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INFORMATION SYSTEMS AND HEALTH CARE II: BACK TO THE FUTURE WITH RFID: LESSONS LEARNED – SOME OLD, SOME NEW

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ABSTRACT

Healthcare facilities face limited resources and expanding expenses. Emerging information technologies offer a means for healthcare to measure and control their resources and workflow processes, and ultimately improve patient care. The usefulness of one emerging information technology, Radio Frequency Identification (RFID), is examined in a "proof of application" study conducted at a Level-1 trauma unit. Results from the study suggest not only that RFID technology can assist in the measurement and ultimate control of workflow processes, but also that traditional and non-traditional IS practices are necessary for successful RFID implementation. Lessons learned about the idiosyncrasies of RFID implementation and the cleansing and analysis of RFID-generated data are reported.

Keywords: RFID, healthcare, systems implementation

I. INTRODUCTION

Healthcare facilities, from private practices to multi-physician clinics to large metropolitan hospitals, are resource starved. Not enough trained professionals are available to fill demand. Patient beds that were plentiful in the 1990s are now in short supply. Financial resources such as insurance payments and government funding are being cut. These shortages are exacerbated by escalating costs for pharmaceuticals, equipment, and supplies that compete for limited budgets.

The economic realities of healthcare are especially hard on so-called "safety-net" hospitals – hospitals with longstanding missions to provide care for any and all patients. Increasing healthcare costs, decreasing state funding, and reduced insurance and job benefits payments pushed many of these critically important healthcare facilities to the brink of insolvency. Many of these effects can be traced in part to poor economic conditions, but there are other economic forces at work as well. As the economy slows, the unemployed or under-employed depend more heavily on emergency rooms rather than regular physician visits for their healthcare needs. This practice exacerbates overcrowding at emergency departments, especially those at safety-net hospitals. Safety-net hospitals that earned a "Level 1" trauma designation – those hospitals staffed and equipped to care for a community's most seriously sick or injured – are particularly vulnerable because of the financial and technical nature of the equipment and services they provide.

Technologies of all kinds are continuously considered as potential tools to help address these and other crises faced in healthcare today. While new medical technologies are often showcased as a means for improving healthcare services (e.g., diagnostic procedures with new imaging technologies), information and communication technologies that hold promise for significant benefits often work in their shadows. Healthcare organizations are beginning to recognize that information and communication technologies can also improve the quality of patient care and/or reduce patient wait times [e.g., American College of Emergency Physicians, 2003].

One emerging technology that could aid hospitals in their resource and workflow process management activities is Radio Frequency Identification (RFID). RFID consists of small integrated-circuit "tags" that can store information and announce their existence passively through wireless radio communication to a network of RFID readers. RFID potentially can track physical items – medical equipment, patient charts, even patients – in real time. Data from RFID tags are not only useful in identifying the locations of patients and inventory in real time, but can be accumulated over time to support patient care and resource management decisions.

This paper presents the technological and behavioral challenges encountered during the implementation of an RFID patient tracking system at the Elvis Presley Memorial Trauma Unit of the Shelby County Regional Medical Center (the MED), located in Memphis, Tennessee. First, we provide a brief description of RFID technology (Section II). Next, we present details of the MED project (Section III) followed by a discussion of the project results (Section IV). We conclude with an examination of lessons learned during the implementation of RFID technology (Section V).

II. RADIO FREQUENCY IDENTIFICATION (RFID)

RFID is predicted to be one of the "top ten" technologies for 2004-2005 by research firms such as the Gartner Group and Forrester Research [NextInnovator, 2004; Teradata, 2004]. RFID will enable organizations to deliver value-added applications related to the tracking and intelligent management of any entity that is tagged with an RFID chip [Eslambolchi, 2004; Ramaswami, 2004; Smith and Konsynski, 2003; Goodwins, 2002]. This increase in asset "visibility" has significant implications in the domain of supply chain management. The continual decline in RFID costs makes RFID adoption a serious business consideration for a variety of organizations. Giants such as the US Department of Defense and Wal-Mart not only expressed interest in RFID technology; they required many of their suppliers implement RFID-based supply chain systems. Yet in spite of this mass appeal and industry hype, little experience and a great deal of uncertainty surround RFID implementation efforts.

RFID is used to a small extent in tracking physical assets in hospitals (e.g., heart monitors) to facilitate patient care by allowing medical staff to identify the location of needed equipment in case of an emergency. However, to the best of our knowledge RFID was not used previously to track patients or the services provided to them.

III. THE MED PROJECT

The MED serves as the safety net hospital for the region and operates the only Level 1 trauma facility serving Memphis, Shelby County, and the five states located within a 150-mile radius of Memphis. In addition to receiving 100% of the Level 1 trauma cases in the region, Emergency Department (ED) visits at the MED are 19% over capacity. Like other safety net hospitals across the United States, the MED is overwhelmed with severe economic constraints and ED overcrowding. Improving throughput of patient-related processes is one way of addressing these difficulties, and emerging technologies such as RFID offer a possible solution. The objective of the study was to test the extent to which RFID hardware, software, and data can be embedded within a hospital's clinical operations and decision-making activities.

RFID tags were worn by patients on ankle bracelets. The tags announced their location in a passive manner whenever they were in the proximity of a tag reader (about twenty of which were strategically located throughout the Trauma ED). These "announcements" can be collected to identify the specific tag and its respective location in the Trauma ED. This approach differs from the more traditional process of manually scanning a bar-code worn by the patient (an active rather than passive process). The passive approach is believed to be superior in that it does not put any extra burden on the hospital staff to remember to scan the patient.

BACKGROUND

Founded in 1829, The MED is Tennessee's oldest hospital. Of the five EDs located at the MED (trauma, burn unit, wound care, high-risk obstetrics and newborns, and psychiatric), the Trauma ED was chosen for two primary reasons:

1. Any improvements in patient care could potentially spell the difference between life and death, and
2. The Trauma ED is a relatively small, self-contained organization that provided enough control to serve as our study "laboratory."

Of the many obstacles faced daily at the MED, an ongoing challenge is to look for ways to provide more effective, efficient, and timely care for patients. Performance measurements are a key factor in achieving that goal. Unfortunately, the nature of the patient care and the hospital environment make that a difficult task. For example, prior to the project, the MED could account for only one-fourth of the hours of an average patient's stay. The average trauma patient spends approximately ten to twelve hours in the Trauma ED receiving care, undergoing diagnostic procedures and recuperating, but only two to three hours could be explained using data collected prior to the RFID project. Hospitals and emergency facilities, in particular, understand where their patients are spending time. This knowledge can help identify bottlenecks or unusual patterns of behavior and allow administrators to take corrective actions. The result is better utilization of hospital resources and a reduction in patient wait times to improve patient care.

To address this need for accurate and timely performance measures, an interdisciplinary project team of hardware and software professionals, medical staff, and IS academicians was created to ascertain the technical feasibility of using RFID technology to track patients as they move through the trauma care process at the MED. The research described here was the focus of a "technology demonstration" project funded through a grant from The Robert Wood Johnson Foundation.

PROJECT REQUIREMENTS GATHERING

Before hardware and software installation could begin, it was important to conduct a thorough requirements analysis to identify the needs and expectations for the project. In general, requirements determination activities consist of reviewing documents, interviewing stakeholders, and observing critical processes. In this study, the research team interviewed trauma doctors and nurses, training and development personnel, and IT/systems personnel. We investigated the trauma ED processes, ancillary services, and existing IT systems. We also reviewed existing ED process data that had been collected as part of a prior process improvement effort. However, this data collection required the participation of the trauma doctors and nurses and consequently suffered from compliance deficiencies.

We decided to perform some preliminary data collection of our own in order to fully understand patient movement through the Trauma ED. Several individuals were stationed throughout the Trauma ED where they were able to observe the movement of the patients from point to point.

The time between locations was recorded for each movement. Each patient was identifiable via a unique number prominently displayed on the gurney. Examination of this data showed quite different results than previously reported. It was obvious to us that the presence of unfamiliar people in the trauma ED, equipped with clipboards and stopwatches, created a change in behavior. Wondering why we were monitoring the halls, the staff was on their best behavior. We had encountered a classic example of the Hawthorne Effect – the processes worked quite well as long as we were observing them.

The development of detailed process maps[1] depicting the "as is" state at the trauma center was an important part of building our understanding of ED processes. Several benefits were realized from the development of the process maps:

1. They were tools by which the MED trauma staff could educate the project team about important activities in patient care.
2. Their development helped establish personal relationships between the team and the MED's medical and IT personnel.
3. The process maps were used to identify problems associated with the manner and timing of how, when, and where trauma patients, nurses, doctors, and others moved through the trauma ED.
4. The maps helped the MED staff and research project team to develop a mutually-held version of "reality" against which the project's outcomes could be validated.
5. They were used to develop shared meanings and interpretations [Boland, 1979].
6. The process maps helped stakeholders identify opportunities for future projects, such as real-time interface capabilities to identify the location and history of a trauma patient.

The next step was to use the process maps to identify potential bottlenecks and chokepoints[2] in patient flow. These points were used to determine the optimal locations of the RFID readers within the Trauma Unit.

FINDINGS

The information collected by the project team was consolidated to form a set of project requirements considered necessary to the success of the RFID demonstration project. The requirements can be categorized as "environmental" or "system related needs and expectations.

Environmental Requirements

A fundamental requirement for the introduction of RFID was that it be as "invisible" as possible. We were looking for the least intrusive way to intervene in the activity of the staff. First we had to determine if the RFID tags would work on the human body. Considering the size and shape of the tag, the nursing staff and project team identified preferred locations for the tag's application. Because applying the tag requires the nurses' time and attention, and patients in the trauma ED require critical care, we worked to identify ways to simplify tag application and management.

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[1] Process maps, long used for modeling organizational processes [Forrester, 1961; Senge, 1990], are useful for reducing process cycle time [Wetherbe and Frolick, 2000], for educating the process team, and for identifying problems and opportunities for improvement [Handfield and Nichols, 2002].

[2] Chokepoints are places where patients must pass in moving from one location to another, e.g., a doorway or a location in a hallway.

Another environmental concern centered on the number and location of the RFID readers. The readers should be situated throughout the trauma facility to maximize potential "reads."[3] However, free space in the Trauma ED is at a premium. In addition, to avoid patient contamination, sterile environment policies prohibited the disruption of any wall or floor surfaces without extensive containment efforts. We decided to locate the readers above the doorways in the treatment and service areas. This placement proved to be the least disruptive and most accessible choice. Twenty-three readers were positioned throughout the Trauma ED facilities.

The medical staff required training. Because the success of the project hinged on the compliance of the medical staff, they needed to feel comfortable with the application and handling of the RFID tags. Furthermore, they needed to understand the impact of mismanagement of the tags on the reliability of the data. Training was conducted in partnership with the MED's nursing training and development staff. We believe that this focus on training also facilitated the overall acceptance of the system by the medical staff.

System Requirements

Several system requirements needed to be addressed. We determined the fundamental data needs based on the questions: "Where is our patient?" and "How long has he/she been there?" The goal was to identify the kinds of information that could be collected, the decisions to be made from this information, and the actions that could result from this information. From this information, database design requirements were determined.

It was necessary for our RFID readers to piggy-back on the MED's intranet to interact with our database server. As a result, we faced issues of compatibility, capacity, and reliability. Our demonstration system needed to integrate with the existing technology infrastructure.

The RFID system was tested using several Basic Operational Backscatter (BOB) tests. This test required one of the project members—who also happened to be named "Bob" – to lie on a gurney with about a dozen RFID tags attached to various parts of his body, and be ferried around the Trauma Unit to test the ability of the RFID readers, network and databases to trace the journey. A member of the project team recorded the path and times of this test. This manually collected data was then compared to the RFID data as a validation check.

IV. PROJECT RESULTS

Three sets of findings were obtained:

1. The acceptability of the technology by the medical and IT staffs during the data collection period.
2. The effectiveness of procedures for collecting, preparing, and analyzing RFID-generated data.
3. The identification of opportunities for future projects.

USER ACCEPTANCE OF RFID TECHNOLOGY

The medical and IT staffs at the MED differed in their levels of acceptance. The medical staff was especially excited about the project. Their excitement may have been related to the way that the RFID technology was presented to them. Past research shows that information technology is more likely to be accepted when it is framed within the context of user problems and social situations rather than "the latest and greatest" technology [Rogers, 1962].

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[3] In what follows, we use the shorthand term "read" to refer to the interrogation of the RFID tag by the RFID readers

RFID's ease-of-use was another factor in its acceptance by the medical staff. All that was required was of the nursing staff was to:

1. Attach the RFID tag on the patient with Coban™, a self-adherent elastic wrap, when the patient first arrived at the MED, and
2. Remove the RFID tag and place it in a RF-proof container when the patient was discharged.

The sterilization facility would then disinfect the tag between patients. Competing data entry technologies (e.g., bar coding or manual data entry) are less easy to use than RFID because they require greater manual effort.

The IT staff was more cautious with the RFID project. Interviews and conversations exposed their concerns about how the RFID hardware, software, and data resources would mesh with the MED's current IS resources. Their apprehensions, which can be summarized as concerns about the "ability to adopt" rather than "benefits from adoption," were consistent with similar behaviors reported in past IS and organizational research [Chau and Tam, 1997, Attewell, 1992].

DATA ANALYSIS

Most business data entry processes require some level of human intervention to monitor the data entry process and promote data accuracy. For example, bar-code scanning at retail stores usually generate an audible "beep" when the item is correctly scanned. In addition, a receipt or invoice is generated at the completion of the transaction so that the customer can verify that all items were scanned correctly. RFID data collection, on the other hand, requires no such human intervention. While this capability creates an easy-to-use application, it also means that no one may be monitoring the data entry process to ensure that data was entered accurately, if at all. Consequently, as part of the implementation testing, a random sample of dozens of RFID-generated data records were compared with the hand-written patient records to compare when patients were admitted, when they received certain diagnostic tests, and when they were discharged. In most all of these cases, the RFID data corresponded very well with the manually generated data. In some instances the RFID data was superior to hand-written documents. However, in some instances the RFID data looked suspicious, or did not match the hand-written records.

Manual inspections of the RFID-generated data showed a significant amount of noise and "dirty data." Closer examinations showed that dirty data could be classified into several categories.

Within-Patient Data Anomalies

The anomaly is characterized by the appearance of short "blips" of incongruous reads in an otherwise acceptable stream of tag reads. An example of this type of error is displayed in Table 1. In this example, a stream of RFID tag reads in the Critical Care Assessment area (CCA), but there is also an anomalous "blip" which is highlighted in boldface type. The read, which lasts less than a hundredth of a second, was picked up by a reader at the X-Ray Waiting Area, a moderately distant location from CCA. To move between these two areas in such a short time would be physically impossible. It is difficult to explain exactly why such blips occurred, but they probably resulted from unique environmental factors (e.g., metal doors opened and reflected or focused the RFID signal to a distant reader or interference was generated by other equipment). Data records that met these requirements for "blip" status (i.e. short time duration and distant reader location) were deleted in creating a cleansed data set. However, an original copy of the uncleansed data was maintained as a backup.

Table 1. Within-Patient Data Anomalies

Tag ID Number	Reader Name	Area	Tag First Read	Tag Last Read	Elapsed Time
10142003 0548	Shock Trauma I	CCA	3/14/04 3:39	3/14/04 3:41	0:02:26
10142003 0548	Shock Trauma Hallway	CCA	3/14/04 3:42	3/14/04 3:42	0:00:00
10142003 0548	Shock Trauma I	CCA	3/14/04 3:42	3/14/04 3:43	0:01:24
10142003 0548	**Trauma X-Ray Waiting Area**	**X-Ray**	**3/14/04 3:44**	**3/14/04 3:44**	**0:00:00**
10142003 0548	CCA Main Door	CCA	3/14/04 3:44	3/14/04 3:44	0:00:00
10142003 0548	CCA Visitor Door	CCA	3/14/04 3:48	3/14/04 3:48	0:00:11
10142003 0548	Trauma X-Ray Waiting Area	X-Ray	3/14/04 3:48	3/14/04 3:48	0:00:11
10142003 0548	Shock_Trauma_I	CCA	3/14/04 3:49	3/14/04 3:49	0:00:12
10142003 0548	Primary_Enrollment_Station	CCA	3/14/04 3:51	3/14/04 3:51	0:00:00
10142003 0548	CCA_Main_Door	CCA	3/14/04 3:51	3/14/04 3:51	0:00:00

Unassigned Tag Data Anomalies

A related type of noise involved records that could not be associated with any particular patient. An example of this type of error is shown in Table 2. The records attributed to the anomalous

Table 2. Unassigned Tag Data Anomalies

Tag ID Number	Reader Name	Area	Tag First Read	Tag Last Read	Elapsed Time
10152003 2344	Shock Trauma Hallway	CCA	3/15/04 6:59	3/15/04 6:59	0:00:00
10152003 2344	**Trauma CT Scan II**	**CT/MRI**	**3/17/04 9:03**	**3/17/04 8:50**	**0:12:37**
10152003 2344	**Shock Trauma Hallway**	**CCA**	**3/17/04 9:04**	**3/17/04 9:04**	**0:00:11**
10152003 2344	CCA Visitor Door	CCA	3/20/04 8:57	3/20/04 8:57	0:00:07
10162003 0248	Trauma OR Entry Door	Misc	3/16/04 1:39	3/16/04 1:39	0:00:00
10162003 0248	**X-Ray Waiting Area**	**X-Ray**	**3/17/04 21:33**	**3/17/04 21:32**	**0:00:45**
10162003 0248	**Trauma X-Ray II**	**X-Ray**	**3/17/04 21:39**	**3/17/04 21:35**	**0:03:46**
10162003 0248	X-Ray Waiting Area	**X-Ray**	**3/17/04 21:47**	**3/17/04 21:43**	**0:04:06**
10162003 0248	**CCA Main Door**	**CCA**	**3/17/04 22:56**	**3/17/04 22:56**	**0:00:00**
10162003 0248	Primary Enrollment Sta.	CCA	3/19/04 22:59	3/19/04 22:59	0:00:00

read are highlighted in boldface type. These records were different from those in the first set because they were not embedded within a stream of data records covering a contiguous time frame (i.e., there are long timeframes preceding and following those data records).

Typically, a valid data record could be associated with a patient because of the close proximity in time of the reads and the location of the reads. Although during some periods of short duration a tag might not be read, the data showed these lapses typically occurred as the patient was being moved from one area of the ED to another. We confirmed this finding through manual inspections of the patient's paper charts.

Since the project was precluded from using patient identifiers because of federal patient confidentiality laws and the MED's patient privacy policies, we relied on other rules to identify when a tag was transferred between patients. For example, a twelve-hour gap between reads (thus allowing enough time for the tag to be removed from one patient, sterilized, and attached to a new patient) would signify a new patient with that tag.

Nonetheless, in many instances a tag was inexplicably read during the twelve-hour wait time. An example of this type of error is highlighted in Table 2, at the Trauma Operating Room Entry Door. This data record does not appear to be connected to any particular patient because the time lags on the reads before and after the highlighted record are quite large.

Almost all of the errors represented in Table 2 were associated with the RFID readers at the Primary Enrollment or Trauma Operating Room Entry Door stations. These errors were examined for possible explanations. For example, at the Primary Enrollment station, it was found that at the time of the errors, the RFID tags in question were placed in a (supposedly) RF-proof container. A close inspection of the container found a one-eighth inch separation between the lid and the container. This separation, it turned out, was large enough to permit the RF waves from the readers to enter the container and trigger responses from some of the tags inside. As a result, Mylar™ bags with an RF shield capability were introduced so that whenever a tag was not being used on a patient, it was enclosed in its own bag. In this way, tags were insulated while in the "RF-proof" container and while being transported by hospital staff between locations.

Across-Patient Data Anomalies

The errors at the Trauma Operating Room Entry Door were more puzzling. Like the Primary Enrollment station errors, the errors at the Trauma Operating Room Entry Door did not appear to be connected to any particular patient because the time lag on the reads before and after the highlighted record are quite large. However, time-spans of the erroneous broadcasts from RFID tags at the Trauma Operating Room Entry Door were much longer, ranging up to about forty-five minutes. Records containing these long transmission errors recorded at the Trauma Operating Room Entry Door were transferred to a separate file and evaluated. That analysis found that these reads were clustering around particular times (see boldfaced records in Table 3). The project team hypothesized that the RFID tags were somehow being collected at the Trauma Operating Room Entry Door, and then handled outside of their RF-proof bags. When the tags were exposed, they signaled the reader as to the locations, which were dutifully noted by the RFID data system.

Table 3. Across-Patient Data Anomalies

Tag ID Number	Reader Name	Area	Tag First Read	Tag Last Read	Elapsed Time
10142003 0605	Trauma CT Scan I	CT/MRI	3/14/04 22:53	3/14/04 22:53	0:00:00
10142003 0605	**Trauma OR Entry Door**	**Misc**	**3/16/04 1:37**	**3/16/04 1:32**	**0:04:59**
10142003 0605	Primary Enrollment Sta.	CCA	3/21/04 0:29	3/20/04 20:13	4:16:44
10142003 0607	CCA Main Door	CCA	3/15/04 15:08	3/15/04 15:08	0:00:00
10142003 0607	**Trauma OR Entry Door**	**Misc**	**3/16/04 1:37**	**3/16/04 1:33**	**0:04:20**
10142003 0607	Shock Trauma I	CCA	3/16/04 23:08	3/16/04 21:37	1:31:25
10142003 0621	Shock Trauma Hallway	CCA	3/15/04 1:38	3/15/04 1:38	0:00:06
10142003 0621	**Trauma OR Entry Door**	**Misc**	**3/16/04 1:40**	**3/16/04 1:33**	**0:07:22**
10142003 0621	Shock Trauma I	CCA	3/18/04 0:48	3/18/04 0:07	0:40:47
10152003 2335	CCA Main Door	CCA	3/13/04 18:07	3/13/04 15:54	2:12:54
10152003 2335	**Trauma OR Entry Door**	**Misc**	**3/16/04 1:41**	**3/16/04 1:33**	**0:08:40**
10152003 2335	Primary Enrollment Sta.	CCA	3/18/04 1:32	3/18/04 1:32	0:00:00
10242003 0508	CCA Main Door	CCA	3/14/04 23:34	3/14/04 23:34	0:00:00
10242003 0508	**Trauma OR Entry Door**	**Misc**	**3/16/04 1:33**	**3/16/04 1:33**	**0:00:00**
10242003 0508	Primary Enrollment Sta.	CCA	3/17/04 20:06	3/17/04 20:06	0:00:05

The errors at the Trauma Operating Room Entry Door showed the RFID data could also be used to track the way in which the staff was handling the RFID tags. The RFID data showed when and where the errors occurred, and that data could be compared against personnel records to see who was working at that time and place. These personnel could then be questioned about what they were doing with the tags, but the discussions had to be handled diplomatically to avoid turning a potential learning opportunity into a "finger-pointing" dispute that could diminish the acceptance of the RFID technology.

Other types of data anomalies were found at other locations. In several cases patient data showed that the patient treatment began in the X-Ray or CT/MRI areas. It was hypothesized that such patients were not tagged when they first arrived in CCA. It was noted that these problems were more frequent at the beginning of the data collection period than at the end—a sign that the staff was learning how to incorporate the RFID into their normal routines.

The levels and complexity of dirty data increased data cleansing costs and thereby ate up some of the savings from reduced data entry. The data cleansing efforts led to the identification of several heuristics that can be useful in preparing RFID data. Some errors are relatively easy to identify, such as those that would initially indicate patient movements that are physically impossible (e.g., a patient moving back and forth across distances of 50 feet or more in sub-second transit times). Some errors appear to be related to environmental factors (e.g., moving metal doors that block or reflect RFID signals, or containers that do not adequately shield tags from readers). Other errors were related to human error or lack of training (e.g., inappropriate handling of RFID tags at the Trauma Operating Room Entry Door). While these heuristics were shown to be useful for patient tracking and decision support within a hospital setting, future research may show that the value of similar heuristics in RFID applications in other industries.

IDENTIFICATION OF PROCESS AND WAIT TIMES

The data cleansing process resulted in a sample of 655 usable patient records over a one month period. Once cleansed, the RFID data was then analyzed to generate workflow process times. RFID data is unlike normal business-oriented transaction-based data in that many important inferences obtained from RFID data cannot be extracted through set-theoretic analysis (i.e., inferences are drawn where elements are related by membership in a set). Instead, RFID data is much like a flowchart in which the elements follow one another. Set-theoretic software (e.g., relational databases) do not represent the logic required to travel across—or traverse—multiple RFID data points. Instead, graph-theoretic analyses were necessary because data records "point" to one another to create path-based patterns of interest. This fundamental difference means that the RFID data must be initially processed by software that can incorporate graph-theoretic analysis. Microsoft® Excel's graph-theoretic capabilities allow calculating values based on relative cell positions. Data was sorted by tag number and read-time order[4].

Various turnaround statistics were then estimated by first clustering an individual patient's data, and then analyzing the first and last reads for each patient to determine the patient's total length of stay at the Trauma Unit. The patient's stream of RFID data could then be dissected to identify turnaround times for subunits within the ED such as x-Ray, CT/MRI, or OR.

Patient turnaround times were calculated and aggregated into sets of related records (e.g., X-ray treatment times). Since these aggregations were indeed sets (i.e., they conformed to requirements of set theory), they could be analyzed via traditional relational databases. Relational data management systems were used to generate reports based on quantified wait times and helped verify the existence of bottlenecks hypothesized during the development of the "as is" process maps. This data was then used to construct reports describing average length of patient stay, average turnaround times for x-Ray and CT/MRI, and standard deviations.

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[4] Again, federal laws regarding patient confidentiality restricted the use of patient identifiers in the data set

One of the first important findings was that RFID data increased the percentage of accountable hours (i.e., the percent of hours of a patient's stay that could be tied to one subunit of the Trauma Unit, such as CCA). Whereas prior to the study, only about 25 percent of a patient's stay could be accounted for, now a little over 80 percent was accounted for. Individual cases that exceeded desired turnaround standards were identified in exception reports. Performance measures of turnaround times were also reported, giving average (mean) turnaround times, their standard deviations, as well as minimum and maximum values. While many of these performance measures are confidential and cannot be reported, the medical staff was generally pleased by the quality and value of the initial results.

For example, the medical staff was especially interested in the average time it took for patients to be served in x-Ray and CT/MRI. Results suggested that cycle times for these ancillary services might be improved through more timely transportation services. That is, patients appeared to have been processed within acceptable time limits by the x-Ray staff, but then the patients were sometimes left in the x-Ray waiting areas for some time before Transportation staff members were able to bring them back to the CCA.

V. LESSONS LEARNED: KEYS TO RFID SUCCESS

THE MORE THINGS CHANGE…

While RFID represents a promising new data source for business intelligence, many tried and true "best practices" will help insure implementation success. They include the following**:**

Beware the Hype

RFID receives much favorable press, which may raise unrealistic expectations. We caution the reader that while RFID survived "proof of concept," it requires additional "proof of application" efforts to verify that RFID technology is appropriate in specific environments, each with unique process requirements and product characteristics. That is, while RFID technology may work well in controlled conditions, it may not be suitable for all environments.

The Importance of Project Management

RFID projects include the integration of new software, hardware, and business practices. Consequently, most RFID implementation efforts will be fairly complex and involve a variety of people, both internal and external to the organization. While an interdisciplinary project team can be an asset, coordinating and controlling these disparate parts is a considerable challenge. A relatively small slip in the schedule for one piece of the project could create a snowball effect on the overall project schedule, resulting in significant setbacks. This complexity underscores the importance of a highly visible and well communicated project plan that is reviewed and updated regularly.

Software Development Principles Still Apply

Much of the intelligence in RFID systems lies in the software that helps to capture, store, process, and report on the data provided by RFID tags and readers. This software centricity mandates the adherence to sound systems development principles. Here is a short list of what still applies:

- Identify problems that RFID can solve. Do not just install the technology and wait for miracles to happen.
- The data belongs to the organization. RFID data can pinpoint poor operations. It is important for the organization to take a problem-solving approach and avoid finger-pointing.

- While data may be used primarily by one department, it is important that everyone be involved in keeping the data clean (e.g., transportation staff shouldn't carry unprotected tags in their pockets).

- Testing is still essential. Although our testing took various forms, we were able to conduct conventional planned testing to some degree; the BOB tests and validation against patient charts are examples. However, because of the limited experience with RFID implementation, we were unable to plan every aspect of our testing. We just did not have a complete picture of what to expect. Therefore, we found it necessary to take advantage of "discovery" as a part of our testing efforts. For additional discussion on this issue, see "Unique Data Issues" in the next section on "Old Dogs Need to Learn New Tricks Too…".

- Training is still important. The project showed that RFID technologies create a variety of classes of users. Some users deal with the data and equipment directly (e.g., medical staff who tag and track patients). Other users deal with the equipment indirectly. For example, in this case non-medical staff were responsible for the transport of the tags to and from the sterilization department and technicians were in charge of the sterilization of the tags. The latter group of users needed training on how to handle the sensitive RFID tags so that dirty data could be kept to minimal levels.

- End-user involvement is essential. The passive nature of the technology makes it important to understand the user processes to create an "invisible" insertion into their work. Cooperative relationships are also important.

Outsource With Care, Expect On The Job Training

As a result of the newness of the technology, RFID is not well understood. The pre-existing skill base of experienced RFID professionals is limited. Therefore, it is not uncommon for the development portion of the project to be outsourced. Unfortunately, few contractors possess the necessary experience with RFID to address the challenges inherent with this technology. Since prior experience with RFID is important, work even more closely with outsourcing companies than normal to determine their true expertise. Furthermore, expect outsourcing companies to learn more about the technology while they are working with/for you. For example, RFID reader/antenna placement is a task that improves with experience. Our installation specialist now knows more about how to locate readers properly to maximize readability and minimize over-reading as a result of having done it. Similarly, the software and firmware associated with readers and tags provides features that can be particularly useful – if the vendor knows the features exist. Through a "learning by doing" process with this project, members responsible for the software and hardware development now know how to use the technology to provide meaningful data.

Beware of Scope Creep

Many are viewing RFID as a panacea for increasing the visibility into business processes. This optimism leads many to expect that RFID will solve all problems and provide data to answer all questions. While the future may prove RFID to be this good, the technology is not there yet. That said, project participants need to be vigilant in helping end-users manage their expectations to keep them at realistic levels. As the end-users begin to see the potential for RFID application, they begin to identify additional features and functions for the project. Any additional functionality must be clearly justified if project scope is to be maintained at manageable levels.

Champions…Still a Critical Success Factor

Progress on RFID implementations tends to be "two steps forward, one step back" in nature. Project champions help to keep projects moving through setbacks and other learning hurdles.

The Two Faces of RFID

Like other online systems, RFID technology can provide data in real time for ad hoc decision making, as well as storing data in warehouses for post-hoc data analysis. From our research we learned that it is now possible to conduct post-hoc analyses. More research and work is needed to develop an ad hoc capability. In the end, the user community must know what it wants from the RFID system, and what is possible at that time.

OLD DOGS NEED TO LEARN NEW TRICKS TOO…

Many of the lessons learned apply universally to RFID and other systems implementation efforts. Perhaps the most notable of these lessons concerns the usefulness of studying IS innovation within a healthcare setting. Other lessons learned appear to be unique to RFID technologies. These lessons involve data, hardware, and infrastructure idiosyncrasies associated with RFID use, and are quite different from typical manually-operated transaction-based information systems.

Healthcare Information Systems *versus* Healthcare Informatics

Healthcare is the world's largest industry. In the United States, for example, it accounts for 14 percent of GDP. In spite of the size of the healthcare industry, only 1.2 percent of IS journal articles concern this industry [Chiasson and Davidson, 2004, cited in Wilson, 2004]. The paucity of healthcare information system research in IS journals can be explained by the large amount of that research being published in health informatics journals. Traditionally, these articles are oriented toward the idiosyncrasies of biomedical information in a clinical context. The topic areas include biomedicine, biomedical engineering, [medical] decision-making, and education [Morris and McCain, 1998:464].

On the bright side, the interest among IS researchers in research that intersects the IS and healthcare disciplines is growing, particularly in the ways in which research within that discipline is applicable to an IS audience [Wilson, 2004]. Our research follows this trend by evaluating an emerging information technology and the data it can produce (i.e., RFID) in the context of a healthcare environment. Our study also provides value to the medical community because it demonstrates the value of *non*-biomedical data—and its corresponding information systems—as a means for improving healthcare services. Specifically, our research demonstrates the feasibility of using emergent RFID technologies to generate non-medical patient location data, and the value of that data for improving medical processes, decision-making, and resource management. The results also show one way in which healthcare information systems research can contribute meaningfully to healthcare research and practice in ways that are outside the typical domain of health informatics.

Unique Data Issues with RFID

We identified three concerns:

1. The real-time and broadcast nature of radio-based data, which is markedly different from traditional "conducted" data flows. Traditionally, systems developers think in terms of business processes and data flows that move in fairly well-behaved ways (e.g., from one database to another or from one location to another). Given the wireless broadcast nature of RFID, data can be acquired by any RFID reader in the vicinity (which of course varies depending on the tag type – unpowered *versus* battery-powered tags). Environmental factors, such as reflective surfaces (e.g., swinging metal doors) or leaky protective devices (e.g., carrying cases with ill-fitting lids) can compound this problem by misdirecting RFID signals. These factors result in a much "noisier" data environment. Data moves in a less manageable way, with some readers capturing data when you may not expect nor want them to. In other words, just because an RFID reader sees the data from the tag, that does not mean that reading is part of the true data flow or business

process progression. Of course, the likelihood of these errors varies depending on the tag type (e.g., unpowered *versus* battery-powered tags). Noise presents the challenge of teasing out meaning from the large amount of data that is captured…a more significant data cleansing challenge than that posed by traditional data stores.

RFID requires a more sophisticated approach to data input verification. Again, system implementers typically think in terms of data entry processes that can be validated in real time (e.g., a customer receives a receipt that can be verified after items have been scanned through a bar code reader).

2. Data verification can be difficult in some RFID implementations because some readers capture unexpected or unwanted data (e.g., when a tag is unwittingly brought into view of an RFID reader). Because RFID systems are much more susceptible to environmental noise, they work in a much "noisier" data environment, which in turn can significantly affect the reliability of reporting, decision-support, and other information systems.

That RFID data is more susceptible to environmental noise does not necessarily mean it is unusable. The "tracer bullet" analogy [Hunt and Thomas, 1999] may be helpful in this regard because it suggests that the benefit of RFID data may stem from its ability to support real-time adjustments to business processes in dynamic environments. As Thomas notes, "Basically, it all comes down to feedback. The more quickly you can get feedback, the less change you need to get back on target" [Venners, 2004].

3. RFID systems can read tags at the rate of a thousand times per second. These high read rates lead to data explosions. System implementers need to understand:

1. the data needs of the organization,
2. the costs associated with storing RFID-generated data,
3. the data-generating capabilities of RFID hardware and software, and
4. the intricacies of matching items 1-3.

The Need For a Flexible Infrastructure

Implementing RFID-enabled systems requires the installation of a significant amount of hardware in terms of networked readers and associated database servers. While the back-end servers remain relatively stable, the pace of technological change with new RFID technologies remains quite high. Form factors, frequency bands, battery-powered or EPC tags, and readers with specific read capabilities require that system designers build flexibility into their RFID systems. Specifically, looking for readers with multi-function read capabilities, and with some amount of backward compatibility for earlier generations of RFID technology will help to minimize the expense associated with wholesale hardware replacement.

Think Like an RFID Tag

Traditionally, when we think of information systems, we tend to focus on the data moving through the system. For example, we focus on interfaces users see, data entered by users, and where the data flows. While this focus is still important with RFID systems, it is perhaps even more important to try to adopt the perspective of the RFID tag itself as it moves through the business process. For example, what does an RFID tag affixed to a carton of small consumer products "see" when it is on the shelf in the warehouse? Does its view of the environment change as it is picked up by the forklift (does the forklift motor and steel body interfere with the tag's view?) and moved through the warehouse (are there blind spots in the warehouse?)? Does everything "go dark" for the tag when it is loaded into a metal-skinned trailer? Adopting this perspective helps to reveal potential problems before the system is hardwired and installed.

A related characteristic of RFID tags is that they are incessantly ready to provide data and will do so whenever they are within range of an RFID reader. This "always on" trait is unforgiving; if a tag is inadvertently exposed to the reader environment when not assigned to a patient, the tag will begin generating dirty data—and a lot of it.

VI. CONCLUSIONS

IDENTIFICATION OF FUTURE DIRECTIONS

Given the success of the demonstration project presented here, it is certainly worthwhile to consider future work with RFID in health care. There is a great opportunity to enhance the business intelligence capabilities of this technology. Further research would increase the understanding of how to architect an RFID reader network to provide fewer read anomalies. An automated data filtering facility would improve the reliability and integrity of the RFID data, and would minimize the time needed to produce actionable reports. In addition, a real-time graphical user interface that displayed the status and location of all patients in a unit would provide decision makers with critical information that should improve their real-time decision making capacity.

PROJECT SUCCESS

The goal of this demonstration project was to establish the feasibility of using RFID technology in a Trauma ED. We believe that goal was achieved. The results of our study show that RFID technology may be a good fit for the hospital environment. The evidence shows technical feasibility (e.g., it is possible to install the technology, the technology is compatible with existing technologies, the technology works) and functional feasibility (e.g., staff will adopt the technology and data can be collected in a passive manner with minimal medical staff involvement). What is less clear is if RFID is financially feasible at this time for other EDs. Financial considerations will become less of an issue since the cost dynamics of this new technology is such that its cost is dropping precipitously as fabrication capabilities improve and wide-spread demand for RFID is generated. Ultimately, however, we show that patient location is available 24X7. Furthermore, we believe that RFID can provide just-in-time business intelligence for the healthcare community, which can impact positively the quality of health care provided.

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REFERENCES

EDITOR'S NOTE: The following reference list contains the address of World Wide Web pages. Readers who have the ability to access the Web directly from their computer or are reading the paper on the Web, can gain direct access to these references. Readers are warned, however, that

1. these links existed as of the date of publication but are not guaranteed to be working thereafter.

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American College of Emergency Physicians. (2003). "Emergency Department Waiting Times." http://www.acep.org/1,2084,0.html.

American Institute of Certified Public Accountants. (2004). "Top Five Emerging Technologies." http://www.aicpa.org/infotech/technologies/toptechs/2004.htm.

Attewell, P. (1992). "Technology Diffusion and Organizational Learning: The Case of Business Computing." *Organization Science*, (3)1, pp. 1-19.

Boland, R. J. (1979). "Control, Causality and Information System Requirements." *Accounting, Organizations and Society*, (4)4, pp.259-272.

Chau, P. Y. K. and K. Y. Tam. (1997), "Factors Affecting the Adoption of Open Systems: An Exploratory Study." *MIS Quarterly*, (21)1, pp. 1-24.

Chiasson, M. W. and E. Davidson. (2004). "Pushing the Contextual Envelope: Developing and Diffusing IS Theory for Health Information Systems Research." *Information and Organization*, (14) 3, pp.155-236.

Eslambolchi, Hossein, CTO and CIO of AT&T. April 15, 2004 http://www.heavyreading.com/document.asp?doc_id=51059

Forrester, J. W. (1961). *Industrial Dynamics*, Cambridge, MA: The MIT Press.

Giaglis, G. M. (1999). "On the Integrated Design and Evaluation of Business Processes and Information Systems." *Communications of the Association of Information Systems*, (2)5.

Goodwins, R. (2002). "The Year Ahead: Top Ten Technologies to Watch." ZDNet UK . http://news.zdnet.co.uk/communications/0,39020336,2127608,00.htm

Handfield, R. B. and E. L. Nichols. (2002). *Supply Chain Redesign: Transforming Supply Chains into Integrated Value Systems*. Upper Saddle River, NJ: Financial Times Prentice Hall.

Hunt, A. and D. Thomas. (1999). *The Pragmatic Programmer: From Journeyman to Master*. Reading, MA: Addison-Wesley.

Morris, T. A. and K. W. McCain. (1998). "The Structure of Medical Informatics Journal Literature." *Journal of the American Medical Informatics Association*, (5)5, pp.448-464.

National Medical Library (National Institute of Health). (2003). "History of Medical Informatics." http://www.amia.org/history/what.html.

NextInnovator. (2004). "Top Ten Technologies for 2005." http://technologyreports.net/nextinnovator/?articleID=3004.

Ramaswami, R. (2004). "Top Ten Supply Chain Challenges. Operations and Fulfillment." http://opsandfulfillment.com/ar/fulfillment_top_ten_supply/.

Rogers, E. M. (1962). *Diffusion of Innovations*. New York: The Free Press.

Senge, P. (1990). *The Fifth Discipline: The Art and Practice of The Learning Organization*. New York: Currency Doubleday.

Smith, H. and B. Konsynski. (2003). "Developments in Practice X: Radio Frequency Identification (RFID) – An Internet for Physical Objects." *Communications of the Association for Information Systems*, (12)19.

Teradata. (2004). "Survival of the Fastest." http://www.teradata.com/t/page/126753/.

Venners, B. (2004). "Pragmatic Programmers, Part 2: Gardening with Tracer Bullets." http://today.java.net/pub/a/today/2004/02/23/davenandy2.html.

Vosburg J. and A. Kumar. (2001). "Managing Dirty Data in Organizations Using ERP: Lessons from a Case Study." *Industrial Management & Data Systems*, (101)1, pp. 21-31.

Wetherbe, J. and M. Frolick. (2000). "Cycle Time Reduction: Concepts and Case Studies." *Communications of the Association for Information Systems*, (3) 13, pp. 1-42.

Wilson, E. V. (2004). "Editorial Statement: Information Systems and Healthcare Department." *Communications of the Association for Information Systems*, (13)27.

LIST OF ACRONYMS

CCA	Critical Care Assessment area
CT/MRI	Computed Tomography/Magnetic Resonance Imaging
ED	Emergency Department
EPC	**Electronic Product Code**
MED	Regional Medical Center (Shelby County, TN)
OR	Operating Room
RF	Radio frequency
RFID	Radio Frequency Identification

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