RFID-Embedded Decision Support for Tracking Surgical Equipment

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Abstract
Healthcare and supply chain management have recently been the two most active areas for RFID applications. The healthcare environment is a natural fit for generating and utilizing instance-level data for decision support. We consider a scenario from the French healthcare environment involving tracking and tracing of surgical equipment within and among hospitals and develop a knowledge-based system for decision support that helps improve the overall performance of the surgical instrument management process while reducing errors. We illustrate the process through the developed healthcare knowledge-based system and evaluate its performance.

1. Introduction
Healthcare and supply chain management have been the two most active areas for RFID applications in recent years. The healthcare environment is a natural fit for generating and utilizing instance-level data for decision support. RFID, with its relatively small footprint and reasonable enough memory and processing power, is an ideal candidate in such applications.

Not surprisingly, RFID tags are increasingly being used in the healthcare environment with varying levels of success (Tu et al., 2009). For example, tagging pharmaceutical items to prevent counterfeiting as well as tagging items in a hospital environment for inventory purposes have been fairly successful. However, certain RFID applications have faced resistance in a hospital setting where their electromagnetic interference could affect normal operation of medical instruments (e.g., Ashar and Ferriter, 2007; Seidmann et al., 2010; Togt et al., 2008). Nevertheless, in spite of these issues, there is a large untapped potential for RFID applications in healthcare organizations.

Researchers and practitioners are continually searching for improvements in process efficiency while safely and uncompromisingly delivering healthcare services. While it is difficult to achieve dramatic improvements in efficiency in the delivery of healthcare processes, it is possible to provide appreciable improvements in several scenarios that when put together results in the overall improvement of the healthcare delivery process in terms of patient outcome, efficiency, accuracy, and cost.

We consider a scenario from the context of healthcare delivery in France that lends itself to improvements in efficiency and effectiveness (Meiller and Bureau, 2009). This scenario involves tracking of surgical equipment within and among hospitals. Given the complexities associated with this scenario, there is a need to develop an intelligent means to semi-automatically support decisions in this dynamic environment. We modify and instantiate an adaptive knowledge-based system framework to this scenario and study the dynamics.

The remainder of this paper is organized as follows: in Section 2, we provide a brief introduction to the scenario considered. In Section 3, we introduce the modified adaptive knowledge-based system framework adapted to the scenario considered. We also illustrate the instantiation of this modified framework to the considered scenario. We conclude the paper with a brief discussion in Section 4.

2. Tracking surgical instruments
In the hospital setting we consider, each surgical instrument belongs to a specific set. While instruments from different sets are sterilized together, each instrument is assembled with other instruments in its set after sterilization. I.e., each instrument has to be meticulously tracked and traced to ensure instruments that belong together indeed are stored together in their sterile box. Moreover, these boxes are sterile only for a pre-specified period of time. The content of an entire box is sterilized regardless of the number of instruments in that set that were used.

The primary rationale for such stringent requirements with respect to tracking and tracing of individual instruments include scheduling their maintenance and to minimize risk associated with cross-contamination of certain diseases that are not yet completely understood. An example of the latter is the
need to remove any instrument that has ever been in contact with a patient who presumably has Creutzfeldt-Jacob disease from further use.

Clearly, given the similarity of instruments of a certain type, it is not hard to foresee the occurrence of frequent mishaps and mix-ups. Hospitals generally allocate necessary resources including allocating nurses from the surgical block to address this issue. These nurses have specialized training with high qualification to enable them to assist surgeons during operations. In addition to their exceptional skill-set, these nurses earn high wage, and their work time is therefore more valuable to the hospitals where they are employed. While these nurses deal with assembling surgical instruments after they are sterilized, they are essentially unavailable to assist surgeons perform surgery. An automated means to perform these tasks and relieving the nurses so they can concentrate on performing tasks related to their expertise would certainly benefit the hospitals.

Again, the process of tracking and tracing surgical instruments can be fairly easily done by RFID tagging these instruments. Care should be taken to ensure that these embedded tags are out of the way and do not hinder the intended designed purpose of the substrate instruments. We develop a modified framework and instantiate the same using an automated system for the scenario where surgical instruments are individually tracked and traced.

3. Adaptive knowledge-based system

The scenario of interest in this study is very dynamic and therefore dictates a need to develop a system that continually learns from its environment while dealing with data at a fine level (instance-level) of granularity. RFID tags are capable of generating instance-level data on a continual basis to provide necessary input to such a knowledge-based system. The challenges associated with such fine level data are easily handled by the scalable system used in this study.

The adaptive knowledge-based framework (Piramuthu and Shaw, 2009) we consider has been fairly successfully instantiated in several different domains. We extend this existing stream by modifying and instantiating the adaptive knowledge-based learning system framework for the scenario under consideration. This adaptive framework comprises four primary components including Simulation, Learning, Problem-Solving, and Performance-evaluation. Given that this is a knowledge-based system, the Learning component is used to generate the knowledge-base which forms the core of this system. Without appropriate and necessary knowledge, this system will not be able to perform intelligently. The Problem Solving component comprises the Knowledge-base and the Problem-solver. The knowledge-base contains learned knowledge on the domain of interest. The Problem-solver uses the knowledge-base and an instantaneous snap-shot of the environment to generate the most appropriate decision. A common characteristic of a knowledge-base in any dynamic environment is its tendency to become stale sooner or later. This can be addressed through concerted effort by the three (i.e., Learning, Simulation, and Performance-evaluation) components to keep the knowledge-base current through appropriate measures in a timely manner.

The Performance-evaluation component continually keeps track of the performance of the system. When it determines that the adaptive knowledge-based system is beginning to perform below par, it generates the specifications for new training examples and the Simulation component generates appropriate training examples based on these specifications. The simulation component is instantiated only when necessary data are not readily available in the system of interest. The data generated by the simulation component therefore fills the gaps as and when necessary in a seamless manner. This alleviates problems associated with knowledge-based systems performing below their capabilities due to the lower quality of its input data. The simulation module also eliminates the need to wait for the exact set of pattern to occur in the system to generate the required set of training example data set. The training examples thus generated are input to the Learning component, which incrementally learns new knowledge and accordingly updates the knowledge-base.

We modify this adaptive knowledge-based system framework for our purposes. The result of such modification to accommodate RFID-embedded systems in a healthcare environment is given in Figure 1. In this framework, the Learning component performs a similar function as the Learning component in the framework in [3]. The Measurement and Evaluation components perform a similar function as the Performance-evaluation component in [3]. The knowledge base in the modified framework comprises four sub-components to accommodate the different functionalities that are required of the system including delivery routing and frequency, patterns of local demand and service provisions. The remainder of the components and sub-components in Figure 1 perform the functionalities of the Problem-solving component in [3].
The exogenous factors include the actual medical requirements that further become the demand on both physical and medical labor resources. With these inputs, the problem solver determines the appropriate local and centralized inventory, and effective management and delivery of necessary and appropriate equipment at necessary locations. After a medical service is performed, both service quality and associated cost are determined and evaluated. Based on evaluation, associated benchmarks, and the extent of possible potential improvements, appropriate remedial

**Figure 1. RFID enabled Adaptive Learning framework for Healthcare**

**Figure 2. Schematic of the modeled scenario for tracking surgical instruments**
measures are recommended and implemented. The entire process is accomplished with improved efficiency and effectiveness with simultaneous reduction in errors that are endemic to such systems.

3.1. Modified adaptive knowledge-based framework for tracking surgical instrument

We model four hospitals for this scenario. All surgical instruments are RFID tagged here. A schematic of this scenario is given in Figure 2. Here, in addition to within hospital movements, we consider movement of the surgical instruments among the four hospitals. In this scenario, we investigate the problem of utilizing RFID to better organize medical surgical instruments that have compatibility issues.

Compatibility issue is a common problem in many industries, and it is specifically important in health care institutions when different medical equipment have their own specialized usage and procedures to operate. There are certain rules to utilize, to store and to manage the medical equipment. For example, although the same, the surgical instruments used for cardiac surgery should be managed differently from those that are used for knee surgery and consequently those surgical instruments should probably not be mixed together. Another example is where a set of knives and scissors for surgery should always be placed together to manage their quality deterioration over time whereby those sophisticated instruments have a certain useable life-span that is either mandated by law or by practical experience.

As a result, in every medical unit there should be a set of rules that addresses equipment compatibility issues. In general, the same rules would apply to another unit with the same functionalities, but in practice these rules are not necessarily the same because of the differences in external factors. Compatibility rules are usually different for medical units with different health care purposes. These rules, which are usually examined and enacted by a committee of specialists, can be learned and modified according to the dynamics of real-time working conditions. With the assistance of real-time tracing and tracking capability of RFID, more flexible and more accurate compatibility rules can be discovered with data mining techniques.

This case itself is a natural extension of the first case discussed earlier. When medical equipment are constantly on the move within the medical unit and among them, the problem of efficiently organizing the equipment with compatibility issues becomes more complicated. We utilize a knowledge-based system to discover existing patterns and to make sound recommendations in the health care environment.

The initial set of rules of compatibility \( \{\chi_1, \chi_2, ..., \chi_n\}_{t=0} \) is defined by medical specialists based on their medical knowledge. Later, rules of compatibility can be learned and updated with continuous usage,

![Figure 3. Performance Improvement of Dynamic Control over Re-organize Policy with Compatibility Issue](image)

such that for \( \{\chi_1, \chi_2, ..., \chi_n\}_{t=T} \), \( f(\chi(T)) > f(\chi(0)) \), where \( f(\cdot) \) indicates the medical service quality or rate of medical accidents that is related to compatibility issue.
and three different medical instruments A, B and C. Here, A and B, B and C, A and B and C have compatibility issues at medical units #1, 2 and 3 respectively. Figure 3 illustrates the improvement of our proposed system over traditional policy.

Table 1 shows the mean and standard deviation of service time for each medical instrument. Here, TTwA, TTwB, and TTwC refer to the time taken for A, B, and C respectively in the traditional (i.e., without RFID) control cases and TwA, TwB, and TwC refer to the time taken for A, B, and C respectively in the cases with RFID. Across all the experiments, time spent on arranging each equipment dropped 50% for A and 85% for B and C with the proposed knowledge-based system. Dynamically controlling the movement of surgical equipment using the proposed knowledge-based system both within and among hospitals while they are used, sterilized, and assembled together results in appreciable improvements in decreasing uncertainties. The reduction in uncertainties naturally leads to improvements in system performance. Table 2 compares the result for each pair and further shows that the improvement is significant. The average values of the differences are similar and this is purely by coincidence. In Figure 3, we observe that the improvement over traditional policy is very marginal when the demand is stable. Otherwise, the benefit is significant.

Clearly, when demand is stable, with no unexpected variations, the hospital management can allocate necessary resources to efficiently utilize its resources within present constraints. However, when demand is uncertain as is certainly the case in a medical surgery environment where unplanned procedures are performed, there is a need to effectively and efficiently utilize resources to improve the overall system performance while simultaneously improving health care delivery process and resulting outcome.

<table>
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<th>Equipment</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% CI Lower</th>
<th>95% CI Upper</th>
<th>t</th>
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</table>

4. Discussion

The performance of medical surgery can be either planned or unplanned (i.e., emergency situations that dictate immediate surgery to rectify the situation or at least alleviate present ailment). In general, any given environment where medical surgery is performed witnesses a mix of both planned and unplanned cases.
the overall performance while effectively utilizing resources.

We considered an existing adaptive knowledge-based decision support system framework and instantiated it to accommodate a scenario in the health care domain. Specifically, we considered the scenario where it is necessary to keep track of surgical instruments as they are used, sterilized, and stored in pre-defined sets. RFID tags have begun to permeate a wide variety of application areas. Health care applications, where there is a need to accurately track and trace individual items at any point in time as situations dictate, and RFID tags are in a sense complementary to each other and can be synergistically used to improve performance. We showed that the proposed modified framework results in automating the processes involved. Moreover, we illustrated means to develop an adaptive knowledge-based system for health care applications. We illustrated the use of fine grained information provided by instance-level RFID tags to improve the performance of the surgical equipment management system in the health care environment. This study is a step in the direction of using RFID-tags to automate health care processes while simultaneously reducing errors in this domain.

While the general public is not familiar with RFID tags, they are subjected to a barrage of negative impressions on RFID tags through organizations such as CASPIAN (nocards.org). More studies are essential to increase confidence among the general public as well as medical personnel to illustrate and reinforce the beneficial aspects of RFID tags.

5. References


