a common room visit?

- Less than 10 minutes
- About 30 minutes
- 30-60 minutes or longer

29. How much time is used to search for supplies during an emergency visit to the ER?

    - Less than 10 minutes
    - About 30 minutes
    - 30-60 minutes or longer

30. Who searches for inventory when it is needed at the moment?

    - Doctor
    - Nurse
    - Care-Taker
    - If other, please explain:

31. How often is large inventory (expensive assets such as pacemakers, portable x-ray machines, etc.) misplaced?

    - Very Often
    - Often
    - Somewhat often
    - Not often
    - Never

32. How often are common patient rooms in short supply or no-supply of necessary inventory?

- ○ Very Often
- ○ Often
- ○ Somewhat often
- ○ Not often
- ○ Never

33. How often are emergency rooms in short supply or no-supply of needed inventory?

- ○ Very Often
- ○ Often
- ○ Somewhat often
- ○ Not often
- ○ Never

34. How often do you take supplies from another room?

- ○ Very Often
- ○ Often
- ○ Somewhat often
- ○ Not often
- ○ Never

35. Are you currently using a tracking system for inventory?

- ○ Yes
- ○ No

36. How satisfied are you with this system you are currently using?

(1 = dissatisfied 2=somewhat dissatisfied 3=neutral 4=somewhat satisfied 5=satisfied)

Circle one: **1** **2** **3** **4** **5**

6 Appendix B: Model User Interface and Database Structure

The economic model was created using Microsoft Access. This was chosen over other analysis programs, such as Excel, due to the nature of storing and analyzing a list of equipment and their attributes in a relational manner. It also allows the developer to create better forms to control the input and display of information than Excel does. The VBA code for form creation in Excel is somewhat lacking when compared to Access

Two user interface screens were created: one for managing equipment (shown in Figure 10) and one for breakeven analysis (shown in Figure 11).

Figure 10: Manage Equipment Screen

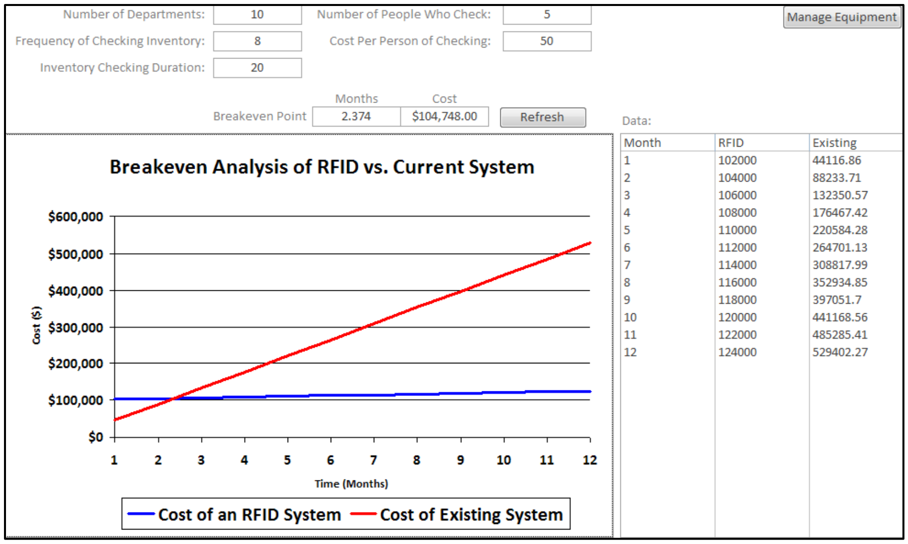

Figure 11: Hospital Information Screen

There were three tables of data that the queries and forms were built off of: equipment and attributes, RFID hardware and software costs, and a list from 1 to 12 to generate the query of monthly data. These three table designs are shown in Figure 12 below.

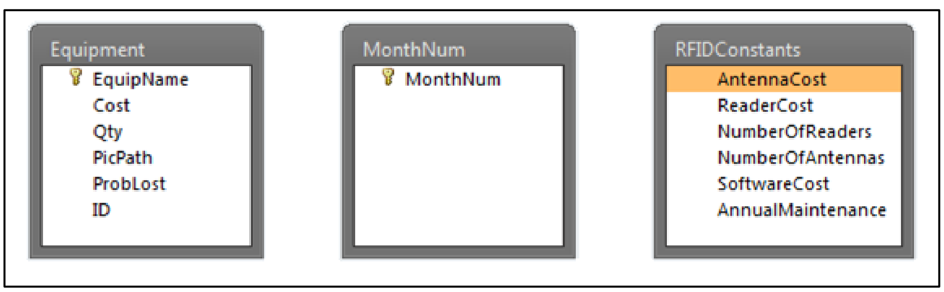

Figure 12: Database Table Designs

7 Appendix C: Model Code

The interface used Visual Basic for Applications (VBA) in order to perform the desired functions. VBA is a standard programming language for Microsoft Office applications and is built off of the Visual Basic 6.0 language. The coding for the managing equipment screen is shown in Section 7.1 and the coding for the hospital information screen is shown in Section 7.2.

7.1 Manage Equipment Code

```
Option Compare Database
Option Explicit

Private Sub cmdAdd_Click()
Dim rst As New ADODB.Recordset
Dim fields(3)
Dim values(3)
Dim aryPath As Variant
fields(0) = "Cost"
fields(1) = "Qty"
fields(2) = "PicPath"
fields(3) = "ProbLost"
values(0) = Me.txtCost
values(1) = Me.txtQty
aryPath = Split(Me.imgEquip.Picture, "\")
values(2) = aryPath(UBound(aryPath))
values(3) = Me.txtProb
rst.Open "Equipment", CurrentProject.Connection, adOpenStatic, adLockOptimistic
rst.AddNew "EquipName", Me.txtName
rst.Close
Me.Form.Refresh
rst.Open "SELECT Cost, Qty, PicPath, ProbLost FROM Equipment WHERE EquipName=""" &
Me.txtName & """", CurrentProject.Connection, adOpenStatic, adLockOptimistic
rst.MoveFirst
rst.Update fields, values
rst.Close
End Sub
```

```
Private Sub cmdBrowse_Click()
Dim rst As New ADODB.Recordset
Dim aryPath As Variant
On Error GoTo errcode
'displays a picture based upon a chosen file path
Dim strPicPath As String
With Application.FileDialog(msoFileDialogFilePicker)
    .AllowMultiSelect = True
    .ButtonName = "Select"
    .InitialView = msoFileDialogViewList
    .InitialFileName = Access.CurrentProject.Path & "\Picture Directory"
    .Title = "Select Picture"
    With .Filters
        .Clear
        .Add "Picture Files", "*.bmp,*.gif,*.jpg,*.png"
    End With
    .FilterIndex = 1
    .Show
    strPicPath = .SelectedItems(1)
End With
Me.imgEquip.Picture = strPicPath

rst.Open "SELECT PicPath FROM Equipment WHERE ID=" & Me.txtID,
CurrentProject.Connection, adOpenStatic, adLockOptimistic
rst.MoveFirst
aryPath = Split(strPicPath, "\")
rst.Update "PicPath", aryPath(UBound(aryPath))
rst.Close
Me.Form.Refresh
Exit Sub
errcode:

End Sub

Private Sub cmdDelete_Click()
If Me.lstEquip.ListIndex = -1 Then Exit Sub
Dim rst As New ADODB.Recordset
rst.Open "SELECT EquipName FROM Equipment WHERE ID=" & Me.txtID,
CurrentProject.Connection, adOpenStatic, adLockOptimistic
rst.Delete
```

```
Me.Form.Refresh
With Me
    .imgEquip.Picture = "(none)"
    .txtName = ""
    .txtCost = ""
    .txtQty = ""
    .txtProb = ""
    .txtID = ""
    .frmMode.Value = 2
End With
End Sub

Private Sub cmdScreen_Click()
DoCmd.OpenForm "HospInfo", acNormal
End Sub

Private Sub Form_Load()
With Me
    .lstEquip.Selected(1) = True
    .txtName = DLookup("EquipName", "Equipment", "EquipName=""" & Me.lstEquip & """")
    .txtCost = DLookup("Cost", "Equipment", "EquipName=""" & Me.lstEquip & """")
    .txtQty = DLookup("Qty", "Equipment", "EquipName=""" & Me.lstEquip & """")
    .txtProb = DLookup("ProbLost", "Equipment", "EquipName=""" & Me.lstEquip & """")
    If DLookup("picpath", "Equipment", "EquipName=""" & Me.lstEquip & """") = "(none)"
Then
        .imgEquip.Picture = "(none)"
    Else
        .imgEquip.Picture = CurrentProject.Path & "\picture directory\" & DLookup("picpath",
"Equipment", "EquipName=""" & Me.txtName & """")
    End If
    .frmMode.Value = 1
    .frmDataType.Value = 2
    .txtGrouping = "Bucket"
End With
End Sub

Private Sub frmDataType_Click()
Select Case Me.frmDataType.Value
    Case 1
```

```
        Me.lstEquip.RowSource = "SELECT Equipment.EquipName AS [Equipment Name]
FROM Equipment WHERE Grouping = ""Categorical"" ORDER BY Equipment.EquipName"
        Me.txtGrouping = "Categorical"
    Case 2
        Me.lstEquip.RowSource = "SELECT Equipment.EquipName AS [Equipment Name]
FROM Equipment WHERE Grouping = ""Bucket"" ORDER BY Equipment.EquipName"
        Me.txtGrouping = "Bucket"
End Select
Me.Form.Refresh
End Sub

Private Sub frmMode_Click()
Select Case Me.frmMode.Value
    Case 1
        With Me
            If DLookup("picpath", "Equipment", "EquipName=""" & Me.lstEquip & """") = "(none)"
Then
                .imgEquip.Picture = "(none)"
            Else
                .imgEquip.Picture = CurrentProject.Path & "\picture directory\" & DLookup("picpath",
"Equipment", "EquipName=""" & Me.lstEquip & """")
            End If
            .txtName = DLookup("EquipName", "Equipment", "EquipName=""" & Me.lstEquip &
"""")
            .txtCost = DLookup("Cost", "Equipment", "EquipName=""" & Me.lstEquip & """")
            .txtQty = DLookup("Qty", "Equipment", "EquipName=""" & Me.lstEquip & """")
            .txtProb = DLookup("ProbLost", "Equipment", "EquipName=""" & Me.lstEquip & """")
            .txtID = DLookup("ID", "Equipment", "EquipName=""" & Me.lstEquip & """")
        End With
    Case 2
        With Me
            .imgEquip.Picture = "(none)"
            .txtName = ""
            .txtCost = ""
            .txtQty = ""
            .txtProb = ""
            .txtID = ""
        End With
End Select
End Sub
```

```
Private Sub lstEquip_Click()
With Me
   .frmMode.Value = 1
   If DLookup("picpath", "Equipment", "EquipName=""" & Me.lstEquip & """") = "(none)" Then
       .imgEquip.Picture = "(none)"
   Else
       .imgEquip.Picture = CurrentProject.Path & "\picture directory\" & DLookup("picpath", "Equipment", "EquipName=""" & Me.lstEquip & """")
   End If
   .txtName = DLookup("EquipName", "Equipment", "EquipName=""" & Me.lstEquip & """")
   .txtCost = DLookup("Cost", "Equipment", "EquipName=""" & Me.lstEquip & """")
   .txtQty = DLookup("Qty", "Equipment", "EquipName=""" & Me.lstEquip & """")
   .txtProb = DLookup("ProbLost", "Equipment", "EquipName=""" & Me.lstEquip & """")
End With
End Sub

Private Sub txtCost_AfterUpdate()
Dim rst As New ADODB.Recordset
If Me.frmMode.Value = 2 Then Exit Sub
rst.Open "SELECT Cost FROM Equipment WHERE ID=" & Me.txtID, CurrentProject.Connection, adOpenStatic, adLockOptimistic
rst.MoveFirst
rst.Update "Cost", Me.txtCost
rst.Close
Me.Form.Refresh
End Sub

Private Sub txtName_AfterUpdate()
Dim rst As New ADODB.Recordset
If Me.frmMode.Value = 2 Then Exit Sub
rst.Open "SELECT EquipName FROM Equipment WHERE ID=" & Me.txtID, CurrentProject.Connection, adOpenStatic, adLockOptimistic
rst.MoveFirst
rst.Update "EquipName", Me.txtName
rst.Close
Me.Form.Refresh
End Sub
```

```
Private Sub txtProb_AfterUpdate()
Dim rst As New ADODB.Recordset
If Me.frmMode.Value = 2 Then Exit Sub
rst.Open "SELECT ProbLost FROM Equipment WHERE ID=" & Me.txtID, CurrentProject.Connection, adOpenStatic, adLockOptimistic
rst.MoveFirst
rst.Update "ProbLost", Me.txtProb
rst.Close
Me.Form.Refresh

End Sub

Private Sub txtQty_AfterUpdate()
Dim rst As New ADODB.Recordset
If Me.frmMode.Value = 2 Then Exit Sub
rst.Open "SELECT Qty FROM Equipment WHERE ID=" & Me.txtID, CurrentProject.Connection, adOpenStatic, adLockOptimistic
rst.MoveFirst
rst.Update "Qty", Me.txtQty
rst.Close
Me.Form.Refresh

End Sub
```

7.2 Hospital Information Code

```
Option Compare Database
Option Explicit

Private Sub cmdRefresh_Click()
Call refreshGraph
Me.Form.Refresh
End Sub

Private Sub cmdScreen_Click()
DoCmd.OpenForm "MngEquip", acNormal
End Sub

Private Sub Form_Load()
Call refreshGraph
End Sub
```

```
Sub refreshGraph()
Dim dblShrinkage As Double, dblAntCost As Double, dblReadCost As Double, dblSoftware As Double, dblMaint As Double
Dim intNoAnt As Integer, intNoRead As Integer
Me.Form.Refresh
dblShrinkage = DLookup("[Shrinkage Cost]", "Shrinkage Cost Per Month")
dblAntCost = DLookup("AntennaCost", "RFIDConstants")
dblReadCost = DLookup("ReaderCost", "RFIDConstants")
dblSoftware = DLookup("SoftwareCost", "RFIDConstants")
dblMaint = DLookup("AnnualMaintenance", "RFIDConstants")
intNoAnt = DLookup("NumberOfAntennas", "RFIDConstants")
intNoRead = DLookup("NumberOfReaders", "RFIDConstants")
Me.txtBEMonths = Round((dblAntCost * Me.txtNoDepts * intNoAnt + Me.txtNoDepts * intNoRead * dblReadCost + dblSoftware) / (dblShrinkage + Me.txtCostPP * Me.txtFreq * Me.txtNoPpl * Me.txtDuration - 0.08333 * dblMaint), 3)
Me.txtBECost = Me.txtNoDepts * (dblAntCost * intNoAnt + dblReadCost * intNoRead) + Me.txtBEMonths * dblMaint / 12 + dblSoftware
End Sub

Private Sub txtCostPP_AfterUpdate()
Call refreshGraph
End Sub

Private Sub txtDuration_AfterUpdate()
Call refreshGraph
End Sub

Private Sub txtFreq_AfterUpdate()
Call refreshGraph
End Sub

Private Sub txtNoDepts_AfterUpdate()
Call refreshGraph
End Sub

Private Sub txtNoPpl_AfterUpdate()
Call refreshGraph
End Sub
Private Sub txtNoPpl_AfterUpdate()
```

```
Call refreshGraph
End Sub
```

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