Redesigning the replenishment process of medical supplies in hospitals with RFID

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Purpose – To present a case study of a hospital nursing unit that has evaluated and approved a 2-bin “e-kanban” replenishment system based on passive HF RFID technology.

Design/methodology/approach – The case study analysis is based on both qualitative and quantitative data that was collected using (i) semi-structured interviews, (ii) on-site observations and (iii) experience from previous implementations. The data and simulation analysis presented in this paper were validated by key respondents thereby increasing their reliability.

Findings – Results indicate that implementing the e-kanban RFID solution in conjunction with the redesign of the ward floor and of the roles & functions can substantially improve business and operational performance. The most important benefits for the hospital are derived from the time saved from non value-added activities that can be transferred to patient care activities and the significant reduction of on-hand inventory at distributed storage locations. The solution is considered an alternative that requires less initial investment than RFID enabled cabinets used in the replenishment of consignment and high value supplies in operating rooms and cardiac catheterization laboratories.

Research limitations/implications – There is a need to conduct further research on RFID Supply Chain Management applications in the healthcare sector as this area holds a great potential for performance improvements. Additionally, there is a need to conduct more in-depth research into the isolated impact of RFID technology in comparison to the change management and process redesign that it generates. One key limitation of this research is the case study approach based on a single case. This paper therefore provides direction for practitioners on how to assess RFID’s potential impact in the healthcare supply chain.

Originality/value – While most of the research on RFID in healthcare sector focuses on active RFID technology for asset management, this research presents a novel RFID application and contributes to our understanding of RFID’s potential in intra-organizational Supply Chain Management processes.

Keywords: healthcare, replenishment process redesign, Kanban, RFID, performance, two bin, hospital

Paper type: Case study
1. Introduction

“It has become common wisdom that 30 to 40 cents of each health care dollar is wasted, that is, spent on no-value-added activities; whether or not that wisdom is valid, it is a fact that the proportion of the U.S. Gross Domestic Product (GDP) devoted to health care spending is 50% greater than in any other country and growing, without any evidence that health care in this country is better...” (The Joint Commission Public Policy Initiatives, 2009).

Reducing waste in healthcare and improving its efficiency is a global challenge. An increasing demand for healthcare services due to an aging population and a move away from institutional care is being confronted by an increasing shortage of doctors, nurses and skilled ancillary personnel, undue work pressure, ineffective communication mechanisms and already existing but unreadily available clinical information (Crounse et al., 2006), inappropriate resource allocations, and complicated or poorly presented rules and procedures that sooner or later may cause adverse events especially when combined (Blais, 2008). There is no doubt that we need to develop strategies to meet this expanding workload, especially in operating rooms (Cleary et al., 2004). With approximately 80% of their expenses tied to patient care activities, healthcare institutions can certainly garner substantial savings while improving their clinical practices by better managing their labour, supplies, equipment, and facilities (Kumar and Ozdamar, 2004).

Among the technological solutions proposed to increase healthcare efficiencies are new automation technologies such as Radio Frequency Identification (RFID) technology which is emerging as the standard for hospitals and healthcare centers to track valuable and strategic mobile assets in medical facilities, identify and locate patients, and manage staff (Fisher and Monahan, 2008). With 30% to 40% of hospitals indicating that they expect to purchase Real Time Location Systems (RTLS) to perform asset tracking within the next one to two years, there is no doubt that RTLS is still the most “popular” emerging application in the healthcare sector (KLAS Research, 2009). However other uses of RFID technology can also contribute to generate substantial savings, particularly those pertaining to Supply Chain Management (SCM). Indeed, since most clinical decisions involve managing products and medical supplies, supply chain activities have an important role in effective and efficient service delivery in hospitals (Ontario Buys & Healthcare Supply Network, 2007).

The objective of this paper is to present a case study of the impact of RFID on supply chain performance in the healthcare sector. More specifically, the research question is “how does the RFID based e-kanban solution improve the replenishment processes of medical supplies in hospitals”. The next section briefly highlights some facts on the use of RFID in the healthcare sector to add some context to the case study. In section 3 we present the technology with respect to its potential and limitations. In section 4 some alternative RFID healthcare supply chain applications are presented. Section 5 presents the case study of an RFID supply chain initiative that was evaluated and approved by a hospital. Results and discussion are presented in section 6, and the paper finally concludes with broader implications of adopting such technology in section 7.

2. RFID in the healthcare sector

Today, hundreds of healthcare facilities across the world are improving their asset utilization and maintenance by using RTLS to track mobile devices and assets, improve patient and staff workflow, improve patient safety by ensuring correct drug dispensation, improve patient billing through the automatic capture of performed services and the automatic creation of itemized billing, etc. The key characteristic driving all these benefits is the highly automated tracking of the identity, location and movement of products, people, assets and sometimes a combination of each.
Following an extensive structured literature search and analysis, Vilamovska et al., (2008) revealed that not only does a large functional range of RFID applications in healthcare exist, but implementations, trials and pilots evaluating these applications are already in existence and are becoming widespread. In fact, RFID spending in the healthcare sector is expected to increase dramatically from $474 million in 2008 to $3.1 billion in 2013; a potential market 6.5 times larger than the current one (Kalorama Information, 2008). The healthcare sector will account for a large portion of the overall RFID industry. According to recent market data from ABI Research (2009), total revenue earned from RFID transponders, readers, software and services will amount to more than $5.6 billion in 2009. IDTechEx (2009) forecasts similar numbers taking into account the global economic slow down, suggesting that the value of the entire RFID market will be $5.56 billion, up from $5.25 billion in 2008.

Interestingly, the leading frequency in 2008 remained HF (13.56MHz) used in conjunction with the ISO14443 and ISO15693 international standards and is responsible for more than five times the expenditure on RFID to any other specification (IDTechEx, 2009). It is this specific HF technology that is used in the e-kanban case study presented in this paper.

3. An overview of RFID technology in healthcare

RFID technology is a wireless Automatic Identification and Data Capture (AIDC) technology (Fosso Wamba et al., 2008) used to track and manage products, people and assets with minimal human intervention. An RFID system can be represented as a multi layer system composed by (i) tags - containing encoded data (e.g. identification number) onto an integrated circuit and an antenna, (ii) readers that use radio signals to communicate with the tags, (iii) a middleware system that interprets the information and roots it to (iv) a host system which receives and manages the relevant information generated by the RFID infrastructure. In the case of the healthcare sector, the host system will be referred to as the Hospital Information Systems (HIS).

It is therefore interesting to realize that RFID “does not provide much value on its own, but it enables companies to develop applications that do create value” (Chuang and Shaw, 2008, p. 677). There exists multiple configuration alternatives by which these components can be assembled together into a working system for a given application (Boeck et al. 2008), but the resulting configuration will depend upon the business objectives and the physical environment in which the system must operate.

3.1. RFID tags

RFID tags are primarily categorized according to their power source (active vs. passive) and frequency of operation (LF, HF, UHF or microwave). They can either transmit their signal at regular intervals in the case of certain active tags or upon request when interrogated by a reader. The most popular RFID applications in hospitals involve active tags which are used to track mobile assets such as infusion pumps and wheelchairs or medical staff and patients. These tags use an onboard battery that powers the transmitter's signal to a range of 100 meters. Some solution providers that provide active RFID solutions have developed tags that can leverage the hospital's existing Wireless Local Area Network (WLAN) infrastructure and use the Wi-Fi network to communicate with the middleware system. Other competing technology solution providers propose active Ultra-Wideband (UWB), ZigBee Mesh Networks, Infrared (IR), proprietary active RFID 433 MHz technology or Ultrasound Identification (USID). Active and semi-passive RFID tags (which do not have a battery-powered transmitter) can also be outfitted with onboard sensors and be used in applications where the monitoring of their environment is required such as temperature monitoring of blood bags or vaccines.
Passive tags on the other hand are not equipped with a battery. They are exclusively powered by the reader’s radio signal with a read range varying from a few millimeters up to 12 meters depending on the type of tag. For instance, Ultra High Frequency (UHF) passive tags from suppliers like Alien Technology, Impinj and Avery Dennison are most commonly used in SCM applications, while HF tags from suppliers like 3M, TagSys and Texas Instruments are used in applications such as access control, medical garment tracking or medical file tracking. LF tags like the VeriChip can be used in subcutaneous applications because they are least sensitive to water present in the human body and their very limited read range contribute to enhanced security.

Furthermore, In terms of technology, while presented separately, active and passive RFID should not be understood as competing technologies but as complementary, leading progressively to highly reliable pervasive environments within healthcare facilities (Thuemmler et al., 2009; Nagy et al., 2006; Orwat et al., 2008, Bardram et al., 2006).

### 3.2. RFID readers

Although the active RFID Wi-Fi tag market is recording phenomenal annual growth in healthcare, other communication standard alternatives besides Wi-Fi (IEEE 802.11) can be used. The portfolio of RFID readers also includes proprietary fixed and portable reading devices such as the ones proposed by Motorola-Symbol, Alien or Impinj. These readers can use embedded or external antennas to communicate with the tags and then transfer the data captured to the middleware system enabling backend system integration. For example RFID portals can be installed at the receiving docks to enable automatic receiving of tagged pharmaceutical products or in cabinets where high value items are stored. Today, a new generation of hybrid portable readers incorporates mixed communication standards such as RFID and Bluetooth while providing a much smaller, lighter and more convenient method of scanning passive RFID tags. A case in point is Cathexis' RFID pen, the IDBlue, which the company has developed to be used at the point of care to control the administration of prescription drugs.

### 3.3. RFID middleware

The middleware system is a software platform which acts as the bridge between the hardware components (i.e. RFID infrastructure) and the host system that often takes the form of a HIS. It ensures essential data management functions such as collecting, storage, filtering, aggregating and rooting data to the appropriate HIS modules. Moreover, it is a critical component for the event management functions like patient and staff workflow management and for other more advanced features such as real time alerts and notifications or data analytics (Fosso Wamba et al., 2008). The RFID system truly reaps its full benefits when connected to a HIS since the data processed by the middleware allows for automated transactions to be performed. Indeed, for RFID to demonstrate its commercial value, the technology “must be integrated into existing business systems (…) included within the overall business framework with respect to issues such as workflow, supply-chain relationships and leveraging of business capabilities” (Tzeng et al., 2008 p. 612).

### 3.4. Hospital information systems (HIS)

From a process perspective, hospitals are very similar to other organizations that manage personnel, assets and supplies in order to offer services to a customer. In the case of hospitals, patient care is the core “service”. Many of the information systems used in hospitals are therefore similar to the ones found in other vertical industries where the systems support process integration that result in increased operational efficiencies and improved inter-departmental
access to data. For instance, the “SAP for Healthcare Solution” offers various customized modules for care support (e.g. medical documentation management, diagnostic and treatment activities coordination); patient management (e.g. patient identification and registration, inpatient and outpatient tracking); enterprise management & support (e.g. staff management, financial management) and logistic support systems (e.g. material documentation and replenishment support) (SAP, 2008). It is important to mention that because the IT function in healthcare is considered as a support activity rather than a primary one, fewer resources than necessary are sometimes allocated to the function which results in many hospitals that still have proprietary host systems written in legacy code. This situation creates major integration issues with emerging technologies such as RFID and limits its full value potential. While some IT systems like the Electronic Health Records (EHR) have been very slowly adopted, IT is inevitably permeating all the healthcare system (Grant, 2008). In this context, Chaudhry et al., (2006) use a “health IT frameworks” to suggest that, to date, most IT applications have centered on administrative and financial transactions rather than on delivering clinical care. In our view, while the RFID based e-kanban solution discussed in this paper is primarily designed to optimize replenishment processes of products in distributed storage locations, it is a tool that supports the delivery of care by improving quality and efficiency of service delivery.

4. SCM RFID applications in healthcare

RFID applications in healthcare can be classified among six, sometimes intertwined, categories: asset & maintenance management, SCM, condition monitoring, patient & staff safety, workflow management, and security and access control. Although RFID shows tremendous potential to enhance the efficiency of healthcare SCM activities by securing the medical supply chain and increasing the safety and efficiency of healthcare processes (Wicks et al., 2006), it is an often neglected activity in this industry. It is predominantly viewed as tactical and as providing no strategic input to the overall management of the hospital. This view contrasts with a recent report from Ontario Buys & Healthcare Supply Network (2007) which indicates that the logistic function (purchase and supply of goods and services) represents 20% of a hospital’s total operational budget, thus representing hundreds of millions of dollars per year and which suggests that financial priorities should be re-evaluated. Indeed, initiatives such as an Enterprise Resource Planning (ERP) system, e-commerce transactions, AIDC or Business Intelligence reporting systems clearly contribute to modernizing key elements of the hospital’s supply chain and can generate substantial benefits, including improvement of patient care and service levels. Additionally, advanced information systems including ERP, SCM, e-commerce and now RFID are part of a continuum of business process improvements that not only serve specific business functions but also contribute to organizational capability (Chuang and Shaw, 2008).

Thus far, most RFID uses in healthcare have been for patient safety, inventory management, and asset tracking (Nagy et al 2006) or have considered the social impact of RFID in terms of security and privacy (Fisher and Monahan, 2008; Halamka et al., 2006). In other cases it has been more application specific by looking at patient and staff workflow (Laskowski et al., 2009; Amini et al. 2007; Wang et al., 2006; Chen et al., 2006) or asset tracking (Hakim, 2006; Castro et al., 2008) projects. These papers represent some of the trends found in the healthcare RFID literature. Unfortunately, they do not address issues related to emerging SCM applications. Even though RFID has been the topic of interest in various fields of research (Ngai et al. 2008) and has generated an increasing number of papers in SCM, very little research has been published on how the technology is implemented in healthcare institutions for improving supply chain applications (e.g. Wicks et al., 2006).
Previous work on the impact of RFID in this area can be classified in 3 main categories: early conceptual papers (Pramataris et al., 2005, Tajima, 2007), simulation modeling papers (Heese, 2007; Gaukler et al., 2007; Bottani and Rizzi, 2008) and field studies (Delen et al. 2007, Bendavid et al., 2009). Although these studies have made some interesting contributions for better understanding the general impact of RFID in the supply chain, this paper looks at specific RFID initiatives within healthcare such as RFID enabled cabinets and alternative automated replenishment solution. This approach is in line with recommendations to consider research on RFID usage within its context as it is affected by specific business and market forces (Prater et al., 2005).

4.1. RFID enabled cabinets
Several hospitals are adopting RFID enabled real-time inventory management systems for high value products. For instance, the University Mass. Memorial Medical Center (UMMC) in Massachusetts implemented Wavemark's RFID cabinets to store, track, and manage their utilization of high cost cardiac rhythm devices and supplies in its electrophysiology and cardiac catheterization laboratory. UMMC identified significant reductions in inventory of selected high volume, high cost items: 38% in the first month with an additional 3% reduction the following month (Collette and Johnson, 2008). Another hospital, the Heart Hospital Baylor Plano in Dallas implemented Mobile Aspect's RFID cabinets to manage its utilization of high cost devices and supplies which cost up to several thousand dollars per unit. Since each cabinet is equipped with a reader and with accompanying software for collecting data from RFID personnel identity cards, the cabinet records each transaction through a combination of what was removed, who removed it and for which patient the product is intended. By providing real-time data the process simultaneously feeds the clinical documentation system, improves expiration & recall management and eliminates the need to maintain excess inventory because the staff knows exactly how many drug-coated cardiac stents, pacemakers, defibrillators and other high cost cardiology supplies are available in the hospital (Godinez, 2007). Unlike conventional manual tracking, RFID cabinets monitor their inventory around the clock, have a high degree of accuracy, permit access-level management & control, and offer chain of custody verification when equipped with sensory data capture (Lingle, 2008). For example, the University of Texas Southwestern Medical Center has been using Terso's Internet RFID enabled medical cabinets and “Smart Freezers” since 2003 to track medical supplies.

However, a very high percentage of hospital medical supplies do not justify item-level tagging. An alternative tagging approach would be to tag the container in which the items are stored instead of the item itself. The next RFID application presents such a solution in which automated replenishment is achieved by combining an RFID tagged bin with an “e-kanban” item replenishment system.

4.2. RFID enabled e-kanban replenishment solution
Kanban is a Japanese term that means “signal”. Pioneered by Toyota, a kanban system signals the authorization to move material/products from the supplying location to the consuming location. Under the RFID enabled kanban system, the replenishment signal is automatically captured when the bin is empty and then material/products are delivered to the required location upon request. This approach changes material/product flow from a “push” to a “pull” system. In open loop supply chain applications where data is shared among its members, this signal can also trigger the authorization to produce or acquire additional products.
Various RFID enabled kanban systems are being used today. For instance, in 2006 Daimler Chrysler initiated an RFID pilot project to increase parts visibility at two of its German production sites (Collins, 2006). An early proof of concept indicated that the company could leverage on the existing kanban system by adding EPC Gen 2 UHF RFID tags to the existing printed cards that identified the part/production workstation. Alternatively, an active RFID system can be considered when the physical limits of the system hinder readability. More recently, Thermo King, an international manufacturer of temperature control systems has implemented Aeroscout's active Wi-Fi RFID to automate its parts replenishment system at its factory in Galway, Ireland. When available parts at assembly stations drop to pre-set levels, workers push a call button on the tag. The signal indicates the part number and location that requires replenishment which is transmitted through the facility's WLAN and in turn triggers a new order for delivery to the appropriate workstation (Berzins, 2009). Similar material flow replenishment processes can be optimized using Zebra's WhereNet real-time location-based system. Whirlpool Corporation uses this multimode RTLS asset tag through ISO/IEC 24730-2 communication protocol and IEEE 802.11 Wi-Fi telemetry to wirelessly make part requests (Phillips et al. 2009). The same RFID enabled replenishment logic is now used in the healthcare sector.

5. Improving intra-organizational supply chain process performance: a case in a hospital environment

While replenishment solutions for consignment supplies or high value products can be managed with RFID enabled cabinets other methods can achieve the same purpose while limiting the infrastructure costs (i.e. the cabinets and the multitude of tags used for item level tagging). The case study at hand presents a passive HF RFID enabled 2-bin replenishment system which functions as an “e-kanban” item replenishment system for stock and non-stock items (i.e. items stored in a central storage location and delivered upon request vs. items delivered directly from the external vendor to the nursing unit) stored in operating rooms (OR), procedure rooms, laboratories and nursing units. While the following study is presented in a closed loop context; the replenishment model can include the supplier when the HIS is linked to an Interorganizational System (IOS).

5.1. A HF RFID 2-bin replenishment system for medical supplies

The RFID 2-Bin replenishment system is presented in Figure 1. It is composed of (i) tags attached to the bins with a clip, (ii) a reader and its antennas inside a wall board where the tags are clipped on by the employee to automatically initiate data collection and (iii) a middleware system which analyzes the data and, based on defined business rules, transmits the replenishment order to the Hospital’s ERP.

The process functions as follows (see Figure 1). Stock quantities are generally evenly split between the primary and secondary bins. Products are initially taken from the primary bin (a). Once the primary bin is empty, the nurse simply clips the bin tag on the board to alert of diminishing stock and trigger a replenishment procedure (b,c). While waiting for the replenishment to take place, products are now taken from the secondary bin which acts as a secondary picking area that provides a stock buffer (d). When the tag signal is received by the middleware it associates the tag ID with the bin and a specific medical supply as well as the quantity to be delivered to the location. Examples of the business rules that then trigger the replenishment order include: when a predetermined number of tags appear on the board; when a tag has been on the board longer than a preset period of time or; when a critical product tag appears on the board. This
information is then passed on to the hospital ERP for processing. When the replenishment stock arrives, the remaining stock from the secondary bin is placed in the primary bin to ensure stock rotation (e) while the newer stock is placed in the secondary bin (f). The system is then reset by placing the bin tags back in place from the board in their original location on the bins (g).

![RFID 2-Bin replenishment system for medical supplies](image)

**Figure 1: RFID 2-Bin replenishment system for medical supplies**

### 5.2. Methodology

As a result of the scarce RFID literature pertaining to SCM in healthcare and the fact that projects that allow interdepartmental collaboration through the access and sharing of (medical) product information are still in their infancy, a lot remains to be done before RFID actually revolutionizes the way healthcare institutions manage their supply chain processes. The prime motivation for this research was therefore to contribute to this literature. Because RFID enabled SCM projects in the healthcare context is an emerging phenomenon, and because it represents a complex, multidimensional phenomenon (i.e. multiple stakeholders, multiple technologies, multiple products, multiple impacts), the case study approach was selected in order to facilitate the identification of the main concepts involved (Yin, 2003).

The paper is based on empirical evidence collected from 4 representative clinical departments of one 700+ bed public Canadian hospital. The case study research was conducted in 4 distinctive
phases over a period of six months. (1) The initial phase corresponded to the research project's startup activities which included the development of strategic alliances with a healthcare institution and the preparation of the data collection and analysis tools required to assess the supply chain processes. (2) SCM improvement opportunities were then identified and evaluated in the next phase by assessing selected product value chain activities and processes. (3) Information flow charts and business processes were mapped and their associated costs were validated by the respondents. (4) Lastly, the potential benefits of automating portions of the supply chain through the use of RFID technology were estimated. The designed RFID enabled scenarios were validated with the institution at this point and a Return On Investment (ROI) analysis proposed.

Both qualitative and quantitative data was collected and analysed using (a) semi-structured interviews, (b) on-site observations and (c) experience from previous implementations:

a) Using a questionnaire, semi-structured interviews were conducted within each of the 4 clinical departments under study with the department managers as well as with 2 to 3 process owners from each department such as nursing aids, administrative technicians, managers and team leaders for the distribution instances that provide central replenishment services. The combination of interviewed auxiliary and nursing personnel varied because each department and their administrative units were organized differently in term of replenishment processes and their involvement with the central store. This step helped to prepare the team for the on site observations and to gather information on the hospital's SCM specificities such as product availability (i.e. level of service) shrinkage issues, involvement of nursing staff in the process, management of urgent deliveries, etc. High level processes were also identified during this process. Questions included very specific aspects for a better understanding of the processes, such as:

- “When you place an order, how much time do you require on average to evaluate the needs for prod. X and complete the request”
- “What is the frequency of replenishment for prod. X”
- “In a regular week, how much time do you estimate spending on the verification and the sorting of the delivered products”

More general questions were also asked such as:

- “Do you have any comments on the replenishment processes for stocked products within your department”

b) On-site observations were conducted in the healthcare institution's same 4 departments with the main objective being to map & assess the “as-is” intra-organizational processes related to the replenishment of medical supplies. A sample of 8 nurses and 20 auxiliary personnel (e.g. administrative clerks, nurse's aide, etc.) were observed at this step. The main idea was to follow the processes, identify key personnel involved at each step in delivering the replenishment and gathering information relative to the process. Three main processes were assessed: (i) replenishment of stocked items (i.e. items available in the central store of the institution), (ii) replenishment of non-stocked items (i.e. items sourced externally), and (iii) replenishment of secondary storage locations. On average, each department managed 3 primary storage locations where official inventory count and replenishment activities are conducted as well as a variable number of secondary storage locations which are closer to the point of use stored on mobile medical carts or near the patient's bed. The number of secondary storage locations and the amount of inventory they hold varies based on the physical constraints and criticality of the clinical treatment.
provided on the unit. Using a discrete, non intrusive data capture approach, a data log analysis (replenishment transactions in the hospital’s ERP) and a time and motion study were also performed to gather quantitative information. A similar approach to the time driven activity-Based Costing (ABC) analysis approach (Kaplan and Anderson, 2004) was adopted to perform the analysis. The approach is mainly based on 2 parameters: (1) the “unit cost of supplying capacity” meaning the committed resources and their cost and (2) the time required to perform the activity. In this case, it was used to combine resource expenses (resource cost driver), statistics on frequency of activities (transactional cost driver) and results of the time and motion study (duration cost driver) to determine process costs. The selection of this method was motivated by the need to identify cost centers and assign them to specific activities and processes. In order to increase data reliability, triangulation of the data sources was achieved by asking the personnel involved in the process for an entire week to fill a survey (i.e. time and motion self assessment). 30 surveys were collected for the purpose of this exercise.

c) The next step was to validate the mapped processes and their related costs. This was achieved by building draft flowcharts and associated cost time tables and presenting them to key respondents in the hospital. Revised process maps & flow charts were then finalized and cost tables approved. For further validation, all the information was then presented to key personnel, namely process owners, nursing unit managers and the management team identified during the first step. Finally, RFID enabled scenarios were designed and their performance improvements were estimated based on (i) data gathered in previous steps, (ii) time and motion estimated savings from implementing the technology and automating the selected processes, and (iii) experience from previous implementations at other healthcare facilities for supplemental estimates and to increase the face validity of the data and its results. All the results were presented to key respondents for validation to ensure that the estimates were realistic. While past experience is used to refine the anticipated financial benefits and justify the required investments, it is still necessary to complete a full assessment at each new site where the solution is to be implemented. Investments and returns will vary based on various parameters such as the type of environment (institution that services children instead of adults), the criticality of the treatment provided to patients (long term patient instead of an Emergency Department) and its related replenishment process, the “as-is” specific processes of each institution, the current IT infrastructure, the initial storage layout, etc. These parameters have a direct impact on the redesigned processes and proposed technological solution. This explains why potential adopters often refuse to accept cost analysis from other healthcare institutions where similar RFID enabled systems are in place as a means to anticipate their specific benefits.

5.3. Research site
The study was conducted at a public Canadian hospital which offers patient care, medical education and research and which specializes in ophthalmology, hemato-oncology and nephrology. This 700+ bed institution employs over 5000 employees who work in 16 departments and 53 services (e.g. Medicine department: cardiology service, hematology, etc.; surgical department: dental, intensive care, etc.). The hospital services a population of roughly half a million people and holds a stable volume of ambulatory activities approximated at 350 000 visits/year. In recent years, the hospital witnessed a significant increase in inpatient visits, especially among the portion of patients aged between 65-80 years. The increase in demand
combined with limited resources encouraged the hospital to search for technology based solutions to improve its efficiency and reduce operating costs.

6. Results and discussion
Table 1 presents a summary of the benefits of automating the nursing unit's supply chain which are commented in the next paragraphs.

Analysis of the collected data indicates that automating the nursing unit’s supply chain with the RFID 2-bin replenishment system in conjunction with the redesign of the ward floor and of the roles & functions can substantially improve business and operational performance (Table 1). This re-engineering is be supported by the optimization and automation of business and operational processes in the central stores area in order to absorb some of the additional activities generated by the function redesign (see “Productivity gains for logistics processes - (Central) Store personnel” in Table 1). The automation of the central stores area is achieved by introducing proven material management solutions used in other industries to improve productivity in the distribution activities. These include a Warehouse Management System (WMS), a Horizontal Storage and Retrieval System (HSRS), a redesign of the physical layout and the introduction of other adapted storage system. Our analysis is in line with the study from Devaraj and Kohli (2000) who analyzed the combined effect from IT investments in conjunction with corporate initiatives such as Business Process Reengineering (BPR) and who suggest that the impact of technology is contingent on BPR practiced in hospitals.

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
<th>Savings/ 1 year (Hours)</th>
<th>Savings / 1 year ($)</th>
<th>Savings / 5 years ($)</th>
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<tbody>
<tr>
<td>Recurring time savings</td>
<td>Nursing staff</td>
<td>2 480</td>
<td>$153 883</td>
<td>$769 415</td>
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<tr>
<td></td>
<td>(Central) Store personnel</td>
<td>9 239</td>
<td>$220 130</td>
<td>$1 100 650</td>
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<tr>
<td></td>
<td>Auxiliary personnel</td>
<td>24 281</td>
<td>$589 424</td>
<td>$2 947 120</td>
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<tr>
<td>Productivity gains for logistics processes</td>
<td>(Central) Store personnel</td>
<td>4 799</td>
<td>$113 287</td>
<td>$566 437</td>
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<td></td>
<td>Administrative clerk</td>
<td>617</td>
<td>$13 467</td>
<td>$67 335</td>
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<tr>
<td>Time not spent on logistics processes</td>
<td>(Central) Store personnel</td>
<td>78 521</td>
<td>$(3 097 373)</td>
<td>$(15 486 865)</td>
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<tr>
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<td>Auxiliary personnel - stock items</td>
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<td>$(83 961)</td>
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<tr>
<td></td>
<td>Auxiliary personnel - non-stock items</td>
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<td></td>
<td>Central service - stocks</td>
<td>$(32 453)</td>
<td>$(32 453)</td>
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<tr>
<td>Sub-total (non-recurring inventory related savings)</td>
<td>Total</td>
<td>$(3 922 124)</td>
<td>$(19 610 620)</td>
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</table>

Table 1: The benefits of automating the nursing unit's supply chain
A conservative ROI for the RFID 2-bin replenishment system component was estimated by the technology supplier at a little over 3 years. This time frame was estimated by (i) taking into account the cost of the solution which includes fixed costs for RFID readers, antennas and boards (an average of 3 boards per unit), HF labels (related to the number of products, with an average of 500 per unit), the middleware system, licenses and estimated costs for the labour/hours required for system integration and, (ii) comparing them with the savings presented in Table 1. The list of material and expenses were taken from a more holistic and detailed listing of the cost categories associated with more complex RFID projects which include: (i) hardware equipment (RFID readers, antennas and boards, labels, mounting accessories, RFID printers and ancillary devices, other infrastructure costs such as new servers and computers, infrastructure upgrade, etc.), (ii) software (middleware system licenses), (iii) RFID implementation/integration costs (project preparation costs, opportunity assessment, business case development, use case generation, system integration assessment, business process assessment, etc.), (iv) installation costs (i.e. limited site survey, hardware installation, testing and troubleshooting, middleware system interface customization and integration, engineering/business process changes, etc.), (v) other expenses (building layout modification/expenses, training for all employees including medical workers), and finally (vi) ongoing system maintenance/administration costs (network management system, reader firmware upgrades, damaged readers/antennas, performance monitoring, etc.).

6.1. Business and operational performance improvement

Many common sources of inefficiencies in the healthcare sector such as hospital over procurement of medical supplies, storage location multiplicity, losses due to outdated products and nursing staff spending valuable time on non value-added activities have pressed the hospital administrators to look for SCM solutions. Business and operational performance improvements were therefore identified by the key respondents as the main objective when adopting RFID technology. The “Time” variable was clearly identified as strategic which is quite understandable in an environment with scarce qualified resources. This preoccupation is coherent with recent research that identifies drivers of inefficiency in nursing work processes and nursing unit design as Hendrich et al. (2008) suggest that changes in technology, work processes, and unit organization and design may allow for substantial improvements in the use of nurses’ time and the safe delivery of care.

Productivity gains from logistics processes: The RFID 2-bin replenishment system facilitates the transfer of responsibility of item ordering from the nursing staff to the materials management clerks for non-stock items. Additionally, it almost completely eliminates backorder situations in the nursing units. As it can be observed in Table 1, the replenishment process improvements are associated to the nursing staff and ancillary personnel. Respectively, these gains were estimated at 2,480 working hours valued at $153,883 and 24,281 working hours valued at $589,424 for the first year. On the other hand, as the processes are redesigned a greater scope of material management responsibilities is now transferred to store personnel. For example, the material management clerks must now replenish the bins of a wider range of products and in different storage locations such as non-stock items and replenishment of carts at the point of use. This accounts for an additional cost of $220,130 in the form of 9,239 additional hours. These overall productivity gains can represent “hard savings” if they are transformed into full-time equivalent (i.e. actual jobs) reductions. They are achieved largely by the adoption of the proposed RFID 2-bin replenishment system.
More specifically the proposed solution helps (i) eliminate counting stock and facilitates the evaluation of stock and non-stock item needs at different storage locations which is particularly useful in limited access areas. Rounds at storage locations (e.g. nursing units, catheterization laboratory, OR, emergency rooms (ER), etc.) are no longer required which (ii) reduces manual requisitions and transcribing and retranscribing data, along with its associated errors, as data capture is automated. It (iii) automates the replenishment process triggered by the tags and (iv) generates real-time reports and frees the nursing staff and ancillary personnel from such laborious and non productive tasks. Other process related impacts were also quantified in the central stores area by taking into account the reduction in the number of lines in the picking orders and in the number of orders which decreased substantially while urgent orders were almost completely eliminated.

Based on observations, the potential time savings using the RFID 2-bin replenishment system can be assigned to each service (e.g. ER, OR, catheterization laboratory, etc.) considered as cost centers. The formula presented below indicates how the estimates were obtained. Each component of the formula is described and additional information is presented beneath it. For example, the average time required by the auxiliary personnel to count/assess the demand for products at different storage locations was estimated at 15 minutes. Similarly, the average time required by the nursing personnel to pick products from the different units was estimated to be between 15 to 25 minutes/nurse/day/working shift (the variance is relative to the layout of the storage location, disposition of the products, type of bins, etc.). The average time is then multiplied by the number of storage locations visited per employee type (StoLoc) and by the yearly frequency of the visits (FreqRep) in order to determine the amount of time spent each year to these replenishment activities. The average salary of each employee type (SalaryAP) is then taken into account which results in the recurring cost savings presented in Table 1.

\[ \text{Time Related Potential Savings} = \text{TimeStoLoc} \times \text{StoLoc} \times \text{FreqRep} \times \text{SalaryAP} \]

- **TimeStoLoc**: The time required for the replenishment rounds at the different storage locations (e.g. cath. laboratory, OR, ER, etc.) is calculated by taking into account the time per storage location for counting/assessing the demand for stock and non-stock items or picking products. The average time was measured by personnel type. The estimated time required to perform the activities with the proposed solution was reduced to 7.5 minutes for the nursing personnel and by 100% for auxiliary personnel since the needs assessment and requisition processes would be fully automated.
- **StoLoc**: The total number of storage locations. On average 1 to 3 locations are visited within the different units.
- **FreqRep**: The frequency of replenishment at the different storage locations which varies from 3 to 6 times per week, depending on the units.
- **SalaryAP**: The hourly salary range for auxiliary personnel and nurses varies between 23.61$ and 60$. Since the replenishment processes and central store involvement for each administrative unit are organized differently, the combination of auxiliary and nursing personnel varies. The potential time savings were calculated accordingly.

The **Time not spent on logistics processes** is another dimension of performance improvement that has to be considered when quantifying the impact of the RFID 2-bin replenishment system. Based on the time & motion study there is a difference between the total amount of time observed for logistic processes and the actual amount of time allocated to this category. While this difference is “normal” and can be attributed to various activities like talking with a colleague, looking for information, moving from one location to another, reengineering the work using the proposed solution allows to recover some of this “non productive” time. Results indicate a potential saving of 4,799 working hours for the central store personnel valued at $113,287 and 617 additional working hours for the administrative clerks, which represents $13,467.

Furthermore, **Impact on nursing staff** is another category of potential gain that benefits from improvements to personnel movement and the retrieval of products from storage locations. Based
on interviews, observations and post implementation measures at other sites, the savings were estimated at 78,521 working hours which represent 7.5 minutes/day/nurse/working shift and is valued at $3,097,373. This number is derived from a reduction of 67% in the walking distance due to the reorganization of primary and secondary storage location. Savings are also linked to a reduction in time associated to searching products in storage locations and to the use of the double bin system. These are considered “soft savings” because it is difficult to reallocate the few saved minutes to other more productive tasks. However, these time savings have a direct impact on patient care as nurses can use this time to treat patients instead of looking for products. In addition to improving the replenishment response time and almost eliminating stock outs, the proposed RFID 2-bin replenishment system thereby also improves the overall service level of the nursing staff.

**Inventory shrinkage** deserves special emphasis as it represents a particularly challenging aspect of inventory management. The “shrinkage ratio” could be assessed by using various factors including (i) the evaluation of the global value of product loss based on the value of a hospital’s purchases and the level of efficiency of its supply chain; (ii) by the amount of expired products; (iii) the poor knowledge of inventory levels; (iv) unused products in OR that can not be restocked; (v) the lack of data regarding the excessive use of high value products from one period to another; and (vi) pilferage. In this study, the reduction in costs associated with expired products is estimated at a conservative amount of 3% of the distributed volume which represents $109,453 for stock items and $65,367 for non-stock items.

Essentially, the quantifiable benefits gained from the optimization of inventory levels are based on the improved visibility of consumption offered by the RFID 2-bin replenishment system. The replenishment is triggered automatically and at a calculated level rather than based on human experience and interpretation. This helps to (i) provide better control over ordered quantities and reduces inventory levels, (ii) ensures (built-in) stock rotation activity thus reducing the amount of expired items, and (iii) reduces shrinkage. While certain functions of the peripheral stores remain in place like “sterilization”, other functions such as “distribution of disposable supplies” is eliminated. These represent interesting non recurring savings of $395,195.

### 6.2. Ward floor redesign & optimization of storage space

Previous experience with similar implementations indicates interesting saving opportunities for this category, but also cautions on the importance of factoring out the impact of the Business Process Reengineering and ward floor redesign when evaluating the benefits derived from RFID. For instance, as a result of implementing an integrated modular storage replenishment and inventory management system combined with the appropriate process changes, a certain hospital reported improvements in service delivery through increased frequency of product deliveries (45%), increased number of SKUs delivered (33% more) and increased number of delivery locations (19%) (Ontario Buys & Healthcare Supply Network, 2007). Moreover, the system reduces storage space by 25% to 50%. While these numbers seem optimistic, it should be noted that the use of high density storage systems combined with a redistribution of storage locations and the reduction of on-hand inventory derived from real-time visibility can make it a reality. Again these numbers should be considered with caution as they are specific to each research site. While the actual outcome of this study is not available, the researchers anticipate that the redesign & optimization of ward floor storage space will provide proportionately similar benefits. Considering that hospital space is often limited and valuable, the key performance indicators “dollars per square foot” or “number of patients treated per square foot” could serve as a basis to build a solid business case. Relocating the obsolete central store outside the main building and
freeing the space for the hospital’s core activities could finance part of the project. With more visibility of near real-time demand, lean SCM processes can be implemented without being influenced by central store location. Recently, hospitals have shifted towards supply chain leading practices which include the use of a shared services initiative to outsource part of their supply chain functions as is the case with the Shared Support Services Southeastern Ontario (3SO).

6.3. Roles & function redesign
Using the RFID 2-bin replenishment system automates the supply replenishment process and transfers its responsibility from the nursing unit to the materials management personnel for most product categories. This redesigned process improves the service level and has a direct impact on the level of patient care.

7. Conclusion and further research
In recent years, RFID has emerged as a powerful and disrupting technology (Lefebvre et al., 2008; Fine et al., 2006) which can have a major impact on organizations by changing the way core processes are designed. With other ubiquitous and pervasive technologies such as sensors, microcomputers and networks, RFID will enable the design of more effective IT systems into “need driven highly dynamic personalized interventions” (i.e. around the patient) (Thuemmler et al., 2009).

While RFID technology has been heralded as “the killer app” in the healthcare sector, the promised impact and benefits are only starting to be confirmed. Many potential adopters are thus awakening from the “wait and see” mode as various factors are contributing to RFID adoption in healthcare. These include a continued emphasis on clinical service optimization, ongoing improvement of the technology and falling prices of RFID equipment and supplies, the appearance of standards and vertical initiatives by industry groups, the structuring of the market through joint ventures, acquisitions and partnerships with established healthcare players, the development of multiple RFID enabled applications and middleware platforms, shorter ROI time frames especially for established closed loop applications such as asset management, the evidence of success stories from all over the world, and more competent vendors.

In terms of practical implication, the paper is in line with recent research suggestions by authors (Ngai et al., 2008; Curtin et al., 2007) about developing models, theories, concepts, frameworks, methods, techniques, and tools to support the needs of RFID professionals to develop and implement such technologies. This paper therefore provides direction for practitioners on how to assess RFID’s potential impact in the healthcare supply chain. There is however still a need to conduct further research in this area as it represents a great potential for performance improvements. Given the unobtrusive nature of RFID and its capability to collect high volume and high quality data, it opens a variety of uses for research and practice (Amini et al., 2007). One of the challenges is now to efficiently process and analyze this collected data into a usable form while using key performance indicators as the basis for improving targeted processes. This is particularly relevant when considering that inappropriately scoped and resourced evaluation efforts, inappropriate choice of metrics, inadequate planning for data collection and analysis are common challenges experienced by healthcare IT project teams (Poon et al., 2009).

There is also a need to conduct more in-depth research to isolate the impact of RFID from change management and process redesign often intertwined in such projects. In this research, the potential ROI was assessed using categories validated by respondents (i.e. “business and operational performance improvement”, “ward floor redesign & optimization of storage space”, ...
“roles & function redesign”). While some dimensions within the categories, such as “productivity gains from logistics processes”, “inventory shrinkage” and “optimization of inventory levels” appeared important, the major potential savings where attributed to the “impact on nursing staff”. This is a clear indication of the importance of “time related savings” in healthcare environments. In another supply chain context (i.e. distribution centers, warehouses) the “time” dimension was found to be less important than “inventory levels” (e.g. Bendavid et al., 2009). Again, in line with Prater et al. (2005), this highlights the need to consider RFID business cases within its specific context.

In terms of project implementation, as we are reminded by Chaudhry et al. (2006, p742) “while the benefits of health information technology are clear in theory, adapting new information systems to health care has proven difficult and rates of use have been limited”. More specifically, even though implementing information systems in the healthcare supply chain is difficult (Benfatto and Del Vecchio, 2008) and that RFID can still be quite challenging in real life environments (Bourgault and Bendavid, 2009; Kuo and Chen, 2008), our experience indicates that managers responsible for leading such innovative projects in dynamic environments should consider moving from the IT technical issues to business and managerial issues with an emphasis on business process redesign for increased efficiency.

By bridging a link between the technological (i.e. RFID) and business (i.e. ROI) aspects of a healthcare IT project (i.e. the 2-bin “e-kanban” replenishment system), this paper is also a partial answer to preoccupations raised by many authors about developing a framework that supports the needs of IT project teams to properly evaluate the impact of such technologies on (i) hospital performance, and (ii) on project implementation processes (e.g. Poon et al. 2009; Kaplan and Harris-Salamone, 2009; Chaudhry et al., 2006; Ammenwerth et al., 2003). For instance, this paper addresses three main problem areas that may hinder the performance evaluation of IT in healthcare, which are adapted from dimensions proposed by Ammenwerth et al. (2003): (i) the complexity of the evaluation object (i.e. RFID 2-bin “e-kanban” replenishment system), the complexity of an evaluation project (i.e. impact analysis and project implementation plan), and the motivation for evaluation (i.e. demonstrate cross benefits for all participants including auxiliary, medical and administrative stakeholders).

Finally, despite recognized best practice and documented critical success factors for health IT projects, many projects still fail. While functionality and interoperability issues are important, the difficulty of “getting all the stakeholders in harmony” has been put forward in a recent report from the American Medical Informatics Association (AIMA) (Kaplan and Harris-Salamone, 2009). The report states that most of the problems related to IT project failure in healthcare are due to sociological, cultural, and financial issues, and hence are more managerial than technical. RFID projects may not be an exception. In order to avoid such an undesired result, various dimensions appear vital for RFID projects to be a success, namely: educating on RFID technology to build internal competencies, defining clear operational and IT project requirements, building a cross disciplinary project team, drawing a good understanding of integration issues and challenges with existing (often proprietary) hospital information systems, addressing interoperability challenges such as healthcare information seamless transfer of medical patient information, conducting careful analysis on the impact of RFID projects on the hospital’s process redesign and, ensuring a proper diffusion of the technology to facilitate the adoption by medical staff and auxiliary personnel.
References


