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Improving the Quality and Cost of Healthcare Delivery

The Potential of Radio Frequency Identification (RFID) Technology

Anna-Marie Vilamovska

This document was submitted as a dissertation in May 2010 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Richard Hillestad (Chair), Evi Hatzianandreu, and Robin Meili.
Preface

From 1990 to 2007, total U.S. spending on healthcare almost tripled, rising to $2.2 trillion, or the equivalent of 16.2% of U.S. gross domestic product (GDP). Further rises are projected — to 25% of national GDP in 2025, and 49% in 2082 — unless drastic changes occur. Yet repeatedly, publicly and privately provided healthcare has been described as inadequate in quality and too expensive. The quest to expand access to healthcare services in the context of quality and cost challenges, coupled with the substantial role of the government as a purchaser of healthcare services (through the Centers for Medicare and Medicaid) and its very limited resources, makes the need to seek quality-improving and cost-containing reforms in healthcare delivery urgent.

Since the mid-2000s, based on the results of early experiments, radio frequency identification (RFID) technology has been hailed as one of the most promising health information technology (HIT) tools for improving the quality and cutting the cost of healthcare delivery. Yet there has been no rigorous evaluation of healthcare RFID’s capacity to deliver on these promises. There also is no thorough understanding of what healthcare RFID’s spectrum of impacts is, how those impacts range across different domains of care, and wherein lies RFID’s specific value in healthcare. Additionally, there is substantial confusion about healthcare RFID’s bearing on individual privacy protection and the market-readiness of different application types.

Given the emerging political determination to improve the coverage, quality, and cost-efficiency of U.S. healthcare — not least through public investment in HIT — it is important that RFID’s capacity to affect care delivery’s quality and cost, as well as its potential problems, be rigorously assessed. This dissertation seeks to begin answering this challenge by identifying the healthcare RFID solutions most likely to support care delivery quality and cost-effectiveness improvements in the next five to ten years, as well as their spectrum of impacts. In so doing, it also seeks to examine the merit for public policy action on healthcare RFID.

Abstract

The study investigated whether an upcoming class of health information technology (HIT) can be used to address currently outstanding issues in the quality and cost of healthcare delivery. Expert interviews and a literature review were used to describe the 2009 universe of in- and outpatient healthcare RFID applications and to identify those applications expected to have the largest positive impact on the quality and cost-effectiveness of healthcare delivery over the next five to ten years. Next, case studies of actual RFID implementations across seven hospital sites in the U.S. and Europe were conducted to gain an understanding of how each leading RFID application type creates value, what aspects of care it impacts, and what the critical factors driving the promising RFID’s organizational benefits and costs are. As part of this work, an original set of healthcare RFID cost-benefit evaluation tools was developed and tested. The study’s findings indicate that in contrast to other types of HIT, the majority of benefits associated with successful RFID implementation are directly related to money saved (occurring as direct capital and operational cost savings), and that select RFID applications can substantially impact both the cost (e.g., efficiency) and the quality (e.g., timeliness, capacity for continuous improvement) of care delivery. Critical challenges for RFID adoption are described.
Concurrence

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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AHRQ</td>
<td>Agency for Healthcare Research and Quality</td>
</tr>
<tr>
<td>AM</td>
<td>asset management</td>
</tr>
<tr>
<td>AMC</td>
<td>Amsterdam Medisch Centrum, The Netherlands</td>
</tr>
<tr>
<td>AMIA</td>
<td>American Medical Informatics Association</td>
</tr>
<tr>
<td>ARRA</td>
<td>American Recovery and Reinvestment Act</td>
</tr>
<tr>
<td>ASHE</td>
<td>American Society for Healthcare Engineering</td>
</tr>
<tr>
<td>auto ID</td>
<td>auto-identification</td>
</tr>
<tr>
<td>Biomed</td>
<td>biomedical engineering department</td>
</tr>
<tr>
<td>BHH</td>
<td>Birmingham Heartlands Hospital, U.K.</td>
</tr>
<tr>
<td>CMS</td>
<td>Centers for Medicare and Medicaid Services</td>
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<tr>
<td>CSD</td>
<td>central sterile department</td>
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<tr>
<td>ED</td>
<td>emergency department</td>
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<tr>
<td>EMR</td>
<td>electronic medical record</td>
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<tr>
<td>ENT</td>
<td>ear, nose, and throat</td>
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<tr>
<td>EPC</td>
<td>electronic product code</td>
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<tr>
<td>ES</td>
<td>environmental services department</td>
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<tr>
<td>FAQ</td>
<td>frequency asked questions</td>
</tr>
<tr>
<td>FDA</td>
<td>U.S. Food and Drug Administration</td>
</tr>
<tr>
<td>GDP</td>
<td>gross domestic product</td>
</tr>
<tr>
<td>HIMSS</td>
<td>Healthcare Information and Management Systems Society</td>
</tr>
<tr>
<td>HIPAA</td>
<td>Health Insurance Portability and Accountability Act of 1996</td>
</tr>
<tr>
<td>HIT</td>
<td>health information technology</td>
</tr>
<tr>
<td>HSPC</td>
<td>Human services Policy Center</td>
</tr>
<tr>
<td>HUG</td>
<td>Hôpitaux Universitaire de Genève, Switzerland</td>
</tr>
<tr>
<td>ICU</td>
<td>intensive care unit</td>
</tr>
<tr>
<td>ID</td>
<td>identification</td>
</tr>
<tr>
<td>IHI</td>
<td>Institute for Healthcare Improvement</td>
</tr>
<tr>
<td>IOM</td>
<td>Institute of Medicine of the National Academies</td>
</tr>
<tr>
<td>IPTS</td>
<td>Institute for Prospective Technological Studies</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
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<tr>
<td>IT</td>
<td>information technology</td>
</tr>
<tr>
<td>IV</td>
<td>intravenous</td>
</tr>
<tr>
<td>LVOT</td>
<td>leave without treatment</td>
</tr>
<tr>
<td>MF</td>
<td>medical floor</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
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<tr>
<td>MRI</td>
<td>magnetic resonance Imaging</td>
</tr>
<tr>
<td>MRSA</td>
<td>Methicillin-resistant Staphylococcus aureus</td>
</tr>
<tr>
<td>NHS</td>
<td>National Health Service, U.K.</td>
</tr>
<tr>
<td>OF</td>
<td>operation floor</td>
</tr>
<tr>
<td>OR</td>
<td>operating room</td>
</tr>
<tr>
<td>OTC</td>
<td>Caravaggio Treviglio Hospital, Italy</td>
</tr>
<tr>
<td>PACS</td>
<td>picture achieving and communication system</td>
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<tr>
<td>PDA</td>
<td>personal digital assistant</td>
</tr>
<tr>
<td>QALY</td>
<td>quality adjusted life year</td>
</tr>
<tr>
<td>RAH</td>
<td>Royal Alexandria Hospital, U.K.</td>
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<tr>
<td>RF</td>
<td>radio frequency</td>
</tr>
<tr>
<td>RFB</td>
<td>retained foreign bodies</td>
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<tr>
<td>RFID</td>
<td>radio frequency identification technology</td>
</tr>
<tr>
<td>ROI</td>
<td>return on investment</td>
</tr>
<tr>
<td>RTLS</td>
<td>Real Time Location System</td>
</tr>
<tr>
<td>SANCO</td>
<td>Directorate General for Health and Consumer Affairs, European Commission</td>
</tr>
<tr>
<td>SARS</td>
<td>Severe Acute Respiratory Syndrome</td>
</tr>
<tr>
<td>SSS</td>
<td>safe surgery system</td>
</tr>
<tr>
<td>WiFi</td>
<td>a type of wireless WLAN based on the IEEE 802.11 standards</td>
</tr>
<tr>
<td>WLAN</td>
<td>wireless local area network</td>
</tr>
<tr>
<td>WMH</td>
<td>Wayne Memorial Hospital, U.S.A</td>
</tr>
<tr>
<td>UHJ</td>
<td>Universitätsklinikum Jena, Germany</td>
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CHAPTER 1  Why Examine RFID’s Potential Role in Healthcare Delivery

This chapter discusses the context and motivation for my dissertation, as well as its goals and specific aims. I first describe the quality-of-care and cost-of-care challenges affecting the delivery of U.S. healthcare today. I then discuss the capacity of radio frequency identification (RFID) to address these challenges, briefly describing (with acknowledgment of gaps in the current knowledge) what healthcare RFID is, where it fits in the larger cluster of health information technology (HIT), what its current level of diffusion in the U.S. hospital sector is, and why it has received increasing attention from healthcare practitioners, administrators, and IT manufacturers during the past five years. Turning to the question of why this dissertation is important to policymakers today, I then state the policy question and the specific aims I set out to address with this study. The chapter ends with an organizational map of the rest of the document.

1.1  On the policymaker’s menu: improving healthcare quality and containing healthcare costs

From 1990 to 2007, total U.S. spending on healthcare almost tripled, rising to $2.2 trillion, or the equivalent of 16.2% of U.S. gross domestic product (GDP). Further rises are projected — to 25% of national GDP in 2025, and 49% in 2082 — unless drastic changes occur. Yet repeatedly, publicly and privately provided healthcare has been described as inadequate in its quality and cost.

In fact, identified quality and cost-efficiency issues have persisted in spite of system- and organization-level interventions designed and implemented to alleviate them. Evidence published since the Institute of Medicine’s (IOM’s) To Err Is Human and Crossing the Quality Chasm placed the cost of inadequate patient safety at 44,000 to 98,000 U.S. lives and at least $17 billion in direct healthcare costs and productivity losses has consistently indicated that U.S. healthcare quality needs further improvement and that patient safety remains problematic, with roughly 50% of all medical errors being preventable. Today, medication errors alone are estimated to harm 1.5 million Americans and to incur $3.5 billion in treatment costs each year, despite the increasing use of barcode-based patient/medication administration systems. More broadly, a

1 Alliance for Health Reform, 2009 at http://www.allhealth.org/sourcebookcontent.asp?CHID=65
2 The two frequently cited and seminal reports (Kohn, Corrigan, and Donaldson, 1999; Committee on Quality Health Care in America, Institute of Medicine, 2001) warned, respectively, that roughly 10% of all hospital patients suffer a medical error (for an annual aggregate national cost of $16 billion) and that patient care continues to be flawed by being non-patient centered.
2008 study\(^4\) ranking 19 industrialized countries found that the U.S. had the highest number of care-associated unnecessary deaths. Further, data from the Agency for Healthcare Research and Quality’s (AHRQ’s) Healthcare Cost and Utilization Project show that the number of hospital stays to treat MRSA infections\(^5\) more than tripled after 2000, reaching 360,600 in 2005, which suggests that patient safety challenges continue.

Poor communication across care providers — a primary factor for quality-of-care shortfalls — has also been linked to financial waste and rising care costs. A 2006 AHRQ report, for example, set the cost of poor quality and waste in integrated delivery system settings in the U.S. at $2,309 per single-day shift in a 46-bed medical unit, equaling an annual cost of $834,000 per care provider. According to the study,\(^6\) the bulk of this cost is attributable to inefficient use of care providers’ time, and up to one-third of the evidenced waste could have been prevented through better communication and process organization. More recently, Agrawal et al. (2008) estimated that poor communication alone costs U.S. hospitals $12 billion a year — the equivalent of 2% of hospital revenue and more than half of the average hospital margin of 3.6%.

Focusing on other cost inefficiencies, a 2003 (now slightly outdated) Healthcare Information and Management System Society (HIMSS) report that took a system-level perspective identified $11 billion in excess hospital costs annually, including $2.3 billion for inventory management and $1.8 billion for transportation. Given Medicare’s persistent increase in unfunded liabilities and the expectation that this largest federal healthcare program (coverage, in 2007, stood at 44 million Americans) will be depleted by 2016 if no changes in funding and/or coverage are instituted,\(^7\) the need to address such resource waste appears no less than critical.

These documented care-quality and care-cost challenges, together with the expected rise in the costs associated with research and development innovation in healthcare, make it imperative that healthcare delivery reforms capable of both improving care quality and containing costs be found. They also motivate this thesis.

1.2 The case for using RFID in healthcare

1.2.1 HIT, RFID, and their potential for meeting healthcare challenges

One of the tools seen as carrying significant potential to improve the quality and cost-efficiency of healthcare is health information technology (HIT). HIT includes both clinical and non-clinical solutions (one of which is RFID), and has theoretically been shown capable of addressing a significant range of care efficiency and safety challenges in inpatient and outpatient settings (e.g., reducing adverse drug events through the use of computerized physician order entry, and integrating patient data into electronic medical records [EMRs]). A 2005 study of the financial implications of such improvements found that wide adoption of interoperable EMR systems could produce efficiency and safety savings in excess of $81 billion annually (Hillestad et al., 2005). So

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\(^4\) Nolte and McKee, 2008.

\(^5\) Methicillin-resistant Staphylococcus aureus is a type of hospital-acquired staph infection, estimated to be deadly for 1 in 20 patients affected by it.


\(^7\) Financial assets of the Hospital Insurance Trust Fund, which pays for Part A of Medicare (covering inpatient hospital care, skilled nursing care up to 100 days after a hospitalization, home health, and hospice care for people age 65 and older or severely and permanently disabled), are projected to be exhausted by 2019. In early 2009, the Centers for Medicare and Medicaid Services reported that the economic crisis could cause the fund to be depleted even earlier — by 2016. Projections suggest that to finance Part A expenditures by 2083, the Medicare payroll tax would have to be immediately increased by 122% or program outlays would have to be immediately reduced by 51% (Alliance for Health Reform, 2009).
far, particular attention has been paid to clinical HIT applications, given the need to ensure evidence-based care compliance. And while accumulating slowly — mainly due to slower than expected diffusion — empirical evidence supports the expectations placed on these systems. In fact, the evidence is promising enough for the 2009 American Recovery and Reinvestment Act (ARRA) to prominently support the dissemination and adoption of HIT: this act sets aside $23 billion for investment in the development and implementation of HIT and its infrastructure over a five-year period.8

Yet clinical HIT can only be used to improve certain aspects of care. Most notably, by supporting only clinical aspects of care, this technology’s capacity for dealing with the non-clinical resource wastes and quality problems that affect the U.S. healthcare system is limited.9 Focused on the creation of complete and truthful baseline information from which the care process begins, clinical HIT applications do not aim to identify or rectify the shortcomings in the clinical and non-clinical process and workflows that make up care delivery (and that underlie existing care quality and cost issues). Nor do they seek to document occurring processes and events. Indeed, one of the primary roadblocks to solving the severe shortcomings that exist in the safety, continuity, and efficiency of care worldwide is the lack of comprehensive and objective data on what actually takes place during healthcare delivery.

Healthcare RFID, considered to be in its trial phase in 2004, is now one of the fastest developing types of HIT (Harrop et al., 2008). Its early pilots and trials have attracted ever-increasing attention, but as of yet, no one understands its full application range, deployment horizon, or spectrum of impacts.

RFID is argued to be the next disruptive innovation in healthcare (Crooker et al., 2009) and seems poised to address the gaps left currently unanswered by clinical HIT. Healthcare RFID falls under the non-clinically oriented HIT auto identification (auto ID) systems group10 and is based on wireless no-line-of-sight tag and reader communication. Preliminary analysis shows that RFID has an advantage over other non-clinical auto ID HIT in that it can provide high-granularity data capturing interactions between RFID-identified objects and people, thereby enabling continuous quality improvement (and eliminating the need for time-motion studies, which are costly and hard to conduct). It has also shown promising results for improving the safety, timeliness, and patient-centeredness of care, as well as increasing its efficiency.

1.2.2 RFID: The technology

Since Heinrich Hertz’s 1887 experimentation with radio waves, research and development on how radio frequencies can be used to detect and track entities on land, in space, and in the air have been ongoing. In 1915, Robert Watson-Watt employed radio signals to track thunderstorms; in World War II, radar was introduced to track enemy aircraft.11 Today, common uses of RFID in everyday life include tracking and timing marathon runners, electronic identification and payment at toll roads, public transit smart cards, identification of retail items to prevent theft, and managing library collections and patron registration.

As an engineering solution, RFID is best understood as a technology cluster within the auto ID group of technologies (which also includes, for example, barcode and optical character

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9 One example is the inability to obtain information on the pre-operation status of a patient from current bed management systems without making additional phone calls or checking on foot.
10 Chaudry et al. (2006), for example, propose an HIT classification that includes the categories: administration, mobile computing, data exchange networks, knowledge retrieval systems and other.
11 Cisco, 2008.
recognition). Unlike other auto ID, however, RFID has no line-of-sight requirement, which means it provides wireless unique identification at the item level that can be seamlessly retrieved at the group level.\textsuperscript{12} Initially based solely on silicon-based memory chips with a copper or aluminum antenna (referred to as tags) and signal readers, RFID solutions have now become context aware — i.e., they have evolved (and adapted to the requirements of complex business processes) to the point where they offer options for storing and remotely retrieving data associated with individual objects. These engineering advantages over other technologies, and the workflow efficiencies and cost reductions associated with them, have led to RFID’s rapid dissemination in the past decade in both the logistics and the retail industries, with Wal-Mart Stores Inc. being one of RFID’s most publicized adopters.\textsuperscript{13}

As used in healthcare, RFID can be classified according to:

- whether the RFID tag is battery powered and emits its own signal (defined as an \textit{active} tag) or not (defined as a \textit{passive} tag); this distinction also determines the size and strength of the signal (maximum distance currently stands at 100 feet)
- the data-transmission frequency (e.g., low/high frequency, ultra wide band)
- whether the transmitted data operate solely within a single application (closed-loop system) or are shared across applications or, possibly, across institutions (open-loop systems)
- whether the tag is read-only or read-and-write.\textsuperscript{14}

All healthcare RFID applications comprise several key components that fall into two main categories:

- hardware (i.e., RFID tags, readers, collectors, and servers)
- software (i.e., middleware and software system applications).

Hardware components are tasked with the unique wireless identification and physical location (established on the basis of tagged item proximity to designated landmarks) at the item/person level. They also collect and transport these high-granularity data to a host server. There, the software components transform the rough data into meaningful and usable information and then feed it to different intranet web-based applications.

RFID systems can operate on a stand-alone network of RFID readers and collectors, can be embedded into a hospital’s WiFi or WLAN infrastructure, or can be a mix of both. A combination of two alternative healthcare RFID system infrastructures is shown in Figure 1 for an RFID real-time location system (RTLS).

---

\textsuperscript{12} A good way to think about this capability is to picture a shopping cart filled with items. If they were barcoded items, they would have to be removed and read one at a time. But if they were RFID-labeled items, they could all be read by passing an RFID reader over the cart or by having the reader embedded in the physical infrastructure itself, in which case the item information would be captured in transit. (These two forms of RFID readers are discussed further in the text. For more details, see Appendix 1 and Vilamovska et al., 2008.)

\textsuperscript{13} Wal-Mart requires that its supply-chain partners use RFID identification for their product palettes and cases in order to conform with the RFID-enabled inventory management Wal-Mart adopted in 2005 (http://www.scdigest.com/assets/On_Target/09-02-23-1.php).

\textsuperscript{14} For more information on the types of healthcare RFID, see Appendix 1.
Within healthcare, vendors and users of RFID technology have leveraged the engineering capabilities and the high-granularity identification and location data provided by healthcare RFID applications in a number of ways. Figures 2, 3, and 4 illustrate exemplary middleware/software functionalities that have been developed.

Figure 2 shows an end-user mock screen view of an RFID application designed to ensure patient safety and reduce the possibility of patient/procedure mix-up in the preoperative stage. The application uses the capacity of RFID solutions to integrate with other clinical and administrative IT applications and takes advantage of RFID’s ability to uniquely identify tagged entities, in this case patients: an RFID-embedded patient wristband links the patient’s medical record and his photo taken at admission with all steps involved in his perioperative preparation and the treatment for which he was admitted.
Other uses of healthcare RFID are aimed at improving the overall efficiency of care delivery: by creating a virtual map of the unit/hospital environment, they allow frontline care staff to better communicate with each other, more quickly assign rooms and care providers to staff, and stay abreast of any substantial increases in patient waiting times and the availability of patients’ laboratory and imaging results (if application integration is in place). Such process and workflow visibility is created by actively tracing mobile assets, patients, and medical staff within departments/hospital floors (see Figure 3). Using easily recognizable icons, symbols, and event-designated color coding, the application can provide visible, accurate, and timely data available at a glance to users without requiring any technical competency.

Finally, software/middleware data analytic functionalities based on aggregating the individual event data to achieve better hospital management have also been developed. Figure 4 is a snapshot of such an RFID system tool that delivers daily/weekly/monthly hospital-wide assets utilization data for accurate cost and financial analysis.
Figure 3: Healthcare RFID middleware/software functionalities, Example 2 — Visibility of ED patient, portable asset, and staff


Figure 4: Healthcare RFID middleware/software functionalities, Example 3 — Built-in analytical function for portable asset management

These are but a few of the many healthcare RFID technology functionalities that are available today and that cover a spectrum of application goals, including care safety, care timeliness, and operational efficiency improvements.

1.2.3 The current diffusion of healthcare RFID

A preliminary review of peer-reviewed and limited-circulation (or grey) literature sources identified a lack of readily available empirically based estimates of healthcare RFID’s current diffusion level world-wide.\(^{15}\)

A further investigation, this one into HIT data provided by market intelligence companies, showed that although several firms claim to empirically trend the adoption of different types of RFID in the healthcare sector globally, only data collected by the market research arm of the U.S. Health Information Management Systems Society (HIMSS) on HIT usage — the HIMSS Analytics Database — though limited (they cover only the U.S. and only the hospital sectors of the U.S. healthcare systems), are nationally representative.\(^{16}\) Data on the diffusion of healthcare RFID in the U.S. outpatient setting or in the healthcare systems of nations other than the U.S. could not be identified.

An RFID-focused February 2009 abstraction from the U.S. 2008–09 HIMSS Analytics Database showed that as of January 2009, only 385 U.S. hospitals (or 7% of all hospitals in the database) had adopted or were in the process of adopting one or more healthcare RFID applications. The crude count of different healthcare RFID applications in use and under installation across U.S. hospitals as of January 2009 is shown in Table 1. As the table illustrates, the most widely diffused of the RFID applications already in use were those for patient tracking and portable asset management. Yet even those number only slightly more than 200 in absolute terms. In comparison, currently more than 50% of all companies in the North American automotive industry use RFID for their supply chain management process (Gartner, 2008). And in 2009, 43.9% of U.S. office-based physicians reported using an EMR (20.5% of these were basic, and 6.3% were fully functional).\(^{17}\) Hence, although limited to the U.S. hospital sector, these results are strong enough to indicate that healthcare RFID is currently in the very early stage of diffusion. The quality and cost of care effects that have been achieved through some of these applications, and why RFID is attracting significant attention with respect to its capacity to improve healthcare delivery, are discussed next.

\(^{15}\) Some survey data on this topic were available (for public use and for purchase), but the sampling methods used to obtain these data and their overall representativeness could not be identified. See, for example, Spyglass Consulting’s executive survey.

\(^{16}\) HIMSS Analytics is a wholly owned not-for-profit subsidiary of HIMSS. The company collects and analyzes healthcare information related to IT processes and environments, products, information system department composition, and costs. Among the contents of the database are data from over 5,100 hospitals that are segmented by size, funding source, and location; and information on the software and hardware purchasing plans of healthcare providers. The database is not available free of charge.

Table 1: RFID applications used or being installed in U.S. hospitals as of January 2009

<table>
<thead>
<tr>
<th>RFID used or planned</th>
<th>Total (count)</th>
<th>Share of hospitals adopted (out of total HIMSS 2009 sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RFID used</strong></td>
<td>383</td>
<td>7.3%</td>
</tr>
<tr>
<td>Patient tracking</td>
<td>203</td>
<td>3.9%</td>
</tr>
<tr>
<td>Portable asset management</td>
<td>59</td>
<td>1.1%</td>
</tr>
<tr>
<td>Inventory management</td>
<td>30</td>
<td>0.6%</td>
</tr>
<tr>
<td>Patient registration</td>
<td>28</td>
<td>0.5%</td>
</tr>
<tr>
<td>Laboratory</td>
<td>22</td>
<td>0.4%</td>
</tr>
<tr>
<td>Radiology</td>
<td>21</td>
<td>0.4%</td>
</tr>
<tr>
<td>Pharmacy</td>
<td>19</td>
<td>0.4%</td>
</tr>
<tr>
<td>Medication administration</td>
<td>1</td>
<td>0.0%</td>
</tr>
<tr>
<td><strong>RFID in installation</strong></td>
<td>204</td>
<td>10%</td>
</tr>
<tr>
<td>Portable asset management</td>
<td>92</td>
<td>1.8%</td>
</tr>
<tr>
<td>Inventory management</td>
<td>35</td>
<td>0.7%</td>
</tr>
<tr>
<td>Patient tracking</td>
<td>32</td>
<td>0.6%</td>
</tr>
<tr>
<td>Patient registration</td>
<td>15</td>
<td>0.3%</td>
</tr>
<tr>
<td>Pharmacy</td>
<td>13</td>
<td>0.3%</td>
</tr>
<tr>
<td>Laboratory</td>
<td>9</td>
<td>0.2%</td>
</tr>
<tr>
<td>Radiology</td>
<td>7</td>
<td>0.1%</td>
</tr>
<tr>
<td>Medication administration</td>
<td>1</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

1.2.4 The merit of RFID: available evidence on impacts in healthcare

Based on evidence from an increasing volume of healthcare RFID implementations and pilots in the in- and outpatient care settings, a number of authors have suggested that using RFID to streamline processes and reduce dormant quality threats should be part of the solution to current healthcare-delivery challenges involving process and outcome quality and cost containment.18

Specifically, several pilots and trials have illustrated how capitalizing on RFID’s positive identification and automatic data capture and transfer functions can increase patient safety by preventing medical errors. For example, Macario et al. (2006) reported that a handheld RFID scanning device combined with RFID-labeled gauze sponges had an accuracy of 100% for detecting sponges (erroneously) retained in the human body after surgery in less than 3 seconds, making RFID more reliable and efficient than manual sponge counts. Further, Reicher et al. (2007) demonstrated the capacity of RFID-embedded endotracheal tubes to signal improper endotracheal positioning during intubation, thus preventing a common and serious health risk. Another, frequently quoted example is the claim of New York City’s Jacobi Medical Center that an RFID system connecting its EMR, lab, and billing systems “eliminated patient safety issues,”19 resulted in network-wide net savings of $1 million, and freed up two to three hours of nurse time for patient care and contact.20

In addition, applications employing RFID’s positive identification and automatic data capture and transfer capabilities to provide real-time patient record updating and accessibility to physicians

18 See Hardin, 2007; Crounse, 2006; Masanori. 2007; Scott. 2007; Ahrens et al, 2005; Grandt, 2005.
19 According to the technology manufacturer.
20 “Nurse time” was not specified as per patient or per day.
have been shown to offer better care continuity and patient-centeredness. For example, Chen et al. (2005), who implemented an RFID framework that issued real-time safety reminders based on laboratory and radiology reports, found that diagnosis time was reduced by nearly 40%. RFID applications for blood transfusion safety and laboratory sample identification have also been used.

RFID-based solutions aimed at enhancing care effectiveness have been piloted in both the in- and outpatient setting. Of these, the RFID-based at-home intelligent applications for monitoring medication regimen compliance, which have been tested by Novartis and Aardex in the U.S. and Europe, have received the most significant attention. RFID technology is also used in capsule endoscopy, an alternative endoscopy procedure thought to be safer and more effective than the traditional procedure (Banerjee et al., 2007; Delvaux et al., 2005).21

Several authors have described how RFID-based systems have been used to identify and trace patients in busy environments in order to improve hospital workflow efficiency and satisfy regulatory recommendations on patient wait and care-process times (Sutherland et al., 2005; Meyer et al., 2006). A number of real-world RFID trials have also shown RFID’s potential in this regard. For example, in 2006, Memorial Medical Center, in California, reduced its emergency-department door-to-care time for incoming patients from 80 to 9 minutes after introducing an RFID workflow and room-use application. St. Vincent Hospital, in Alabama, achieved a net revenue increase of $2.58 million, a 20% increase in the number of patients discharged by noon, and 25% and 60% drops in patient diversion in, respectively, its critical-care and surgical units after installing an RFID patient-tracking application in 2005 (StatCom, 2005).

Another application for RFID involves the large stocks of portable assets (such as intravenous [IV] pumps and wheelchairs) that many hospitals keep on hand. These items are critically important and difficult to keep track of (a recent study by RF Code reported that up to 30% of a facility’s assets are not actively available and that hospitals annually write off up to 4% of their inventory as unaccounted for), and the upkeep for these large and not well-used stocks can be costly. A real-time asset tracing application now in place at Wayne Memorial Hospital, North Carolina, illustrates how RFID can be used to avoid such costly capital and operational outlays. In 2007, the hospital began using an RFID real-time location system to track about 1,300 medical devices, including IV pumps and blood warmers. The result was a substantial drop in inventory counts that led to net cost savings in excess of $300,000 (Bacheldor, 2007).

RFID applications are also being used in other ways to cut operational costs. St. Olav’s Hospital, which is a large university hospital in Trondheim, Norway, that has over 7,500 employees and approximately 1,200 beds spread over a large site, implemented an RFID application for daily management of its staff’s 130,000 work garments. The hospital management authority expects space savings alone of over $6 million (40 million Norwegian kroner); it also expects that the more-efficient data collection system will bring substantial ongoing savings in operational costs through improved logistics management, automated ordering, and saved staff time now that garments are much easier and quicker to find (Texas Instruments, 2008).

Finally, RFID’s tracking and identification capabilities have led to its being leveraged for medical device maintenance control and for the management of compliance with national regulations in this area. For example, the U.S. Food and Drug Administration (FDA) requires medical device companies to be able to identify each of their units by serial number. At this point, there is no RFID-alternative technology that can remotely identify, locate, and display hospital-wide the whereabouts of specific assets or inventory in real or near-real time. But a proof-of-concept trial at the Bon Secours Hospital in Massachusetts has indicated that RFID can meet the government’s performance goals and can offer additional benefits, as well. The hospital estimates that an RFID-enabled program deployed in 2005 to manage mobile assets brought in over $200,000 in net benefits per year and, by cutting the time and effort spent to locate

21 Capsule endoscopy is an innovative procedure in which the patient swallows an RFID-tagged capsule whose passage through the patient’s body is then monitored continuously. This approach has been proposed as less likely than the traditional endoscopy procedure to lead to adverse events for patients.
equipment, increased nurse time for interacting with patients by more than 30 minutes per day (Sweldberg, 2009).

1.3 This study’s importance for policymakers

Although attracting ever-increasing attention from healthcare practitioners, care delivery organizations, and policymakers, these preliminary results on RFID’s capacity to improve the quality and reduce the cost of care delivery in the in- and outpatient care settings have three critical limitations:

- They are overwhelmingly from industry-sponsored studies, which means they are potentially biased.
- They are from studies that explicitly assessed only some benefits and some costs, and did so only for some types of RFID, which means RFID’s benefits and costs have not been comprehensively evaluated or understood.
- They are from studies not designed for comparison, which means that we do not know what capacity different types of healthcare RFID have to positively affect the quality of care delivery and its cost-efficiency, and how that depends on the organizational setting in which they are implemented.

In other words, current research and literature on healthcare RFID provide an inadequate portrait of healthcare RFID’s spectrum of impacts and added value, and of how these range across different domains of care and different types of care delivery organizations. In addition:

- No study has ever attempted to comprehensively capture the universe of ways in which RFID is being used in healthcare.
- The market readiness of different types of RFID applications is vague at best (i.e., it is unknown which of the different RFID applications discussed in the literature are off-the-shelf ready or ready to use22).
- Because of the technology’s early stage of diffusion, today it is not clear whether healthcare RFID:
  - poses a threat to personal privacy (anxiety and a rejection of the technology have occurred in certain consumer groups23) or initiates other concerns24 that necessitate public policy action
  - is confronting key barriers that are stifling the technology’s rate of adoption and might be overcome with subsidies.

In summary, one can only say that the current knowledge on RFID, its application range, its potential benefits and costs, and its deployment horizon, in both theory and practice, is fragmented and incomplete.

So why is it important that RFID’s potential for improving healthcare delivery in the U.S. be determined? The government currently has a substantial role as a purchaser of healthcare services (through the Centers for Medicare and Medicaid), one that places explicit responsibility on policymakers to seek solutions that optimize healthcare quality and cost-efficiency. In addition,

22 As opposed to in-house developed systems, which may not be easily replicable.
23 Cap Gemini, Ernst & Young, 2005.
24 A recent study (Van der Togt et al., 2008) reported instances of RFID and electromagnetic interference in an ICU.
the American Recovery and Reinvestment Act (ARRA) has assigned heightened priority to public investment in HIT, which means the government is looking to this form of technology as an effective way to respond to healthcare challenges. Finally, the Obama administration has promised decisive action aimed at expanding Americans’ access to care and at improving care quality, adding urgency to an already serious need to contain care cost growth and better the efficiency of healthcare delivery. In this environment, healthcare RFID’s encouraging preliminary results suggest that this upcoming class of HIT may offer potentially effective tools for solving a select sample of the currently persisting healthcare quality and cost-efficiency issues that U.S. healthcare patients, care providers, and payers face. But policymakers need to know more about RFID’s potential than what the preliminary results offer. They need the answers to six key questions:

- Can the application of RFID in healthcare really improve the quality and reduce the cost of care delivery?
- If so, which healthcare RFID applications can have the greatest positive impact on the quality and cost-efficiency of healthcare delivery?
- Are these technologies market ready today?
- How can we evaluate the success of these applications?
- Is their use in healthcare associated with any problems, for example, privacy threats?
- Finally, and most importantly, are there any policy levers that policymakers can utilize to ensure that RFID use in healthcare is associated only with positive effects and that it successfully diffuses among healthcare delivery organizations that stand to benefit from its adoption (e.g., use regulation, technology standardization, subsidies for adoption)?

To help policymakers address the challenge they face, my thesis answered the following policy question: What are the most-promising means by which RFID can address currently outstanding issues in the quality and cost-efficiency of healthcare delivery over the next five to ten years, and are any policy actions on healthcare RFID needed?

1.4 **Specific study aims**

My study pursued four specific aims:

1. Describe today’s universe of RFID use in healthcare, and identify the RFID applications with the largest positive expected impact on healthcare delivery over the next five to ten years.
2. Develop a set of cost-benefit evaluation tools that can be used to understand the impact of the identified RFID applications on the quality and cost of healthcare delivery at the healthcare organization level.
3. Conduct case studies of actual healthcare RFID implementations to validate the evaluation tools, to collect evidence on actual RFID benefits and costs in different organizational environments, and to identify the critical factors affecting the value that adopters can derive from promising RFID applications.
4. Derive conclusions about the merit of public policy action on the use and further diffusion of RFID in healthcare.
Thus, my goal was to create an evidence base on healthcare RFID’s near-term (five-to-ten-year) capacity to improve the quality and cost-efficiency of healthcare delivery\textsuperscript{25} — one that fills both the substantive and the methodological gaps in the current knowledge and can be used by policymakers to gain insight into the technology’s potential; the conditions for its large-scale, effective, and secure implementation; and, ultimately, the merit of supporting or more stringently regulating the diffusion of healthcare RFID.

1.5 **The organization of the rest of this document**

Chapter 2 describes the structured literature analysis and expert interviews I conducted to document the usage range of the healthcare RFID cluster as of 2009, and to identify the RFID application types expected to have the largest positive impact on the quality and cost-efficiency of healthcare delivery in the U.S. over the next five to ten years (i.e., the most-promising near-term market-ready types of healthcare RFID). In this chapter, I also summarize available evidence on the costs and the care quality and cost-efficiency benefits associated with healthcare RFID.

Chapter 3 offers evaluation tools I created for the identified promising near-term market-ready types of healthcare RFID, developed from the point of view of private healthcare delivery organizations and building on current HIT evaluation practices. These tools are the first to address RFID adopters’ and evaluators’ need for a consistent set of constructs, variables, and measures that can be used to assess the impacts of RFID applications on the quality and cost-efficiency of the processes they are expected to improve. Implemented at a grander scale, the evaluation tools can support the meaningful comparison of RFID applications of different kinds and sophistication. I also describe the range of organizational benefits and costs associated with each promising application type, and the mechanisms through which they arise.

Chapter 4 presents the findings of a case study research design that builds on and validates the evaluation tools described in Chapter 3. Delivering the first systematic attempt to assess the effects of healthcare RFID, the eight case studies collect evidence on actual RFID benefits and costs in different organizational environments, covering all four types of leading RFID solutions. Using results on what outcomes have been achieved with the RFID applications, and how, I identify the critical factors (including privacy and interference threats, and organizational characteristics) affecting the value that adopters can derive from promising RFID.

Finally, Chapter 5 highlights the key conclusions that emerge from my analyses on RFID’s potential to improve the quality and cost-efficiency of healthcare delivery in the U.S. over the next five to ten years. I also outline the policy implications of the study’s results. The chapter closes by sketching the key directions for further research on RFID use in healthcare.

\textsuperscript{25} My study leaves outside its scope the question of healthcare RFID’s long-term potential in healthcare delivery and, with it, the forecasting of the diffusion of the currently less market-ready types of healthcare RFID applications, which include all currently available outpatient applications and a handful of inpatient healthcare RFID solutions. It also does not address healthcare RFID’s capacity to affect the cost or quality of healthcare through altering the supply chains of medications, assets, or inventory. Such an assessment ought to constitute a stand-alone investigation.
As indicated in Chapter 1, although healthcare RFID is commonly referred to as a singular technology, it is in fact a technological cluster uniting many different applications. Thus far, however, no study has ever comprehensively captured the spectrum of RFID uses in healthcare or their benefits and costs.

Hence, to begin to answer the policy question explored by this thesis — the potential of healthcare RFID to positively affect the quality and cost-efficiency of care delivery over the next five to ten years — I first document RFID’s current uses in healthcare and the existing evidence on their impacts. Section 2.1 reports the findings of a literature review on the universe of ways in which RFID was being used to support healthcare delivery as of April 2009 (including both conceptual prototypes and commercially available products) and the available evidence on the costs and care quality and cost-efficiency benefits associated with these applications.

Given that the quantitative benefit and cost data available were limited, precluding a comparative analysis, I describe, in Section 2.2, how I used interviews with experts identified in the course of the literature review as representing the key healthcare RFID stakeholder groups to rank-order the documented healthcare RFID applications according to their capacity to positively affect healthcare quality and cost-efficiency, as well as their market readiness. In this manner, I arrive at a priority list of “promising” healthcare RFID applications — that is, those likely to have a sizable positive impact on the quality (safety, timeliness, continuity, effectiveness) and the cost (staff time/resource efficiency, cost-efficiency) of healthcare delivery over the next five to ten years.

2.1 RFID’s current uses in healthcare, evidence on impacts

2.1.1 Methodology for literature analysis

This section summarizes the methodology and analytic approach I used to capture and describe the universe of in- and outpatient healthcare RFID applications as of April 2009 and to document existing evidence on their costs and benefits: an analysis of 436 sources on RFID use and impacts in healthcare that were published between 1999 and 2009.

To comprehensively capture existing evidence on the universe of use, benefits, and costs of the healthcare RFID technological cluster and to account for the fast pace of technological development and academic journals’ relatively long publication cycle, the review covered both peer-reviewed and non-peer-reviewed sources with limited circulation (grey literature).

The inclusion criteria applied to both groups of information sources were:
Focus: discussion of RFID actual or potential use in healthcare, or care delivery, regardless of setting

Publication date: between January 1999 and April 2009

Publication language: English, Italian, German, and French

Study type: experimental, observational, and epidemiologic studies; case studies and case study series; editorials/letters to the editor; healthcare engineering and management studies; and research syntheses.

Information sources were identified as follows:

For peer-reviewed sources, a combination of three approaches was used:

- electronic keyword-based mining of bibliographic databases (e.g., PubMed/MEDLINE, ABI/INFORM, Applied Science and Technology Abstracts, and Wilson Select Plus)
- citation cross-checking (“snowballing”)
- hand search of selected journals (e.g., International Journal of Healthcare Quality Assurance; Health Affairs; Journal of the American Medical Association; Academy of Management; Healthcare Financial Management).

Relevant grey literature was identified through the following approaches:

- from the RFID Journal, an online journal providing daily updates on RFID applications and developments across sectors from around the world. Using the search feature of the website, a list of healthcare-related articles was generated, after which articles meeting the inclusion/exclusion criteria were handpicked.
- through key informants (RAND colleagues, mentors, and external advisors), Google searches, and targeted searches of the websites of The Institute for Prospective Technological Studies (IPTS); the MIT RFID Special Interest Group on RFID; the Health Information and Management Systems Society (HIMSS); the Institute for Healthcare Improvement (IHI); the American Society for Healthcare Engineering (ASHE); the American Medical Informatics Association (AMIA); and leading healthcare RFID manufacturers. A set of relevant sources with limited distribution was also collected for initial screening; these included commercial reports and industry white papers, industry conference presentations, testimonies, and other documents.

Using these data search and selection criteria, 4,481 citations were collected for initial screening. Of these, following title and abstract review and a check for duplicates (described in more detail in Appendix 3), 436 relevant and unique sources on the uses and impacts of RFID in healthcare delivery remained and were obtained for analysis (a complete list of these sources can be found in Appendix 2).

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26 It can be argued that a five-year span would be more relevant for determining the application range and impacts of healthcare RFID. However, to clarify confusions regarding the mechanisms through which RFID benefits arise that were observed in the preliminary review, which only included sources published after 2003, I expanded the horizon of the structured review to 1/1999.

27 Although the majority of leading medical informatics and health policy journals are published in English, the additional languages were included to avoid the omission of any early-stage or institutional intramural research on RFID (as such research covers healthcare systems experimenting for a number of years with the technology).
The final set of 436 data sources was analyzed via a data abstraction protocol (available in Appendix 3). The protocol was developed in Microsoft Excel and used drop-down menus and notes fields in which additional data could be filled in to collect information on:

- the type of RFID application discussed in each source (including primary intended user, and primary and secondary functions performed by the application).
- the costs and benefits cited in the source as originating from the use of the application. (Drop-down menus were used to record whether the source provided information on only costs, only benefits, or both costs and benefits; whether the provided information was qualitative or quantitative; what evaluation design, constructs, and measures were used in the study; and if the data were based on actual assessment or on projections.)
- whether the discussed application was designed or used to address specific concerns in the process of care delivery. (A notes field and two drop-down menus were used to record this information — one on quality concerns, per the domains of care highlighted by the IOM [i.e., timeliness, safety, effectiveness, efficiency, patient-centeredness]; and one on cost [including as subcategories “resource waste”, “staff time”, and “other, explain”].)
- any specific problems associated with developing, purchasing, implementing, or using the application. (A drop-down menu was used to identify whether personal privacy, RFID technology maturity, cost, or “other, explain” concerns were discussed in the source, and who had voiced these concerns [e.g., end-user, manufacturer, regulatory authority]; and there was a notes field in which the motivation for the concerns was summarized using narrative synthesis methods.)

Each information source was coded using the protocol. All summaries were recorded in a Microsoft Access database. Following data extraction, I used both quantitative and qualitative approaches to analyze the collected data. For example, I analyzed how frequently “personal privacy” was mentioned as a problem confronting healthcare RFID (quantitative analysis), what ranges of view and themes could be noted in the motivations presented for “personal privacy” concerns (qualitative analysis), and which agents (i.e., stakeholders) expressed them. I followed a similar approach to identify the range of RFID uses in healthcare and to analyze available evidence on the applications’ benefits and costs.

While the structured review covered sources published between 1999 and April 2009, information sample analysis showed that 89% of the retained and reviewed literature was released after 2005 (see Figure 5). More importantly, more than 50% of all sources were published between January 2007 and April 2009, suggesting that the results of the review are current and potentially only slightly outdated (considering the pace of technological innovation and publication cycles; a potential threat addressed through the expert interviews is discussed in Section 2.2).

---

28 Drop-down menus were developed on the basis of a preliminary review of a sample of studies with different topics and sources.
The information sample analysis also showed that 64% of all selected and reviewed sources originated in the U.S., with European and Asian countries, Australia, and New Zealand providing the rest (in descending research share order; see Table 2). This country-mix ensures that the findings of the review are relevant to the realities of the U.S. healthcare system but also adequately capture the international experience with healthcare RFID. To the extent that the U.S. healthcare system is almost unique, adding information from other systems is beneficial because it allows us to investigate whether any of the constraints characterizing the U.S. system critically affect healthcare RFID adoption and impacts.

### Table 2: Top 7 country sources of reviewed information

<table>
<thead>
<tr>
<th>Country</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.A.</td>
<td>280</td>
<td>64%</td>
</tr>
<tr>
<td>UK</td>
<td>27</td>
<td>6%</td>
</tr>
<tr>
<td>Germany</td>
<td>26</td>
<td>6%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>13</td>
<td>3%</td>
</tr>
<tr>
<td>Italy</td>
<td>11</td>
<td>3%</td>
</tr>
<tr>
<td>Taiwan</td>
<td>8</td>
<td>2%</td>
</tr>
<tr>
<td>Belgium</td>
<td>6</td>
<td>1%</td>
</tr>
</tbody>
</table>

In addition, slightly less than a quarter of the 436 captured information sources originated in peer-reviewed journals,\(^{29,30}\) the largest share being sourced from the *RFID Journal* (see Table 3).

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\(^{29}\) Of these, more than 90% (n=96) were retrieved through PubMed, with a fraction of duplicates available through other databases.

\(^{30}\) While some industry journals do practice peer review, typically the process is not equal in purpose and rigidity to that of academic journals. To reflect this, a distinction was made between academic peer-reviewed and industry journal publications.
Grey-source literature accounted for another quarter of all information sources. These were predominantly industry white papers and industry conference presentations, which jointly yielded 60% of all grey sources.31

Table 3: Breakdown of reviewed information sources by type

<table>
<thead>
<tr>
<th>Data source type</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID Journal</td>
<td>165</td>
<td>38%</td>
</tr>
<tr>
<td>Grey literature</td>
<td>112</td>
<td>26%</td>
</tr>
<tr>
<td>Peer reviewed journal</td>
<td>106</td>
<td>24%</td>
</tr>
<tr>
<td>Industry journal</td>
<td>52</td>
<td>12%</td>
</tr>
<tr>
<td>Book</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>Total</td>
<td>436</td>
<td>100%</td>
</tr>
</tbody>
</table>

A per-type breakdown by source publication year (Figure 6) indicates an exponential growth of attention paid to RFID technology in both the peer-reviewed and grey literature after 2004 (with the exception of industry journals; see below).

Figure 6: Total number of reviewed sources on RFID in healthcare, by type and year

This mix of source types provides a good indication of the different strands of the RFID literature, including critically reviewed outcomes-oriented studies (originating from peer-reviewed journals), implementation-focused sources (industry journals), and publications reflecting opinions on healthcare RFID by patients, healthcare professionals, regulators, and the mass media (collectively covered in grey literature sources). Nonetheless, this information source mix also exposes the findings of the structured review to publication bias through the increased probability that small studies or studies reporting negative outcomes do not get published. Industry white

31 See Appendix 3 for more details on the different types of reviewed sources.
papers and conference presentations and proceedings — which account for 71% of all grey sources and provide a significant portion of the empirical cost benefit data on healthcare RFID applications — are most likely to be affected by the bias.\textsuperscript{32}

Finally, information sources could be grouped in four research domains:\textsuperscript{33, 34}

- **Engineering focused**: both empirical and conceptual sources primarily concerned with the engineering of RFID solutions
- **Standardization focused**: sources primarily concerned with the development of standards for healthcare RFID applications, including operating frequencies, data content and structure, tag types, conformance, and performance
- **Management issues focused**: sources taking a management perspective in analyzing the use and value of RFID solutions in healthcare delivery
- **Ethics and privacy issues focused**: sources primarily concerned with the ethical and privacy implications arising from the use of RFID applications in the healthcare setting.

This research domain (i.e., topic) classification captures 72% of all information sources as single-topic papers/presentations and can hence be considered a valid taxonomy (source distribution per topic is shown in Figure 3). The remaining 28% of the reviewed information sources fall simultaneously under two or more of the topics of discussion identified below, but do not include additional themes.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{chart.png}
\caption{Topics of discussion across single-topic articles (N)}
\end{figure}

\textsuperscript{32} Although no formal tests for publication bias affecting the literature on the uses and potential impacts of RFID in healthcare were carried out, it is likely that a bias exists. Negative studies are least likely to be published in grey sources originating from the RFID manufacturing industry and in the *RFID Journal*, whose objective, in both cases, is to promote the technology. They are slightly more likely to be published in peer-reviewed journals (classical bias against small studies).

\textsuperscript{33} The domain descriptors were chosen based on the results of the initial review and agree with the observation of Bureau et al. (2008) on the main domains of research on healthcare RFID.

\textsuperscript{34} Studies covering more than one of these topics in depth were assigned all applicable category descriptors.
2.1.2 The 2009 universe of RFID uses in healthcare

Roughly half (n=238) of the 436 reviewed studies centered on the use of RFID applications in the inpatient care (hospital) setting. How healthcare RFID can be used in the outpatient setting (including at long-term care facilities and patients' homes) was the focus of 7% (n=69) of the studies. Finally, roughly 16% (n=30) of all information sources analyzed RFID applications suited to both the inpatient and outpatient settings (see Appendix 3 for the healthcare settings covered in the literature sample).

Identifying RFID’s current spectrum of uses in healthcare proved more problematic. Available classification attempts at describing the range of RFID use in healthcare largely:

- mixed RFID’s range of use with RFID’s benefits (e.g., included as entries both “unique patient identification” and “improving quality of care”)
- employed wrong or incomplete definitions of what constitutes a healthcare RFID solution (e.g., referred to healthcare RFID as “wireless chip and reader technology,” creating an ambiguity about where its software functionalities come from)
- included misrepresentations of what RFID can really do (e.g., discussed healthcare RFID’s potential use for “Big Brother”–style ubiquitous monitoring of human activity irrespective of existing Health Insurance Portability and Accountability Act [HIPPA] regulations, illegality of sale of personal health information, maximal RFID reading ranges being restricted to 100 feet, and the practice of limiting data stored on RFID tags to numeric IDs).

Hence, these classification attempts were not helpful for understanding the range or the value of RFID use in healthcare. None of them was empirically based either.

To overcome these problems, and to create a sounder basis for documenting the spectrum of RFID’s uses in healthcare, based on the review results I proposed and used in my analysis a taxonomy (see Table 4) that describes healthcare RFID systems in terms of:

- the baseline engineering tasks RFID applications perform
- the operational purposes RFID applications are tasked with
- the overarching functional goals RFID applications serve.

35 See Appendix 4 for a sample of existing classifications, and see Vilamovska et al., 2008, for more examples.
36 See Bureau et al., 2009.
37 The current review is the first systematic analysis of healthcare RFID uses and benefits in the peer-reviewed and grey literature.
Table 4: A non-technical taxonomy for healthcare RFID

<table>
<thead>
<tr>
<th>Definition</th>
<th>A) Baseline engineering tasks of healthcare RFID</th>
<th>B) Healthcare RFID operational purposes</th>
<th>C) Healthcare RFID overarching functional goals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
<td>Singular tasks performed by a system's hardware, software, and middleware components</td>
<td>Specific uses to which an application's engineering tasks are put</td>
<td>High-level goals supported by an application's uses</td>
</tr>
<tr>
<td><strong>Example</strong></td>
<td>Primary tasks: 1) no-line-of-sight unique wireless item/person identification; 2) physical location (proximity to designated landmarks); 3) tracing (i.e., continued location, only for active RFID)</td>
<td>Using an RFID application to verify patient identity and prescribed medication type, dosage, route, and time</td>
<td>Improving patient safety by decreasing medication errors</td>
</tr>
<tr>
<td><strong>Relationship</strong></td>
<td>Similar engineering tasks can support different operational purposes</td>
<td>A single operational purpose can support multiple functional goals</td>
<td>A single functional goal can be supported by a range of operational purposes</td>
</tr>
</tbody>
</table>

Using this taxonomy, a quantitative count analysis of the 436 reviewed sources identified:

- a very narrow spectrum of healthcare RFID engineering functions
- a substantially wider range of healthcare RFID operational purposes and functional goals.

An analysis of RFID application operational purposes and functional goals based on primary RFID application user further suggested that reported healthcare RFID applications (both conceptual prototypes and commercially available products) can be divided into four groups:

- RFID applications designed to meet the needs of healthcare providers (including physicians and nurses, henceforth referred to as “staff”)
- RFID applications designed to meet the needs of patients
- RFID applications designed to meet the needs of biomedical engineering and auxiliary services departments (henceforth referred to as “assets and high-value biomedical inventory”)

38 These included the primary tasks identified above and a handful of secondary engineering tasks: carrying pre-recorded data, time-stamping tag-reader interactions, and detecting ambient and core product temperature. This also validates the taxonomy and the relationships between its components.

39 The four categories of applications are not mutually exclusive, since RFID solutions can have more than one purpose and can be actively used by or benefit more than one interaction party (healthcare process stakeholder). For example, an RFID-based system that incorporates real-time care process safety reminders for staff is primarily used by staff but also has a direct impact on patients.

40 Although some sources used **assets** and **inventory** interchangeably, the two categories are in fact distinct. **Assets** are stationary and portable pieces of biomedical and other equipment that are repeatedly used (e.g., bladder scanners, IV poles, wheelchairs), whereas biomedical **inventory** includes materials that can only be used once (e.g., cardiac surgery stents, blood products, medications). RFID is reportedly used to manage both assets and some types of inventory; therefore, the distinction between the two has been preserved.
RFID applications designed to meet the needs of researchers involved in clinical trials (henceforth referred to as “clinical trials”).

Sections 2.1.2.A through 2.1.2.D document the universe of ways in which healthcare RFID is used to support healthcare delivery (as of April 2009) by capturing the range of functional goals and operational purposes reported for RFID application types within each of these four groups.

The domain of functional (i.e., high-level) goals supported by staff-focused RFID applications emerging from the structured literature review is summarized first, followed by breakdown tables presenting the variety of operational purposes reported in the literature as supporting each identified functional goal. Similarly structured descriptions of the functional goal and operational purpose ranges reported in the literature for patient, portable asset, and clinical trial healthcare RFID applications are presented next.

Finally, RFID application areas that information sources referred to as “problematic” are summarized in Section 2.1.2.E. The evidence that exists on the benefits and costs of the identified applications is subsequently discussed in Section 2.2.

2.1.2.A Staff-focused applications

A thematic and a count analysis41 of the collected data identified seven functional goals — i.e., seven key ways in which healthcare RFID applications tailored to the needs of healthcare providers (i.e., “staff”) are being used to support care delivery. Figure 8 lists these goals, rank-ordered by frequency of mention in the reviewed sources.42

As the figure shows, the three healthcare RFID functional goals most frequently discussed in the literature as served by staff applications were improving process efficiency at the department or hospital level, improving patient safety, and reducing the administrative burden on staff.

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41 In the thematic analysis, I determined what healthcare delivery objectives (i.e., what purposes) the reviewed sources associated with healthcare RFID applications tailored to the needs of healthcare providers. In the count analysis, I identified how frequently individual objectives were listed in each of the reviewed sources.

42 The frequency of mention displayed in Figure 4 and the following figures and tables is based on the screening approach chosen for this analysis. Using the abstraction protocol presented in Appendix 3, all relevant RFID application areas were selected when a source was reviewed. Therefore, on occasion, more than one functional goal was identified for each information source. Thus, the frequency of mention of a category simply represents how often a healthcare delivery objective, or the applications comprising it, was referenced in all screened sources.
I next discuss what are the separate operational purposes (i.e., specific uses to which applications are put) that support the identified functional goals, and how specific applications within each of these staff-focused RFID operational purpose groups work. Because a single application purpose can promote more than one functional goal, unique purposes can appear in several tables. For example, RFID solutions that have the operational purpose of preventing data entry and collection errors serve to both improve the safety of patients and reduce the administrative burden on staff.

2.1.2.A.a Staff-focused healthcare RFID applications designed to improve process efficiency at the department or hospital level

Staff-focused RFID solutions with the functional goal of improving process efficiency at the department or hospital level (see Table 5) overwhelmingly take the form of networked active RFID chips attached to staff (as identification badges) or patients (as ankle or wrist bracelets) and directly to assets (stationary and portable). The software component of the applications transforms the individual signals these chips emit at regular intervals (e.g., 2 to 10 seconds) into a virtual map of the covered area that displays the location of each tagged entity. These provide, among other things, the continuous identification of care providers and patients through the healthcare facility, the collection of information about dwell time (i.e., process and workflow bottlenecks) at different locations, and asset and room use status information (improving room turnaround and patient placement).
For example, one RFID application supporting staff's efficiency incorporated room-level tracking of patients in radiology, cardiac surgery, and catheter laboratories. An electronic board at the nurses’ station in each of those units indicates where patients are physically and where they are in their care process (e.g., waiting to be seen in radiology). Streamlining these patient pathways (by identifying workflow bottlenecks and reducing the number of calls needed to locate a patient and confirm his/her process in the course of treatment) helps improve patient throughput and prevent patient diversions (Nagy et al., 2006).

Another frequently discussed type of staff RFID application aimed at improving process efficiency focuses on care delivery on the operating floor (OF) and in the operating room (OR). In addition to the patient-location information, such systems integrate clinical data on each patient (such as notification of lab results, prescription orders, and other medical instructions), sourced through a real-time link to the hospital’s clinical information system. The application’s software interfaces patient and equipment tracking data with the surgery schedule, the nurse call, and wireless telephony. Essentially, the RFID software acts as a centralized workflow portal for the OF. Patients are assigned an RFID-embedded hospital ID bracelet on arrival at hospital admitting, and a unique ID number is assigned to each patient in the RFID tracking system. Patients are scheduled for surgery via an automated surgery scheduling system (part of the application’s software), and color-coded graphics and icons allow nurses to tell at a glance what care a patient requires. Patient location and amount of time spent in each location are immediately and automatically tracked. Software algorithms translate low-level events into patient care milestones, and each time a patient reaches a milestone or moves to a new area, information is updated on the electronic grease board. For example, when a patient is prepared for surgery and pre-operative antibiotics are administered, the nurse presses the “patient ready” button, which activates a “room dirty” signal for housekeeping staff and a “patient arriving” sign for the OR. As a result, the perioperative team remains focused on patients rather than on paperwork, inter-departmental phone calls are reduced, antibiotic administration time before incision is improved, and the post-anesthesia care unit can anticipate patients and their acuity level 30 minutes prior to arrival (as opposed to at arrival) (Agarwal et al., 2007; Egan and Sandberg, 2007).

Other RFID systems belonging to this class of applications that were described in the literature include solutions used to locate and call care providers when needed, which prevent procedure delays (Krizner, 2004).

**Table 5: Range of staff-focused RFID operational purposes: process efficiency**

<table>
<thead>
<tr>
<th>Improve department- and hospital-level process efficiency</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staff monitoring at hospitals for management purposes</td>
<td>44</td>
</tr>
<tr>
<td>Better staff time utilization</td>
<td>16</td>
</tr>
<tr>
<td>Workflow optimization at hospitals</td>
<td>16</td>
</tr>
<tr>
<td>Staff tracking and tracing at hospital (ER) to speed up service</td>
<td>16</td>
</tr>
<tr>
<td>Staff identification at hospitals to manage access</td>
<td>14</td>
</tr>
<tr>
<td>Improve labor productivity</td>
<td>10</td>
</tr>
<tr>
<td>Eliminate in-hospital service bottlenecks</td>
<td>6</td>
</tr>
<tr>
<td>Staff and event identification for quality management at hospitals</td>
<td>3</td>
</tr>
<tr>
<td>Laboratory sample identification for improved management</td>
<td>2</td>
</tr>
<tr>
<td>Asset/inventory recall/returns management</td>
<td>2</td>
</tr>
<tr>
<td>Drug procurement and administration</td>
<td>1</td>
</tr>
</tbody>
</table>
2.1.2.A.b  Staff-focused healthcare RFID applications designed to improve patient safety and regulatory compliance

Staff-focused RFID solutions having the functional goal of improving patient safety (see Table 6) can take a number of forms, the most common of which is networked RFID chips attached to patients, staff, and medications.

These systems most frequently rely on pre-recorded information on patient treatment and surgery plans, information that the RFID application sources from other HIT and clinical systems or collects from its own administrative and clinical decision support components. Based on this information, safety-focused RFID applications require an “electronic handshake” — i.e., a match between the patient’s tag (typically a wristband or badge) and the medication tags/treatment plan — before a medical procedure is allowed to take place (e.g., administration of medication, surgical intervention, blood transfusion, or radiological image contrast agent administration).44 If no handshake occurs, the system issues a failure alarm and prevents next steps from being recorded (establishing medial liability for the care provider). Each successful or unsuccessful handshake is then recorded as an event by the RFID system, along with additional environment information, including the IDs of the staff present or initiating the event,45 the time of the event, and its specific location. As these systems are operated by care providers but benefit both them and patients, they are also featured in the patient-focused list of RFID applications discussed in the next subsection.

One example of RFID applications for helping care providers ensure patient safety is a system that includes a portable RFID reader and gauze sponges that have been embedded with passive RFID tags.46 The system eliminates potential errors in the sponge count that OR staff perform prior to chest closure. The portable reader is used to quickly scan the patient, applying an automated, non-line-of-sight inventory system of all sponges during the procedure (Rogers et al., 2007; Macario et al., 2007).

Another frequently referenced RFID solution belonging to this application class is aimed at error-proofing medication administration at bedside. These systems are designed to ensure the “Five Rights” of medication administration — that the right patient is receiving the right dose of the right drug at the right time via the right route — thereby minimizing the risk of medication errors, especially at the drug ordering and administration stages. Information about the patient and the medication at the point of care is critical to the success of such a program and must be accessible in a concise, on-demand, and process-specific manner in order to expedite rather than impede the clinical activity of hospital staff. Without this information, it is at the final stage of this process, during which the nurse administers the medication, that no “second check” is available to ensure the Five Rights of patient safety.47 RFID bedside medication administration systems...

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44 RFID tags identifying patients are linked to patients’ records, which contain information on treatment plans, and care providers are requested to follow a verification procedure to ensure that the correct medication and dosage are given or the correct surgery is carried out on the correct patient (part).

45 Typically, systems involve a role-based clearance for different care providers involved in a patient’s treatment plan. For example, when a patient is being prepared for surgery, editing of patient data can be restricted so that only a surgeon of the same specialty can access and change the surgery check to be made, and he/she will have no authority to introduce changes in pre-operative checks to be fulfilled by the anesthesiologist.

46 The aim is to keep foreign objects from being accidentally left in chest cavities upon surgery completion. Gawande et al. (2003) estimated that as many as 1 in 1,000 to 1,500 surgeries worldwide may result in a retained surgical instrument.

47 Deshmukh (2005) reported that almost one in five medication doses administered in hospitals is given in error. The two most common errors cited were medication dispensing at the wrong time (43 percent of incidents) and omitting a dose (30 percent). Seven percent of errors were found to be potentially harmful. In a 300-bed facility, this translates into 40 potentially harmful errors each day. Similar findings have been reported by the FDA, which in its own study found that adverse drug events ranged from 2.4 percent to 6.5 percent per facility (Zebra, 2005).
are also engineered to address the medication administration errors that have not been effectively handled by currently existing barcode-based medication administration systems because of problems with barcode technology. These problems, such as unreadable medication barcodes (e.g., crinkled, smudged, covered by another label) and unreadable or missing patient identification wristbands (e.g., soaked, chewed), make it necessary for nursing staff to create “workarounds” (such as scanning a single medication label for all patients in a room) to efficiently perform their duties. Passive, high-frequency RFID tags ensure correct delivery of medications in terms of timing, dosage, drug, and patient. The system includes RFID-based patient identification wristbands. Identification badges for hospital staff members are also tagged. The application’s software runs on handheld devices such as personal digital assistants (PDAs) and mobile computers. Nurses check identification and verify drug information by checking a drug order at the time of medication administration. The tools also allow staff members to update patients’ records at any time. A database collects information wirelessly every time a barcode is scanned, including date and time. The handheld device has voice commands telling when to verify the patient, including an alternate in case there is a discrepancy. The electronic system also updates automatically (Wu et al., 2005; Wessel, 2006; Koppel et al., 2008).

Table 6: Range of staff-focused RFID operational purposes: patient safety

<table>
<thead>
<tr>
<th>Improve patient safety</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error prevention (e.g., via SurgiChip)</td>
<td>10</td>
</tr>
<tr>
<td>Process automation</td>
<td>8</td>
</tr>
<tr>
<td>Ensure accurate medicine dosage given to patient</td>
<td>5</td>
</tr>
<tr>
<td>Implementation of real-time safety reminders for staff</td>
<td>5</td>
</tr>
<tr>
<td>Prevent data entry and collection errors</td>
<td>6</td>
</tr>
<tr>
<td>Haemovigilance safety-ensuring systems</td>
<td>3</td>
</tr>
<tr>
<td>Reduce liability-related problems</td>
<td>2</td>
</tr>
<tr>
<td>Check drug interactions at the point of care</td>
<td>1</td>
</tr>
<tr>
<td>Enhance patient and staff working conditions</td>
<td>1</td>
</tr>
<tr>
<td>Hand-washing compliance monitoring</td>
<td>1</td>
</tr>
<tr>
<td>Drug procurement and administration</td>
<td>1</td>
</tr>
<tr>
<td>Access management to protect patients/staff in psychiatric wards from violence</td>
<td>1</td>
</tr>
</tbody>
</table>

The literature displays wide variability in the degree of sophistication of patient-safety focused systems, ranging from singular interaction systems (e.g., comprising a wireless reader and a tagged surgical set and sponges to prevent retained foreign bodies after surgery48) to highly complex ones (e.g., following a patient’s complete journey through an episode of care49) that are also used to manage patient administration, record Joint Commission guideline compliance, and automate certain processes, thus reducing the administrative burden on staff and data entry and collection errors. The latter class of applications is also frequently seen as a tool to reduce exposure to liability claims and to improve regulatory compliance (see Table 7 for the number of occasions on which these two operational purposes were explicitly mentioned in the reviewed sources).

An example of this type of application is a context-aware perioperative RFID information system used to construct the context of surgical procedures and detect medically significant events. In it, RFID is leveraged to provide basic context information on the presence of medical staff, devices,

48 See Parikh et al., 2008.

instruments, and medication in the OR. Patient monitoring systems, such as pulse oximeters and anesthesia machines, provide continuous streams of physiological data. These low-level data streams are processed to generate higher-level primitive events, such as a nurse entering the OR. A hierarchical knowledge-based event detection system correlates primitive event, patient, and workflow data to infer high-level events, such as the onset of anesthesia. A role-based pre-surgical protocol is embedded in the RFID application that requires explicit indication by each team member that role-relevant clinical guidance and protocol-based care have been administered (e.g., verifying all pre-operative checks are carried out, eliminating the chance of events involving wrong patient or wrong procedure/medication). This confirmation can be given by voice command. The resulting electronic medical record (EMR) provides medical staff with a permanent record of the surgery that can be used for subsequent evaluation and training and to detect potentially significant errors (Agarwal et al., 2007; Sutherland and Ganous, 2007).

Table 7: Range of staff-focused RFID operational purposes: regulatory compliance

<table>
<thead>
<tr>
<th>Improved regulatory compliance and reduced liability risk (explicit)</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve Joint Commission and HIPAA compliance</td>
<td>3</td>
</tr>
<tr>
<td>Reduce liability-related problems</td>
<td>2</td>
</tr>
</tbody>
</table>

2.1.2.A.c Staff-focused healthcare RFID applications designed to reduce staff’s administrative burden and to make care more patient-centered

Tables 7, 8, and 9 report staff-focused RFID applications that, respectively, have the functional goals of reducing the administrative burden on staff, improving care providers’ working conditions, and making care more patient-centered.

The first set of applications operates in a fashion similar to the ones previously discussed, where administrative burden reduction can either be the sole goal of an RFID system or a second-order result. For example, both emergency departments (EDs) and OFs are environments in which automatic patient location and automatic patient status updating can significantly reduce the number of calls needed to place, locate, or move a patient (Sutherland and Ganous, 2007; Swedberg, 2008). The linking of RFID applications with a hospital’s centralized clinical and admission systems also reduces the need to re-enter information (and at the same time reduces the risk of data entry errors and staff time devoted to re-entering data).

RFID applications that enhance the patient-centeredness of care either enable information free-flow for team management of care (e.g., through integrating RFID and lab result and imaging systems, discussed in more detail below) or center on seamlessly alerting care providers to patients’ needs (e.g., RFID-enabled flexible surface wetness sensor for adult paralyzed patients) — see Table 10.

An example of such applications is an RFID solution that features a watch-shaped RFID tag containing information on a patient’s illness, medical records, and current drug treatments. Physicians, equipped with a designated reader, are able to access the complete health record of the patients they are caring for by scanning each patient’s bracelet with a reader-equipped PDA that is also connected to the hospital’s e-prescription system. The result: faster treatments and better traceability of prescribed drugs (Protti, 2007).
Table 8: Range of staff-focused RFID operational purposes: administrative burden

<table>
<thead>
<tr>
<th>Administrative burden</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce administrative burden on staff</td>
<td></td>
</tr>
<tr>
<td>Reduce forms-processing time</td>
<td>10</td>
</tr>
<tr>
<td>Process automation</td>
<td>8</td>
</tr>
<tr>
<td>Prevent data entry and collection errors</td>
<td>6</td>
</tr>
<tr>
<td>Administrations at hospitals</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 9: Range of staff-focused RFID operational purposes: working conditions

<table>
<thead>
<tr>
<th>Working conditions</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve staff working conditions and safety</td>
<td></td>
</tr>
<tr>
<td>Security and safety at hospitals</td>
<td>3</td>
</tr>
<tr>
<td>Protect patients/staff in psychiatric wards from violence</td>
<td>1</td>
</tr>
<tr>
<td>Track movement of staff, patients, visitors to assess</td>
<td>1</td>
</tr>
<tr>
<td>SARS [Severe Acute Respiratory Syndrome] spread</td>
<td>1</td>
</tr>
<tr>
<td>Hand-washing compliance monitoring</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 10: Range of staff-focused RFID operational purposes: patient-centeredness of care

<table>
<thead>
<tr>
<th>Patient-centeredness of care</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve patient-centeredness of care</td>
<td></td>
</tr>
<tr>
<td>Portable, current, and comprehensive health records</td>
<td>5</td>
</tr>
<tr>
<td>Real-time clinical information associated with patient</td>
<td>5</td>
</tr>
<tr>
<td>Alert staff of patient needs</td>
<td>3</td>
</tr>
</tbody>
</table>

2.1.2.A.d Staff-focused healthcare RFID applications designed to improve clinical care quality

Finally, the review identified a number of conceptual prototype and early pilot RFID applications aimed at improving the clinical quality of healthcare. These are grounded solely on RFID-based solutions designed to improve diagnostic reliability at point of care.

One example of this class of solutions is a non-intrusive dissolving RFID-based imaging capsule used for endoscopy that has been shown to reduce patient complications. An RFID chip is encapsulated in a biodegradable body and administered to patients to study their intestinal tract. A scanner is used to detect and track the RFID tag’s progress through the patient’s system. The state of the capsule when it is excreted is used to determine the appropriate next step in treatment. A similar application has been developed to study esophageal reflux, and a patent is pending for a similarly digestible RFID chip that would track the dissolution of medications within the body (Banerjee et al., 2007).

2.1.2.B Patient-focused applications

RFID solutions tailored to the needs of patients make up the second group of RFID applications identified in the literature. As mentioned earlier, many of these systems inadvertently benefit both patients and care providers.
A thematic and a count analysis of information sources identified nine functional goals — i.e., nine ways in which patient-focused RFID applications are used to improve healthcare delivery (see Figure 9). The three most frequently mentioned were improving the safety of inpatient care, improving department-level process efficiency, and improving the patient-centeredness of inpatient care.

Figure 9: Functional goals of patient-focused RFID applications in healthcare, as identified in the literature (% of sources mentioning)

<table>
<thead>
<tr>
<th>Functional Goal</th>
<th>Mentioned Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve patient privacy</td>
<td>5</td>
</tr>
<tr>
<td>More effective clinical care</td>
<td>10</td>
</tr>
<tr>
<td>Improve process quality of inpatient care</td>
<td>15</td>
</tr>
<tr>
<td>Identify patients in disasters</td>
<td>20</td>
</tr>
<tr>
<td>Better inpatient process/event audit capacity</td>
<td>30</td>
</tr>
<tr>
<td>Improve quality of outpatient care</td>
<td>40</td>
</tr>
<tr>
<td>Improve patient-centeredness of inpatient care</td>
<td>50</td>
</tr>
<tr>
<td>Enhance department-level process efficiency</td>
<td>60</td>
</tr>
<tr>
<td>Improve safety of inpatient care</td>
<td>70</td>
</tr>
</tbody>
</table>

Note: The categories are non-exclusive and are listed according to frequency of mention (least to most, top to bottom) in the reviewed sources.

I next discuss what are the separate operational purposes (i.e., specific uses to which applications are put) that support the identified functional goals, and how specific applications within each of these staff-focused RFID operational purpose groups work. The discussion proceeds in accordance with Figure 5, moving from the most-frequently to the least-frequently mentioned functional goals.

2.1.2.B.a Patient-focused healthcare RFID applications designed to improve inpatient care safety

Patient-focused RFID solutions whose functional goal is to improve the safety of care in the hospital environment (see Table 11) essentially build upon RFID's ability to positively identify tagged objects and people. In this case, they are used to introduce accurate, automatic patient identification in the care process without increasing the burden on care providers\(^{50}\) or to

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\(^{50}\) A comparison made in the literature in this regard is between barcodes and active RFID. For example, in the case of medication management, barcodes require that both a patient’s wrist and medicine containers be scanned, adding a number of steps to the care process that have been shown in the literature to lead to “workarounds,” which reduce safety (see Koppel et al., 2008). Active RFID, in contrast, relies on an electronic handshake between the networked components of the RFID system to verify the match, so there is no added burden for staff.
guarantee the physical safety of patients. Both are achieved by equipping patients with RFID-fitted identification wristbands, badges, or woven-in tags emitting a unique signal.

There is a significant overlap between the patient care safety applications and the staff-focused RFID systems aimed at improving patient safety (see Section 2.1.2.1): networked active/passive RFID chips attached to patients, staff and/or medication and assets/inventory used to prevent medical errors and/or to create a history of all procedures, medicines, and supplies used on a patient (based on data logs produced by individual chip-reader electronic handshakes).

Similar systems are deployed to improve haemovigilance; in these, blood products are tagged with temperature-sensitive RFID chips (Sweldberg, 2008).

Other applications described in the literature emphasize the physical safety of patients, including infants and patients with diminished capacity (e.g., dementia or psychiatric ward patients), by introducing RFID-reader enabled “choke points” at the physical boundaries of safe environments (e.g., unit doors) that either deny access or sound an alarm if a patient wearing a sensitized RFID wristband attempts to cross the safety perimeter.

One example of such applications is RFID used to prevent the exit of psychiatric ward patients from safety areas. Patients are fitted with an RFID tag (either on themselves in the form of an ankle bracelet or sewed into their clothing) that is encoded to provide a patient with differential access to hospital areas, and an RFID reader is placed at the entry and exit point (choke point) of the safety perimeter. Upon a patient’s approach, the RFID reader identifies the patient’s level of access and either opens the door to the next area or prevents the patient from crossing the safety perimeter. Such applications are reported to substantially reduce the number of nursing staff that have to be designated for patient watch and access control, which in turn leads either to reductions in full-time employees on guard duty or to increases in the time nursing staff spend taking care of patients (Sini et al., 2008).

<table>
<thead>
<tr>
<th>Table 11: Range of patient-focused RFID operational purposes: inpatient safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve safety of inpatient care</td>
</tr>
<tr>
<td>Patient identification to decrease adverse patient events (wrong drug, dose, time, procedure)</td>
</tr>
<tr>
<td>Accurate patient identification</td>
</tr>
<tr>
<td>Eliminate wrong-patient/wrong-procedure surgery</td>
</tr>
<tr>
<td>Infant tracking and tracing at hospitals to avoid theft (perimeter guard)</td>
</tr>
<tr>
<td>Accurate patient identification for medication safety</td>
</tr>
<tr>
<td>Infant identification at hospitals to forego mismatching to mothers</td>
</tr>
<tr>
<td>Patient tracking to ensure safety/access control (dementia, psych)</td>
</tr>
<tr>
<td>Haemovigilance safety-ensuring systems</td>
</tr>
<tr>
<td>Tracking of drugs, supplies, and procedures performed on each patient</td>
</tr>
<tr>
<td>Patient identification for blood transfusion</td>
</tr>
<tr>
<td>Reduce errors due to misidentification</td>
</tr>
<tr>
<td>Dementia patients tracking and access (inpatient)</td>
</tr>
<tr>
<td>Infection control (nosocomial infections)</td>
</tr>
<tr>
<td>Reduce patient complications</td>
</tr>
</tbody>
</table>
2.1.2.B.b Patient-focused healthcare RFID applications designed to improve department-level process efficiency

RFID applications having the functional goal of increasing department-level process efficiency are listed in Table 12. Some of these mirror the staff-tracing solutions previously mentioned, where patients are equipped with RFID-fitted identification wristbands emitting signals that allow the patient’s path through a healthcare facility to be traced and information to be collected about the time the patient has spent at different locations, which is further used to identify and resolve bottlenecks and improve workflow. The same systems are reportedly also used to account for patients’ whereabouts (e.g., for easy location and care coordination across teams).

Other solutions support better department-level efficiency time utilization by including patients in networked staff/patients/medication systems that result in less time spent on duplicative or non-care-related activities (e.g., asset/inventory tracking, documentation replication, or performing post-operative sponge counts).

<table>
<thead>
<tr>
<th>Improve department-level process efficiency</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient tracking and tracing at hospitals for monitoring patient flow</td>
<td>55</td>
</tr>
<tr>
<td>Monitoring/tracking of patient location</td>
<td>38</td>
</tr>
<tr>
<td>Interventions: automated care, pathways, procedures audit, management</td>
<td>23</td>
</tr>
<tr>
<td>Real-time patient location systems</td>
<td>4</td>
</tr>
<tr>
<td>Accounting for patient whereabouts in ED</td>
<td>3</td>
</tr>
</tbody>
</table>

2.1.2.B.c Patient-focused healthcare RFID applications designed to improve the patient-centeredness of care

RFID applications whose functional goal is to improve the patient-centeredness of care in the hospital setting are listed in Table 13. One group of these systems involves RFID-enabled technological solutions that provide real-time information on the health indicators and vital signs of patients (telemedicine) to care providers on their mobile media (e.g., PDAs) (Krizner, 2004; Anderson and Meadows, 2006; Friedlos, 2009). These applications effectively use the RFID signal hardware as an information platform through which telemetric data are sent to a specific care provider or the centralized information system.

Another group of RFID applications that focuses on improving the patient-centeredness of care is geared to producing portable, current, and comprehensive patient medical records (Traster, 2004). Typically these applications entail linking patients’ RFID IDs and records to the test and imaging lab systems of a hospital facility so that patients’ records are instantly updated with results as they become available and care providers are instantly alerted to the new results. This information can be displayed to care providers at the medical floor (MF) level (where information on all patients is visible on a map with their location, utilizing status icons indication), as well as at the patient level. As discussed in Section 2.1.2.1.1, such applications are frequently folded into

51 In contrast to the findings for staff-focused RFID systems, no hospital-wide patient-centered RFID application aimed at increasing process efficiency was reported in the literature. Therefore, I have assumed that patient systems at present are used only to improve the functioning of departments.
OR and ED process workflow systems; however, stand-alone systems with such more limited functionality also have been reported.

Finally, RFID systems that allow patients to be remotely identified are also credited with enhancing the patient-centeredness of care (e.g., precluding the need to interrupt a patient’s sleep prior to medication administration).

Table 13: Range of patient-focused RFID operational purposes: patient-centeredness of care

<table>
<thead>
<tr>
<th>Improve patient-centeredness of inpatient care</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID ingested or implanted to provide real-time information on health indicators and vital signs, to monitor and report on the results of surgeries, and to regulate the release of medications, telemedicine</td>
<td>22</td>
</tr>
<tr>
<td>Critical information to the patient</td>
<td>11</td>
</tr>
<tr>
<td>Real-time clinical information associated with patient</td>
<td>5</td>
</tr>
<tr>
<td>Portable, current and comprehensive health records</td>
<td>5</td>
</tr>
<tr>
<td>Portable health records</td>
<td>3</td>
</tr>
<tr>
<td>Validating patient charts and imaging</td>
<td>2</td>
</tr>
</tbody>
</table>

2.1.2.B.d Patient-focused healthcare RFID applications designed to improve quality of care patients receive in the outpatient setting

Another large group of patient-centered RFID applications is geared to improving the quality of care patients receive in the outpatient setting, in nursing homes, and in their own home (see Table 14).

One subgroup of these applications is the use of implanted RFID to carry vital medical information, either encrypted or as a designated ID number linked to a secure database accessible to care providers only. These applications are seen as a key to safer, faster care in emergency situations or for incapacitated patients, and as a highly desirable direction for RFID use in healthcare. In one example of such an application, one or more RFID tags are attached to a dementia patient’s clothing or frequently carried item (e.g., shoes, watch), and their signals are used to determine the patient’s whereabouts and to trigger an alarm if he/she exits a safe parameter fitted with an alarm-designated reader. Embedding the chips with coded information on a patient’s identity, critical information (e.g., medication allergies, conditions), and contact person’s telephone number (stored on the chip or in a database that ED staff can access) would allow patients to be identified and their medical record accessed immediately, regardless of their level of mental acuity (O’Connor, 2009).

Another large subgroup is designed to support patient’s medication plan compliance. These can include medication blister packs fitted with an RFID tag that records the patient’s medication-taking history (time, frequency, and count of medication taken), and can further be used by the patient’s pharmacist to assess the patient’s compliance and change treatment plan (Collins, 2006). Such systems can also be interfaced with other systems (e.g., cell phone) and can issue reminders to the patient that the medication needs to be taken at a specific time, to improve care effectiveness. Finally, patents for dissolving RFID-enabled medication absorption products have also been reported (Collins, 2006).
Table 14: Range of patient-focused RFID operational purposes: outpatient care quality

<table>
<thead>
<tr>
<th>Improve quality of outpatient care</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implanted RFID carrying medical record</td>
<td>20</td>
</tr>
<tr>
<td>Intelligent medication monitoring (for elderly at home)</td>
<td>15</td>
</tr>
<tr>
<td>Dementia patients tracking and tracing at elderly homes to avoid going missing</td>
<td>8</td>
</tr>
<tr>
<td>Assisting the visually impaired</td>
<td>4</td>
</tr>
</tbody>
</table>

2.1.2.B.e Patient-focused healthcare RFID applications designed to improve process quality of inpatient care

The literature also reported a number of RFID applications aimed at improving the process quality of inpatient care (see Table 15). An example of these applications is one in which active RFID tags are used to verify the correct depth of insertion of endotracheal tubes in intensive care unit (ICU) patients. While X-rays remain the gold standard for confirmation of appropriate insertion depth, they are usually done only once per day. This may not be sufficient to detect tube migration that can frequently occur during patient care in the ICU. Supplementing the traditional procedure with RFID-embedded endotracheal tubes and having ICU nurses use an RFID reader to verify the tube’s position (shown to be accurate to a precision of a few millimeters) can decrease the frequency of required radiographs, enable early detection of malpositioned tubes, ensure early correction of malpositioned tubes, and ultimately prevent untoward complications (Reicher et al., 2007).

Table 15: Range of patient-focused RFID operational purposes: inpatient process quality

<table>
<thead>
<tr>
<th>Improve process quality of inpatient care</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve patient/staff satisfaction</td>
<td>6</td>
</tr>
<tr>
<td>Proper positioning of the endotracheal tube during intubation</td>
<td>2</td>
</tr>
<tr>
<td>Flexible surface wetness sensor for adult paralyzed patients</td>
<td>1</td>
</tr>
</tbody>
</table>

2.1.2.B.f Patient-focused healthcare RFID applications designed to improve clinical care quality and the privacy of patient data

RFID has also been used as a supporting technology in a number of clinical improvements (see Table 16). For instance, one system uses RFID, sensors, and electric stimulators to assess the functioning of an implanted orthopedic device and the surrounding tissue, as well as to speed up surgical recovery. The application employs sensors to measure pressure on the implant and its positioning, as well as chemical balance, temperature, and the presence of microorganisms around the device after it has been surgically attached to a patient. The sensors are wired to an RFID chip, which transmits the collected data to a portable RFID reader that a physician uses (Swedberg, 2008).
Table 16: Range of patient-focused RFID operational purposes: clinical improvements

<table>
<thead>
<tr>
<th>Clinical care improvements</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical improvements (not specified)</td>
<td>2</td>
</tr>
<tr>
<td>Help surgical recovery</td>
<td>2</td>
</tr>
<tr>
<td>Track healing around an implant</td>
<td>1</td>
</tr>
<tr>
<td>Functional-neuromuscular stimulation</td>
<td>1</td>
</tr>
</tbody>
</table>

Healthcare RFID applications have also been used to improve the privacy of patient data — for example, by replacing handwritten patient records at patients’ beds with encoded information available only to nurses and physicians after log-in (see Table 17).

Table 17: Range of patient-focused RFID operational purposes: patient privacy

<table>
<thead>
<tr>
<th>Improve patient privacy</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protecting patient privacy</td>
<td>3</td>
</tr>
<tr>
<td>Selectively jam RFID readers</td>
<td>1</td>
</tr>
</tbody>
</table>

2.1.2.B.g Patient-focused healthcare RFID applications designed to improve process audit

The ability of RFID systems to generate detailed process and interaction records can also be leveraged to improve the evaluation, management, regulatory compliance, and audit of healthcare processes, as discussed in Section 2.1.2.1.1 (see Table 18).

Table 18: Range of patient-focused RFID operational purposes: process/event audit

<table>
<thead>
<tr>
<th>Improve inpatient process/event audit capacity</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interventions: automated care, pathways, procedures audit, and management</td>
<td>23</td>
</tr>
<tr>
<td>Tracking of drugs, supplies, and procedures performed on each patient</td>
<td>11</td>
</tr>
<tr>
<td>Incident audit trail</td>
<td>2</td>
</tr>
</tbody>
</table>

Finally, RFID’s unique identification ability has been used in several other patient-centered healthcare-related functions (see Table 18).

Table 19: Range of patient-focused RFID operational purposes: other

<table>
<thead>
<tr>
<th>Other outpatient applications</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient identification after disasters</td>
<td>8</td>
</tr>
<tr>
<td>Person identification for forensics</td>
<td>2</td>
</tr>
<tr>
<td>Contactless care payment</td>
<td>2</td>
</tr>
<tr>
<td>Managing the large numbers of seriously injured patients during catastrophic events</td>
<td>2</td>
</tr>
</tbody>
</table>
2.1.2.C Portable asset and biomedical inventory applications

RFID applications designed to meet the needs of biomedical engineering and auxiliary services departments (referred to here as “assets and inventory-focused applications”) are the third group of RFID applications identified in the literature. Centered on the management of portable assets (e.g., portable bladder scanners) and high-value biomedical inventory (e.g., cardiac surgery stents), by functional definition these systems benefit care providers.

My analysis of information sources identified six functional goals — i.e., six key ways in which assets and inventory-focused RFID applications are being used to improve healthcare delivery (see Figure 10). Of these six, the three most frequently discussed in the literature were equipment localization, inventory management, and tissue and blood bank operation.

**Figure 10: Functional goals of asset and inventory-focused RFID applications in healthcare, as identified in the literature (% of sources mentioning)**

![Figure 10: Functional goals of asset and inventory-focused RFID applications in healthcare, as identified in the literature (% of sources mentioning)](image)

Note: The categories are non-exclusive and are listed according to frequency of mention (least to most, top to bottom) in the reviewed sources.

The following subsections discuss the separate operational purposes (i.e., specific uses to which applications are put) that support each of the six functional goals identified, and how specific applications within each of the staff-focused RFID operational purpose groups work. The discussion proceeds in accordance with Figure 6, moving from the most-frequently to the least-frequently mentioned functional goals and summarizing in tables the variety of operational purposes reported as supporting each identified functional goal.

2.1.2.C.a Healthcare RFID applications designed to improve portable asset localization and management

RFID applications whose functional goal is equipment localization (see Table 20) typically consist of networked active RFID tags that are attached to individual pieces of valuable portable equipment (e.g., IV pumps, defibrillators, ventilators, microscopes, lasers) and emit a signal at regular intervals that allows the current location of the RFID-identified assets to be identified. The software functionality of these applications typically generates an electronic map of the covered area, with individual rooms and areas clearly displayed, in which the location of each asset (e.g., organized by type) is noted. Although equipment localization RFID applications do not supply
information on the status of the identified assets (i.e., if it is currently in use, is being cleaned, or is available for use), they provide hospital nursing and clinical engineering staff with unprecedented information.

For example, full inventory cycles are very labor (staff time) intensive. However, a full inventory cycle is the only way an organization can know with certainty what portable assets it has and where they are. A problem with any inventory cycle is that the results are soon out of date, since assets are constantly moving, out for repair, etc. Given that doing an inventory can require several hours for asset location alone, and remote identification of specific assets is virtually impossible, RFID asset localization applications, which introduce the ability to account for critical assets in real time, enable clinical engineers to carry out preventive or corrective maintenance on portable hospital equipment, or to recall a class or a piece of equipment much more easily. Annual inventory cycles, security audits, end-of-lease equipment collections, retired asset counts, tangible asset appraisals for corporate valuation purposes, and regulatory compliance — all of these are also made less staff-time intensive and more accurate by RFID equipment localization systems (Britton, 2007).

RFID applications that support portable asset management build on the simpler tracking-only applications just discussed. But they also provide application users with information on the status of each asset (i.e., currently in use, being cleaned, or available for use), thereby increasing the utility of the RFID application (e.g., a nurse can know with certainty that a portable asset he/she is looking for is indeed ready to be used). This information helps staff locate portable assets faster when they are needed for clinical care, sterilization, and preventive or corrective maintenance. This improves portable asset availability, reduces hoarding (nurses hiding portable assets from other units to ensure their immediate availability), and ultimately makes employees’ jobs easier (Gamble, 2009).

Management-focused portable asset applications can also supply utilization data on the tagged equipment fleet that can further be used for analysis of individual asset demand and utilization and for better purchase and lease planning. For example, reduced equipment rentals and associated maintenance costs (as labor costs or maintenance contracts if outsourced) are further associated with reductions in the mobile assets fleet (and improved equipment utilization). The improved availability of assets can also lead to nurses finding equipment faster, and patients being transported more quickly within the facility (to/from procedures or for discharge). Both of these can contribute to increased patient throughput. Improved asset visibility, use, and management can also lead to reduced capital outlays by reducing the pressure for expanding the physical infrastructure of a facility (i.e., free physical space by decreasing the total number of assets, or cluttering; Bacheldor, 2008).

| Table 20: Range of asset-focused RFID operational purposes: localization and management |
|-----------------------------------------------|------------------|
| **Equipment localization and management**     | # mentioning    |
| Equipment localization                        | 111              |
| Real-time equipment count and location tracking| 68               |
| Equipment tracking to avoid procedure delays  | 42               |
| Locating open beds and medical equipment in wide-scale emergency | 1 |
| **Equipment management**                      | 30               |
| Maintenance of biomedical equipment           | 10               |
| OR equipment tracking to ensure hygiene compliance | 9 |
| Bed identification in hospitals to ensure hygiene compliance | 6 |
| Improved compliance with scheduled equipment inspection/maintenance | 3 |
| Asset/inventory recall/returns management    | 2                |

36
2.1.2.C.b Healthcare RFID applications designed to improve high-value inventory management

RFID applications that have the functional goals of tracking and managing high-value inventory, such as biomedical inventory and medications (see Table 21), also typically take the form of networked RFID tags attached to medical inventory — most frequently, medication and high-value, short-shelf-life products, such as cardiac stents. These applications are used to ensure inventory’s utilization or return to the manufacturer prior to the expiration date, and/or timely restocking, as well as adequate billing to the patient’s record.

One example of such a system is an integrative RFID application that:

- tracks the stock of implantable cardiac devices (such as pacemakers, defibrillators, catheters) maintained in a cardiac unit, identifying each device and its expiration date
- identifies cardiac surgery patients (through an RFID-embedded wristband) and records all cardiac devices that have been used on each patient.

Interfacing the two streams of information, the application delivers accurate and timely inventory data (that can enable a department to reduce its device and equipment inventory) and enables accurate billing of cardiac surgery patients (inaccurate billing being a serious outstanding issue for invasive procedures; O'Connor, 2008).

Medication-focused RFID applications can also consist of passive-tag enabled medication management systems that allow hospital staff to follow the medication’s route from dispensing to patient utilization, as well as active/passive tag-enabled medicine-dispensing cabinets that grant/deny access upon reading staff’s RFID-enabled badges to enforce access control and prevent inventory shrinkage (Dysart, 2007).

RFID applications focused on surgical inventory can consist of surgical instruments and sponges fitted with RFID tags and a portable RFID reader passed over a patient’s body prior to post-surgical closure to detect if any materials have been left in the patient’s body. Such portable readers are also leveraged to avoid inventory loss in busy environments. And RFID tags resistant to high pressure/temperature are reportedly used to verify the decontamination of surgical instruments (Macario et al., 2007).

<table>
<thead>
<tr>
<th>Table 21: Range of inventory-focused RFID operational purposes: tracking and management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inventory tracking and management</strong></td>
</tr>
<tr>
<td><strong>Inventory tracking</strong></td>
</tr>
<tr>
<td>Materials tracking to avoid ‘left-ins’</td>
</tr>
<tr>
<td>Inventory misplacement</td>
</tr>
<tr>
<td>Medication lot and batch tracking</td>
</tr>
<tr>
<td>Scrubs automatic dispensing</td>
</tr>
<tr>
<td><strong>Inventory management</strong></td>
</tr>
<tr>
<td>Inventory tracking for access control and inventory shrinkage decrease</td>
</tr>
<tr>
<td>Inventory management for expiration date and restocking</td>
</tr>
<tr>
<td>In-hospital medication tracking</td>
</tr>
<tr>
<td>Real-time temperature tracking of pharmaceuticals in transport</td>
</tr>
<tr>
<td>Surgical stents and implants management</td>
</tr>
<tr>
<td>Automatic supply and equipment billing</td>
</tr>
<tr>
<td>Decontamination of surgical instruments</td>
</tr>
<tr>
<td>Inventory cost capture at patient level</td>
</tr>
</tbody>
</table>
2.1.2.C.c Healthcare RFID applications designed to improve the operation of tissue and blood banks

RFID applications focused on supporting the operation of tissue and blood banks (see Table 22) typically involve fitting tissue sample boxes with RFID tags that contain information on the patient to whom they belong in order to allow for the samples’ easy location and positive identification.

RFID tags have also been used to reduce diagnostic errors via an application that identifies tissue specimens in gastrointestinal and colorectal surgery endoscopy units (Francis, Prabhakar, and Sanderson, 2009; Korcok, 2009).

Other tissue/blood-bank focused RFID systems involve blood bags fitted with temperature-sensitive RFID tags containing bag content information, which can be easily matched to the characteristics of the patient for whom they are dedicated prior to any procedure, thus preventing transfusion of the incorrect blood component (Edwards, 2007).

One variation of such RFID applications aims to reduce the errors associated with matching blood bags with patients. The patient and the cabinet holding the blood are equipped with RFID tags. Once the blood is tested, the nurse giving the blood to the patient has to go through a process in which he/she validates that the patient is getting the correct blood type. The blood bags can only be retrieved from a locked cabinet, which is opened using patients’ RFID tags. While such systems have been developed on a barcode as opposed to an RFID platform, the use of RFID increases the speed of the system (avoiding the need to scan barcodes several times) and helps keep the hospital in compliance with its procedures (by not creating the need for nurses to “supplement” barcoded bags that have illegible IDs with others, thus increasing the risk of transfusion error later on; Wessel, 2007).

RFID-based haemovigilance systems also cover the labeling of the patient's pre-transfusion sample, the decision to transfuse, and the final bedside check designed to prevent mis-transfusion (a system parallel to those designed to prevent errors in medication administration; Dzik, 2007).

| Table 22: Range of asset-focused RFID operational purposes: tissue and blood bank operation |
|-------------------------------------------------|-----------------|
| Tissue and blood bank operation | # mentioning |
| Blood bag identification in hospitals to ensure blood type matching | 16 |
| Haemovigilance safety-ensuring systems | 11 |
| Tissue sample and other test tube location | 10 |
| Blood bag tagging with temperature sensors to ensure cold chain and efficacy | 8 |

In addition to the five key functional goals identified above, RFID applications focused on assets and inventory are also reported to aid the tracking of documentation in inpatient and outpatient care facilities, to identify and locate dental prosthetics, to monitor and trace the transportation and distribution of vaccines, and to ensure cold chain management via RFID-enabled temperature sensors for perishable goods shipments in disaster response operations.

2.1.2.D Clinical trial applications

The fourth, and final, group of RFID uses in healthcare discussed in the literature consists of applications designed to meet the needs of clinical trial researchers. RFID applications can aid
the conduct of clinical trials in six key ways — i.e., they were found to have six functional goals (see Table 23). In this case, however, the functional goals and operational purposes overlap. Of these goals, the most frequently discussed were data collection for analysis based on unique participant identification via RFID badges/bracelets, monitoring of patient compliance with planned treatment (e.g., via the medication plan management solutions discussed above), and medication-release regulation.

These largely correspond to the uses RFID systems are put to in other settings and emphasize the medication plan compliance and auto ID tasks that RFID systems support.

<table>
<thead>
<tr>
<th>Applications — Trials</th>
<th># mentioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data collection for analysis</td>
<td>7</td>
</tr>
<tr>
<td>Patient compliance with treatment in trial</td>
<td>3</td>
</tr>
<tr>
<td>Medication-release regulation</td>
<td>2</td>
</tr>
<tr>
<td>Test tube tracking for transport control</td>
<td>1</td>
</tr>
<tr>
<td>Reduce trial process errors (test tubes lost, not returned, wrong)</td>
<td>1</td>
</tr>
<tr>
<td>Patient/volunteer management (e.g., loss to follow-up/dropout)</td>
<td>1</td>
</tr>
</tbody>
</table>

### 2.1.2.E Problematic areas for healthcare RFID use

The functional goals analysis brought to light the existence of healthcare RFID application areas that the information sources had highlighted as “problematic.” These were connected with both inpatient and outpatient care. A range-of-view analysis showed that the opinions expressed were motivated by two issues that authors associated with RFID’s introduction in healthcare:

- the surveillance threat and potential privacy intrusion associated with healthcare RFID
- the lack of RFID industry standards ensuring RFID’s non-interference with other clinical systems or bio-medical implants.

Both of these are discussed below.

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52 For more information on the enabers and barriers to RFID diffusion identified in the literature, see Appendix 3.
Figure 11: Areas in which the use of healthcare RFID is undesirable, and reason cited, as identified in the literature (% of sources mentioning)

- RFID use in healthcare should be avoided in general until a universal RFID standard is developed to prevent interference with other HIT
- RFID use in healthcare must be avoided in general because it violates personal privacy by allowing continuous surveillance
- RFID use for personal identification in outpatient care is undesirable due to inability to protect stored data
- Healthcare RFID will confront social privacy norms
- RFID use in the OR and ICU settings needs to be preceded by tests for non-interference with biomedical equipment and other HIT
- RFID use in the in- and outpatient settings needs to follow HIPAA regulations, for patients, and to be restricted to professional duties only, for staff

Note: The categories are exclusive.

2.1.2.E.a RFID and personal privacy

Privacy questions figure in several discussions of RFID technology applications in healthcare (Foster and Jaeger, 2008; Kohno, 2008; Levine et al., 2007). Might vulnerable populations (e.g., geriatric and psychiatric patients) be coerced into having the chips imbedded and the data misused for research or commercial purposes? Might data be accessed and used in inappropriate ways? Overall, literature sources discussing the surveillance/privacy issues surrounding RFID’s use expressed concern primarily with the use of RFID for:

- patient and care provider identification
- patient and care provider continuous geolocation
- implantable RFID tags meant to provide key medical information on patients in emergencies.

The majority of these sources take a positive stance to healthcare RFID, highlighting the need to guarantee individuals’ right to opt out of RFID systems, as well as the potential privacy threats that may be brought on by RFID’s wider dissemination unless the types of data collected through
RFID, its uses, and its protection are explicitly regulated. For example, Halamka et al. (2006) point to the fact that VeriChip (an implantable RFID tag meant to provide key medical information in emergencies) is vulnerable to simple, over-the-air spoofing attacks. Scanning a VeriChip, eavesdropping on its signal, or simply learning its serial number can create a spoof device whose radio appearance is indistinguishable from the original. Thus, the authors suggest that VeriChip should serve exclusively for identification, and not authentication or access control.

A very small group of literature sources, however, take a radically negative stance to RFID use in healthcare. Portraying it either as a tool for Orwellian “Big Brother observation” of the private lives and activities of both patients and care providers (Boulard, 2005) or as the “sign of the Beast” (in the context of Christian philosophy; see Albrecht, 2007), they accentuate RFID’s supposed ubiquitous surveillance capacity (understood as the technology’s ability to report on people’s movement and activities at any time and any place). How this capacity may be reconciled with healthcare RFID’s limited reading range and the existing human subject protection under the Health Insurance Portability and Accountability Act (HIPAA), or why RFID use in healthcare is more dangerous than cell-phone-based tracing is not discussed in these sources. This suggests that the true threats that the technology carries for personal data security and privacy have largely been misunderstood in the popular media (Boulard, 2005; O’Connor, 2005).

To mitigate the privacy concerns associated with healthcare RFID technology, Hagland (2005) suggests that when engineering RFID systems, health entities should ensure that neither personal nor confidential information is transmitted via RFID. Such data should instead be stored in a secure server in compliance with HIPAA.

### 2.1.2.E.b RFID signal interference

Although only one study (van der Togt et al., 2009) emphasized RFID’s potential to interfere with other HIT or clinical equipment, that study was quoted in almost all sources published after its release. The report describes an experiment in an ICU in which the frequency of passive RFID readers was artificially increased (to simulate an accidental event), producing interference in the operation of clinical systems. After testing two different RFID systems against 41 different medical devices, the researchers found 34 incidents of interference in 123 tests.

The FDA, manufacturers, and healthcare providers investigated the reported problems further (DiConsiglio, 2008; Joch, 2008). However, despite the low real-life probability that such a frequency change can occur, as well as the fact that the equipment used in the experiment was outdated, effectively no policy action resulted on federally mandating RFID standards.

### 2.1.3 The evidence on healthcare RFID’s benefits and costs

In this section, I take a look at the evidence that exists on the benefits and costs of the identified applications.

Given the policy question addressed in my thesis — the potential of healthcare RFID to positively affect the quality and cost-efficiency of care delivery over the next five to ten years — the primary aim for this portion of the analysis was to determine what empirical data were available on the benefits and costs of identified RFID applications. The secondary aim was to determine whether these data were sufficient for prioritizing documented applications according to their capacity to positively affect healthcare quality and cost-efficiency and their market readiness (based on

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53 See Vilamovska et al, 2009 for more details.
assumptions the information sources made about benefit and cost replicability given the application's maturity).

A count analysis of:

- the number of information sources listing as a key objective in their abstract (or executive summary) the analysis of the benefits and/or costs of specific healthcare RFID application types (see Figure 12)
- the number of information sources actually containing any kind of quantitative data (including anecdotal) on the benefits and/or costs of the reviewed healthcare RFID application (see Figure 13)

indicated that although roughly 70% of all sources highlighted in their abstracts (or executive summaries) the document's focus on the discussed RFID application's impacts on healthcare quality and cost, only about 36% of them contained any quantitative data.54

This discrepancy is particularly striking when one considers the number of sources that contained information on both the benefits and the costs of the reviewed RFID solution — 23% of all information sources claimed to contain such information, but only 6% did — since only this information can reliably inform the analysis regarding the net benefit of the assessed solutions.

Figure 12: Share of studies stating “cost and/or benefit review” in abstract (N, % total)

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54 This relative prevalence of information is stable over time. See Appendix 3 for a graph showing the number of studies containing cost and benefit data over time.
Investigating what kinds of healthcare RFID applications were reviewed in the studies that carried quantitative benefit and cost information further showed that for many of the documented RFID application types, no quantitative benefit or cost data were available. These included:

- all outpatient applications except nursing-home dementia patient identification and tracing (the benefits of which were discussed in a single non-peer-reviewed industry journal publication)
- all inpatient setting RFID applications designed to enhance the quality of clinical care
- all RFID applications supporting the conduct of clinical trials.

A qualitative analysis of the internal and external validity of reported RFID application benefit and cost estimates additionally showed that the majority of information sources carried anecdotal evidence only; namely, 113, or 72%, of the 158 studies reporting quantitative data on RFID benefits and/or costs. That is, sources presented a single cost or benefit figure taken out of context (i.e., without acknowledgment of the research design or analytic process used to arrive at it) and either:

- attributed it to another information source that could not be found for validation
- framed it as a statement made by a perceived authority (e.g., the Vice President of Nursing of a hospital in which an RFID application was implemented).

Finally, 45 studies contained, as a minimum, information on the cost and benefit constructs or variable measures that authors had employed to evaluate the implementation of healthcare RFID applications: 29 provided benefit estimates only, 5 provided cost estimates only, and 11 provided information on both the benefits and the costs of the discussed application (these are described in detail in Appendix 3). The RFID applications these studies discussed included:

- portable asset tracking and management solutions (n=14)
- ED workflow management solutions (n=8)
• OF and OR workflow management solutions (n=8)
• hospital-wide patient tracing solutions (n=4)
• RFID medication management solutions (hospital wide, n=4; at patient’s bedside only, n=5)
• RFID tracing of dementia patients in a nursing home setting (n=2).

Of the 45 information sources reporting any data on both the impacts and the application costs of healthcare RFID applications/pilots, 34 did not directly provide quantified cost and impact data, instead referring to return on investment (ROI) ratios.

Pooled, the 34 sources showed that a number of healthcare institutions have succeeded in leveraging RFID applications to improve certain aspects of the quality of care they provide and to reduce some of the costs they accrue in delivering that care. With respect to the safety gains delivered by RFID applications, the evidence arising from these studies, if aggregated, highlights RFID’s capacity to support improved safety of care (including decreased medication errors, decreased autologous blood transfusion errors, improved prevention of surgical sponge/instrument retention, and improved capacity to prevent the spread of hospital infections). Available evidence also allowed me to identify many of the key ways in which healthcare RFID can be used to support improvement in the domain of care highlighted by the IOM’s seminal 2001 report (Committee on Quality Health Care in America, Institute of Medicine, 2001); they are listed in Table 24. With respect to cost gains, three key benefits reported by the information sources are reduced capital outlays, increased staff productivity, and staff time savings.

Table 24: IOM quality of care goals that healthcare RFID can support

<table>
<thead>
<tr>
<th>Functional goals</th>
<th>RFID operational purposes and examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safer care</td>
<td>• matching/e-handshake (treatments/procedures, medications)</td>
</tr>
<tr>
<td></td>
<td>• asset management (e.g., prevent nosocomial infections; preventive</td>
</tr>
<tr>
<td></td>
<td>• authenticity verification (patient identity and treatment)</td>
</tr>
<tr>
<td></td>
<td>• tracing (surgical set decontamination, foreign body retention)</td>
</tr>
<tr>
<td>More-effective care</td>
<td>• incorporation of potential error alarm signals (for staff and patients)</td>
</tr>
<tr>
<td></td>
<td>• alerts in remote monitoring of vital signs</td>
</tr>
<tr>
<td></td>
<td>• clinical improvement (imaging, neuro-stimulation, etc.)</td>
</tr>
<tr>
<td>Less-intrusive care</td>
<td>• matching/e-handshake (remote identity verification)</td>
</tr>
<tr>
<td></td>
<td>• tracing (MR/dementia patients)</td>
</tr>
<tr>
<td></td>
<td>• remote monitoring of vital signs (medication absorption, tracheotomy</td>
</tr>
<tr>
<td></td>
<td>• tube tracking)</td>
</tr>
<tr>
<td>More patient-centered care</td>
<td>• asset management and tracing (frees up staff time)</td>
</tr>
<tr>
<td></td>
<td>• patient comfort improvements (e.g., flexible wetness sensors)</td>
</tr>
<tr>
<td>More-efficient care</td>
<td>• asset management (easy recall, maintenance)</td>
</tr>
<tr>
<td></td>
<td>• tracing (inventory shrinkage, liability reduction)</td>
</tr>
<tr>
<td></td>
<td>• authenticity verification and matching</td>
</tr>
<tr>
<td></td>
<td>• matching and tracing (staff tracing and asset management)</td>
</tr>
<tr>
<td>More-timely care</td>
<td>• tracing (asset/patient location)</td>
</tr>
<tr>
<td></td>
<td>• process control (data collection for bottleneck removal)</td>
</tr>
</tbody>
</table>
A detailed review of the remaining 11 studies showed that all but four delivered results that could not be directly compared due to their:

- lack of consistent use of constructs, variables, and measures\(^{55}\) (e.g., even if studies used comparable variable measures, they frequently provided only average or extreme measurement values and did not state to what these referred)
- lack of information on when data were collected and what research design and analytic approach were used (e.g., studies did not clarify whether reported benefits and costs were based on projections of pilot costs or reflected actual implementation outcomes)
- limited contextual information (e.g., how many hospital units actually used the RFID application at the time of the evaluation and what specific functional tasks the application performed).

In contrast to these studies, a group of four non-peer-reviewed studies identified during the review provided detailed setting, research design, and application implementation process information:

- Laskowski-Johnes, 2006,\(^{56}\) delivers the most detailed account of the impacts and adoption process of a patient and staff tracing application in the ED environment of Christiana Care Health Systems, Wilmington, Delaware. Follow-up interviews with the pilot implementation leader, however, revealed that the RFID component of the system is in fact only infrequently used.\(^{57}\) Thus, the achieved benefits and costs of the implemented technology cannot be unambiguously attributed to healthcare RFID.
- In Villarin, 2008, a similar issue was discovered in a case study of a real-world ED management solution implementation at Albert Einstein Medical Center in Philadelphia, Pennsylvania.
- A white paper by Intel (2005)\(^{58}\) presents a cost-benefit evaluation of a patient-tracking and real-time clinical information system pilot on the OF of St. Vincent Hospital, Birmingham, Alabama, in 2005.
- A case study by Agility Healthcare Solutions (2007) presents an account of the impacts and adoption process of a hospital-wide asset management application implemented at Bon Secours Richmond Health System, Richmond, Virginia.\(^{59}\)

Taken together, the review results presented above suggest that the body of current quantitative evidence on healthcare RFID suffers from:

- the lack of a critical amount of comparable evidence on the different RFID applications

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\(^{55}\) This is due, among others reasons, to the problems affecting existing RFID classification attempts that were discussed in the beginning of Section 2.1.2: the mix of RFID uses and benefits, use of wrong or incomplete definitions of RFID, and inaccurate representations of RFID’s engineering capabilities.

\(^{56}\) Also discussed in PCTS, 2008, and Versus, 2008.

\(^{57}\) The RFID component takes over the infrared technology when the line of sight, which is needed for the operation of infrared-based tags and readers, is lost.

\(^{58}\) Also discussed in Gambon, 2006.

\(^{59}\) Also discussed in Becker, 2004, and Harrop et al., 2008.
the general absence of an evaluation framework that coherently captures the full range of benefits and costs brought about by RFID applications in healthcare delivery

- the lack of consistent use of parameters, measures, and, occasionally, constructs across existing evaluations of healthcare RFID applications
- limited contextual data: evaluated systems and implementation environments are heterogeneous and frequently incompletely described.

In addition, a negative publication bias against studies reporting unfavorable results is likely to be affecting industry-promoting sources, which provide a disproportionate share of the currently available empirical data.

Hence, the currently available empirical evidence on the impacts of RFID use in healthcare cannot support a comparative analysis of the potential of documented RFID applications to positively affect the quality and cost-efficiency of care delivery. It also provides us with only a fragmented understanding of healthcare RFID’s capacity in healthcare delivery.

It should be noted that in the course of the source review, I identified two currently existing comparisons of the potential of different healthcare RFID applications (Runyon et al., 2008; Harrop et al., 2008). Both comparisons were done by niche consulting groups. The expectations expressed in them are based on hardware and software sales trends in the HIT and healthcare RFID industries, rates of adoption of individual technologies and applications, and assumptions about the prevalence of early adopters vs. laggards in the pool of potential users of each technology. Although neither contains specific cost or benefit estimates for the applications they discuss, both highlight:

- portable asset management applications
- ED, OR, and MF workflow management applications

as the healthcare RFID solutions expected to deliver greatest added value, in terms of net cost gains and quality improvement, to hospitals. Both sources also indicate that the first RFID application class is likely to reach more substantial market penetration over the next two to four years; for the second class, this is expected in five to ten years.

How these results correspond with expert opinion on the potential of RFID in healthcare is discussed next.

### 2.2 Expectations on the most promising RFID applications for improving healthcare delivery

#### 2.2.1 Methodology for expert interviews

This section summarizes the methodology and analytic approach I used to rank-order the universe of documented healthcare RFID applications (presented in Section 2.1.2) according to their capacity to positively affect healthcare quality and cost-efficiency and their market readiness. I conducted 15 semi-structured interviews with HIT and RFID experts that were identified in the course of the literature review as representing the key healthcare RFID stakeholder groups. The interviews took place between October 2008 and May 2009.

To validate, expand, and prioritize the results from the literature review, an initial sample of key experts on RFID and auto ID technologies in healthcare was identified during the course of the review. This was done with two objectives in mind:
using expert interviews to address the publication time lag and potential bias affecting published materials

capturing different stakeholder perspectives (e.g., vendor, user, patient) on the use of RFID in healthcare.

I chose to use semi-structured interviews (also known as “focused” or “open-ended” interviews) because they are the methodological tool best suited to the two objectives in that they:

- allow respondents the time and scope they need to talk about topics the interviewer is interested in exploring (e.g., understanding different stakeholders’ level of concern about RFID as a personal privacy threat)
- eliminate any prejudgment the interviewer might have formed on the researched topics (e.g., what effects specific RFID applications can have on healthcare delivery processes as they exist today)
- pick up issues that the interviewer has not previously thought of or has no knowledge of (e.g., the range of RFID uses in healthcare, or current sources of empirical data on RFID benefits and costs)
- explore specific topics in detail repetitively, thereby increasing the validity of the findings (e.g., How important are specific RFID applications for improving the quality or reducing the cost of care delivery? How do their effects come about?).

The identified experts included representatives of the key RFID stakeholder categories that emerged from the information source analyses, namely:

- healthcare RFID industry representatives
- non-governmental privacy-defense groups
- healthcare professionals (providers of care and managers) with experience in HIT and RFID
- independent researchers working on health outcomes and HIT/RFID (in academic institutions and non-partisan research organizations)
- non-government organizations focused on healthcare quality improvement and on HIT.

Once the literature analysis was completed, the identified experts were invited to participate in the study through in-person or over-the-phone interviews. Two of the invited experts declined to participate because they were overcommitted, but at least one representative of each stakeholder group accepted the invitation, producing a balanced 15-participant respondent sample. (A list of the respondents’ affiliations is in Appendix 5).

The pairing of semi-structured interviews with a questionnaire that had open-ended and ranking questions allowed a rich set of data to be collected. The interviews examined the following topics (see Appendix 6 for a full version of the interview protocol):

- **The areas that are important for RFID use/misuse in healthcare.** Respondents were asked to identify and rank application areas they thought were important for RFID in healthcare and to give their motivation for their opinions; they were also asked to explore

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60 For more information on the design and uses of and the analytic approaches to semi-structured interviews, see Bernard, 2006, and Rubin and Rubin, 1995.
such questions as, “In what aspect of healthcare can the use of RFID be considered unlikely and/or undesirable?”

- **The benefits and costs of healthcare RFID.** Interviewees were asked to use their own knowledge to rank their identified RFID applications with respect to their importance for addressing currently outstanding problems affecting the quality (i.e., safety, timeliness, continuity, effectiveness) and cost (i.e., staff time/resource efficiency, cost-efficiency) of healthcare delivery over the next five to ten years.\(^{61}\)

- **Personal experiences with RFID applications.** Interviewees were asked about having had first-hand involvement in the piloting of a healthcare RFID application and, if so, what organization-level benefits and costs had resulted from it and how/why they had come about.

- **RFID’s diffusion in healthcare.** Interviewees were asked such questions as, “Which are the main drivers of demand for healthcare RFID?” and “What will be the key developments in the market for healthcare RFID over the next five years?”

Respondents were allowed to freely associate, but prompts based on the functional goals identified through the literature review were used when a question failed to stimulate a response.

The interviews took place over the telephone or in person and lasted from 40 to 60 minutes. At the beginning of each interview, respondents were informed of their right to decline to continue the entire interview at any point, to decline to answer a specific question, and/or to decline to have notes taken.

Data from the interviews were de-identified in the analytic stage. They were analyzed within and then across stakeholder groups to help highlight how opinions differed across groups. Both quantitative methods (frequency of mention of topics, scores given to rating-scale questions) and qualitative methods (view range, belief structures unfolding, and knowledge content analysis) were used to analyze open-ended and rating responses.\(^{62}\)

For example, two approaches were used to increase the validity and reliability of the interview results on the prioritization of the review-identified RFID applications with respect to their potential to positively affect the quality and cost-efficiency of care delivery:

- At the beginning of the interview, respondents were asked open-ended questions on whether they believed there were:
  - “any promising areas for RFID use in healthcare, and if so — which are they.”
  - “any specific RFID applications which can have a positive impact on specific aspects of care delivery, and if so — which are they, and what is this opinion based on.”

- Later on in the interview, respondents were asked to rank the RFID applications identified through the literature review according to their importance for improving healthcare quality, and then according to their importance for containing healthcare costs:
  - first in lists organized around end-user categories (i.e., patient-focused applications, staff-focused applications, asset-focused applications, clinical-trial-focused applications)

\(^{61}\) The information in this section builds upon the results of a Delphi survey that was conducted with a different set of experts and was used to answer a set of similar research questions on the potential of RFID in healthcare, but in the European setting only.

\(^{62}\) For more information on the use of these analytic approaches for interview data analysis, see Bernard, 2006.
then in absolute terms (i.e., “Overall which applications do you see as having the greatest positive impact on the quality of care delivery?” and “Overall which applications do you see as having the greatest positive impact on the cost of care delivery?”).

Respondents’ opinions on market readiness were solicited using an open-ended question for each of the applications a respondent had identified. The same approach was used to elicit respondents’ opinions on the key problems currently affecting healthcare RFID.

2.2.2 Healthcare RFID applications highlighted by experts

The respondents confirmed the comprehensiveness of the spectrum of RFID applications documented in Section 2.1.2. An analysis of the rankings they gave to individual applications further showed a high degree of agreement with respect to an application’s within-user-group ranking and with respect to initially highlighted “promising areas for RFID use in healthcare” (i.e., there was high internal and cross-respondent consistency). Tables 24 and 25 show the experts’ rankings of the top four RFID applications with the greatest positive impact on, respectively, healthcare delivery quality and healthcare delivery cost-efficiency.

Expressing largely conforming opinions on the market readiness of the RFID applications documented, interviewees went on to highlight four main classes of healthcare RFID as leading in their capacity to improve the quality and/or reduce the cost of healthcare delivery in the U.S. over the next five to ten years:

1. Portable hospital asset tracking and management solutions
2. Hospital Emergency Department (ED) process support and workflow management solutions
3. Hospital Operating Floor (OF) process support and workflow management solutions
4. Hospital Medical Floor (MF) and bedside medication management solutions.

Table 25: Experts’ ranking of top 4 RFID applications with greatest positive impact on quality of healthcare delivery

<table>
<thead>
<tr>
<th>Application</th>
<th>Rank-order</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital OF process support and workflow solutions</td>
<td>10 3 1 1</td>
<td></td>
</tr>
<tr>
<td>Hospital MF and bedside medication management solutions</td>
<td>5 8 1 1</td>
<td></td>
</tr>
<tr>
<td>Hospital ED process support and workflow management solutions</td>
<td>4 8 2 1</td>
<td></td>
</tr>
<tr>
<td>Portable hospital asset tracking and management solutions</td>
<td>1 1 1 12</td>
<td></td>
</tr>
</tbody>
</table>

49
Table 26: Experts’ ranking of top 4 RFID applications with greatest positive impact on cost-efficiency of healthcare delivery

<table>
<thead>
<tr>
<th>Application</th>
<th>Rank-order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable hospital asset tracking and management solutions</td>
<td>10 3 1 1</td>
</tr>
<tr>
<td>Hospital ED process support and workflow management solutions</td>
<td>3 10 1 1</td>
</tr>
<tr>
<td>Hospital OF process support and workflow management solutions</td>
<td>4 9 1 1</td>
</tr>
<tr>
<td>Hospital MF and bedside medication management solutions</td>
<td>1 1 2 11</td>
</tr>
</tbody>
</table>

Analysis of the knowledge content and belief structures that motivated the experts’ rankings highlighted two premises consistently evoked when discussing the potential of different RFID applications:

- 13 of the 15 experts referred to RFID as an “enabling” technology with two unique functionalities — lack-of-sight identification and automated data collection — which can be used in the context of specific healthcare delivery business processes to address unresolved needs for positive identification (patient, caretaker, medication, or procedure), time stamping, and interaction recording.

- 14 of the 15 stated that “healthcare RFID’s potential to improve healthcare delivery lies in its capacity to facilitate process improvement and redesign.” In this context, more-advanced healthcare RFID applications (which have more-elaborate software, with built-in analytic functions and the ability to integrate with other hospital HIT) can deliver the greatest value to healthcare deliver organizations. In contrast, RFID applications that perform individual task automation cannot lead to substantial improvements in care quality and cost-efficiency (a fact applicable to HIT in general).

The nuances in the respondents’ opinions and specific justifications for rankings on each of the four “promising” RFID applications are discussed next.

2.2.2.A Portable hospital asset tracking and management RFID applications

Ten respondents identified portable asset tracking and management RFID applications as currently the most actively deployed type of RFID technology in the healthcare setting. They attributed this to the multiple “hard savings” (staff time, and equipment capital and maintenance cost savings) that can be realized through such systems (including high-end medical equipment, device tracking, and “smart shelf” medical cabinets). This group of RFID applications, however, was seen as having a substantially smaller propensity than patient- and staff-centered applications to directly affect the quality of care.

Expressed opinions on RFID-based asset tracking and management solutions can be subjectively summarized as follows:

- Of current and near-term market-ready healthcare RFID, RFID-based asset tracking and management solutions are likely to have the most substantial effect on reducing the cost of inpatient care delivery (stated by 10 respondents).
RFID-based asset tracking and management solutions are the most established type of RFID application and are currently entering mainstream diffusion (stated by 13 respondents).

In the absence of quality improving and assuring processes with respect to assets in a given healthcare delivery facility, RFID-based asset tracking and management solutions can also lead to substantial gains in care safety and timeliness (stated by 7 respondents).

Along with maintenance of medical equipment, RFID-based portable asset tracking is a main tool for improving care delivery efficiency and containing capital outlay and recurring costs associated with clinical care auxiliary services (stated by 9 respondents).

If an RFID-based asset tracking and management solution is integrated with other administrative, billing, or clinical (e.g., portable telemetry) systems, its quality-of-care benefits would be much more substantial and may rival the efficiency gains it brings (stated by 4 respondents).

While RFID-based asset tracking and management solutions do produce substantial (unquantified) staff time savings, they do not result in staff size reduction, only in a drop in staff overtime (and thus labor savings) (stated by 8 respondents).

Although initial staff training time is not a substantial cost component, the preparatory steps needed to tailor a commercial RFID application to the functionality needs of the local users can last several months (stated by 11 respondents).

2.2.2.B Hospital emergency department and operating floor process support and workflow management RFID applications

ED and OF RFID solutions integrating patient management and logistics, asset management, and workflow monitoring capacity were pinpointed by ten experts as the application classes expected to have the largest potential impact on cost-efficiency and quality simultaneously in the short term.

EDs and OFs are the busiest and two of the most complex hospital environments. To provide real-time visibility into the multiple processes and workflows that take place in these two environments (e.g., patient triage, treatment, and discharge or hospital admission in the ER; pre-operative, intra-operative, and post-operative care of multiple scheduled and unscheduled patients on the OF), experts perceived the value of advanced-functionality RFID applications as their ability to provide means to:

- analyze patient flow (from one care milestone and treatment team to another)
- anticipate downstream staff and physical space demand (e.g., from ED to MF, or from surgery to ICU)
- monitor and alert to patient progress along clinical pathway
- adjust in real time to changing circumstances.

Thus, ED and OF process support and workflow management applications were defined as "enabling" care delivery organizations to analyze and identify problematic patterns of activity, timing and efficiency of processes, and patient throughput to a greater degree than is currently available through exiting bed management or triage/surgery schedule boards.

Expressed opinions on these classes of healthcare RFID can be subjectively summarized as follows:
• OF and ED applications that go hand-in-hand with process re-engineering should be prioritized by hospital management because they improve the money-making units of a hospital and are settings in which improved visibility and process organization can result in substantial benefits, including cost and foregone income reductions (stated by 13 respondents).

• The workflow optimization arising from the visibility provided by these applications would include capacity for:
  o efficiency review at the physician level (e.g., for physician reimbursement and annual bonuses) (identified by 6 respondents)
  o efficiency review and improvement at the department level (e.g., monitoring time to medicine administration, time to triage; these can also be traced to downstream issues for the entire hospital) (identified by 10 respondents)
  o educational review and improvement (e.g., analyzing interactions between attending physicians and residents, and education/care outcomes) (identified by 5 respondents)
  o department clinical and management research (identified by 12 respondents).

• True return on investment on “soft indicators” (e.g., care safety, timeliness, and patient-centeredness) for ED/OF RFID applications can come only after patient and staff tracing is implemented on top of asset management solutions (stated by 7 respondents).

• RFID’s operational purpose range and capacity are such that if cost-efficiency improvements in a given healthcare facility are targeted, stimulating RFID applications that have the most substantial effect on hospital-level profitability should be prioritized — namely, OF and ED solutions that include asset and patient identification/management components (stated by 10 respondents).

• These classes of RFID are nearly market ready (likely to be scalable in five to seven years) (stated by 3 respondents); these classes of RFID are currently market ready and likely to reach wider dissemination in the next three years (stated by 8 respondents).

2.2.2.C Hospital medical floor and bedside medication management RFID applications

Patient identification and medication administration supporting systems that automate segments of the medication administration process (most notably patient bedside medication preparation and administration) are the fourth group of RFID solutions that an overwhelming majority of experts highlighted as both promising in their capacity to improve the quality and cost of healthcare delivery and capable of being market ready in the next two to four years.

Expressed opinions can be subjectively summarized as follows:

• RFID applications that combine patient identification — to prevent wrong drug/dosage/time/procedure and to ensure physical safety — with automatic event/process tracking are the tool for improving care safety and overall quality (stated by 8 respondents).

• RFID applications to eliminate wrong patient/wrong surgery procedure, to avoid medication errors, and to track drugs, supplies, and procedures performed on each patient are critical avenues for creating bottom-line cost differentials in the hospital environment (stated by 9 respondents).
RFID applications focused on preventing surgical and medication errors are a key tool through which departments and overall organizations can realize the most-substantial cost and foregone income reductions and can improve quality (stated by 7 respondents).

If improvements in quality of patient health are sought, then RFID applications occurring much closer to the patient and creating patient-centered care need to be prioritized. Being able to capture what medication or food a patient consumes, and how this compares to what the patient’s recommended regimen is, would be a great quality-of-care improvement (stated by 6 respondents).

“Human factor” problems affecting other HIT (such as workarounds in barcode-based medication administration) cannot be automatically solved by RFID technology. This can happen only via process redesign during the preparatory stage of implementation and staff education/incentivizing (stated by 9 respondents).

Quality-improving applications tracing the medications and procedures used on a patient are currently market ready and scalable in the short term (stated by 3 respondents).

2.2.2.D Other promising applications

Interviewees indicated that the remaining types of RFID that I documented can be assigned to two other categories, based on their capacity to support process redesign and their market readiness:

- RFID applications that are currently market ready but have a more-modest positive impact on the quality and/or cost of healthcare delivery
- RFID applications that can significantly improve care delivery but are not market ready yet.

To the first group, respondents assigned a range of currently commercially available RFID applications designed to support process automation, as opposed to process redesign, which experts associated with more-modest improvements in the cost and quality of healthcare delivery. Some of the specific applications that interviewees included in this category were inpatient RFID for biological sample identification and blood product temperature monitoring, stand-alone surgical gauge identification systems (aimed to prevent gauges from accidentally being left in), and stand-alone patient identification systems.63

In the second group — promising but not yet market-ready RFID applications — experts included the majority of outpatient RFID applications, as well as those designed to enhance the clinical quality (or efficacy) of care. These were regarded as having great potential to enhance the safety, patient-centeredness, and cost-efficiency of care, but likely to be market ready only in the medium to long term (10+ years). Specific applications respondents put in this category included patient-home-focused medication-regimen monitoring solutions, medical records carrying

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63 Experts also emphasized the importance of distinguishing between active and passive healthcare RFID solutions, explaining that the two types of RFID technology have very different infrastructure, capabilities, appropriate uses, and, most likely, futures. Probing further revealed that this distinction can be attributed to the current existence of at least two definable generations of healthcare RFID: an early one, which has a more limited silos-centered focus of use; and a later one, characterized by enhanced application functionalities and cross-operability with other clinical and non-clinical IT applications supporting process reorganization in healthcare. Passive-only RFID applications tended to dominate the first wave, whereas more back-end, sophisticated active or mixed active-passive RFID applications have dominated the second. Both were perceived as having a role to play in improving care within specific organizational environments, but the expected net benefits associated with the wider adoption of the second wave of RFID solutions were exponentially larger, even if at present unquantified.
implanted RFID, and RFID geared to improve the effectiveness of care — ingested/implanted to provide real-time information on patient health. Two respondents added to this list RFID systems integrated in open-loop (cross-facility) applications.

2.2.3 Expert feedback on key problems currently affecting healthcare RFID

In addition to deriving a priority list of promising healthcare RFID applications — i.e., those likely to have a sizable positive impact on the quality and cost of healthcare delivery over the next five to ten years — I used the 15 semi-structured expert interviews to explore:

- the importance that different stakeholder groups assigned to the privacy and signal interference concerns voiced in select literature sources (see Section 2.1.3)
- beliefs regarding any other key problems that may be affecting RFID’s potential in healthcare.

For this analysis, the responses from the open-ended questions were screened for themes, view ranges, and knowledge content. The results are presented below.

Is use of RFID in healthcare undesirable? Feedback to privacy and signal interference concerns expressed in literature

As indicated in Section 2.1.3, a handful of information sources expressed moderate to extreme caution against the use of RFID technology in healthcare. These concerns were motivated by:

- the surveillance threat and potential privacy intrusion associated with healthcare RFID
- the lack of RFID industry standards ensuring RFID’s non-interference with other clinical systems or biomedical implants.

Asked to identify any aspects in healthcare in which the use of RFID technology can be considered undesirable, interviewees uniformly responded that there were none.

Asked specifically about the privacy intrusion fear of RFID use in healthcare that was reported in the literature, 14 of the 15 interviewees characterized it as “unrealistic due to the strict regulation of patient data privacy and protection, and the physical laws affecting RFID (e.g., lack of endless reading range).” All interviewees further emphasized that the “Big Brother” analogy made in the literature highlights the lack of public understanding about the feasible risks and challenges associated with healthcare RFID. For example, three respondents expressed concerns regarding the use of RFID technology for patient identification in open-loop (multi-hospital/multi-stakeholder user) systems, due to “the lack of well-established privacy and security mechanisms for such data exchanges,” a problem affecting electronic health records as well. Finally, regardless of their being unrealistic, perceptions of potential privacy intrusion were highlighted by nearly all respondents as a barrier that RFID developers and adopters will need to overcome. For instance:

- Six respondents singled out implanted RFID carrying the patient’s medical record as likely to meet substantial adoption resistance, despite the great benefits that can be reaped through such technology.64

64 Benefits were seen as increased speed and safety of care; suggested examples included non-responsive patients arriving at EDs, Department of Defense personnel on active duty, and patients with diminished capacity in need of urgent care. The intrusiveness of the technology, privacy fears, and signal protection were most frequently cited as reasons for rejection.
Four interviewees shared a general expectation that although the application of RFID to care provider or patient tracing is not undesirable, it is likely to face significant initial obstacles due to fears of privacy intrusion (with staff unions and patient organizations potentially objecting to such use of RFID, as one respondent explained).

On the subject of the potential RFID signal interference with other clinical and non-clinical HIT that arises from a lack of standardization of healthcare RFID technology, 14 of the 15 respondents did not consider it a true problem. As one respondent stated, “Technological industries self-standardize as technologies mature, and this is already underway for healthcare RFID.” Finally, while stating his belief that the healthcare RFID cluster of technologies does not pose a signal interference threat, one respondent emphasized the need for federal regulators to consider RFID and other wireless HIT regulation in the context of potential wireless band depletion given the exponential growth of WiFi-based HIT solutions.

The paucity of empirical data on healthcare RFID benefits and costs, and the need for evaluation tools

In discussing potential obstacles to RFID’s use and further diffusion in healthcare, all 15 interviewees stressed that “the paucity of empirical data on the actual vs. expected care benefits and costs of healthcare RFID” is a significant problem that will need to be overcome as the technology diffuses. As one respondent stated, “There is immense lack of comparable and comprehensive in-depth case study data on RFID application adoptions proving their cost-effective replicability.”

Fourteen respondents saw “the lack of a coherent evaluation approach (that is, a system of consistently used cost and benefit constructs, variables and measures) which can be used to comprehensively assess the costs and benefits associated with implementing different complex healthcare RFID solutions in healthcare delivery organizations” as a critical factor contributing to this problem. (This problem was also confirmed in the literature review.)

Two factors were highlighted (by 8 interviewees) as reasons for the non-existence of evaluation tools for healthcare RFID users and evaluators:

- the rapid development of healthcare RFID resulted in an over-abundance of industry-sponsored studies reporting primarily anecdotal information (a fact documented in Section 2.1.3).
- the relative youth of the technology has left it outside the attention horizon of the research community.

Furthermore, 10 respondents pointed out that the lack of “apt evaluation tools to guide data collection efforts” has resulted in additional challenges likely to affect RFID’s diffusion in healthcare:

- limited visibility of best practices in healthcare RFID (understood as widely disseminated evidence on RFID application impacts through the different life stages of the application)
- fragmented knowledge about RFID’s added value in specific healthcare processes (i.e., lack of clarity on how the implementation of healthcare RFID leads to certain benefits, and what the associated costs are).

For these reasons, the interviewees believed that the first step to assessing the merit for public or private investment in healthcare RFID should be to address the dearth of evaluation tools.

The experts’ responses also revealed a public-good conflict between the significant organizational cost of evaluating deployed RFID applications and the gains that, through the availability of more-comprehensive data on the full-scale impacts associated with adopting RFID
solutions, can be reaped by technology vendors seeking to proliferate their products and by healthcare organizations seeking to improve the cost-efficiency or/and quality of the care they provide (since only a handful of innovation-adoption forerunners presently seem to be benefiting from this technology). Four interviewees believed this problem should be addressed by establishing healthcare RFID as one of the technologies eligible for federal funding under proof-of-concept and continuous quality improvement initiatives.

2.3 **Summary of key findings and implications**

Combined, the structured review of the 436 peer-reviewed and grey sources on RFID’s uses and impacts in healthcare, and the 15 semi-structured key healthcare RFID expert interviews represent:

- a unique literature-based snapshot of the universe of RFID uses in healthcare (as of April 2009)
- a unique attempt at distinguishing those RFID applications that are currently market ready from those that are likely to be scalable in the medium to long term only
- a unique attempt at identifying which applications are both expected to have substantial impact on the quality and/or cost of healthcare delivery and are near-term market ready (hence, worth more-extensive evaluation).

The key findings of the analysis can be summarized as follows:

1. The literature review showed that as of April 2009, the universe of healthcare RFID applications was expansive and included RFID solutions tailored to support the delivery of care in both the inpatient and the outpatient settings.

2. The review further showed that although presently limited, the available quantitative data on the benefits of healthcare RFID applications suggest that:
   - a number of healthcare institutions have successfully leveraged RFID to improve the quality of care they provide and to reduce the costs they accrue in its delivery
   - healthcare RFID applications have the capacity to enhance, among others, the timeliness, patient-centeredness, safety, and cost-efficiency of care.

3. High-quality empirical data on the quality and cost of healthcare RFID applications are scarce: less than 6% of all the identified sources (27 out of 436) contained some information on both the costs and outcomes of a selected RFID application, and less than 1% (4 out of 436) provided more-detailed empirical cost, outcome, and implementation process data to verify the attributiveness of the reported net benefits.

4. Interviews with experts representing key stakeholder groups identified in the literature were used to derive a priority list of “promising” healthcare RFID applications likely to have a sizable positive impact on the quality (i.e., safety, timeliness, continuity, effectiveness) and the cost (i.e., staff time/resource efficiency, cost-efficiency) of healthcare delivery over the next five to ten years.

5. The four healthcare RFID applications that the experts highlighted as leading in their capacity to improve the quality and/or reduce the cost of healthcare delivery in the U.S. over the next five to ten years were:
   - Real-time portable hospital asset tracking and management solutions
   - Hospital ED process support and workflow management solutions
o Hospital OF process support and workflow management solutions
o Hospital MF and medication management solutions.

- Expert interviews further showed that healthcare RFID does not pose a threat to patient privacy, so no policy action to ensure that privacy protection is preserved when healthcare RFID applications are implemented is necessary at this point in time. However, perceptions of healthcare RFID as a privacy threat, although unfounded, are likely to be an obstacle that RFID implementers will have to confront.

- Finally, experts highlighted a clear need for more-objective and independent evaluations of the real-life outcomes and costs associated with deploying RFID solutions in healthcare. Without such evaluations, it remains unclear how RFID benefits and costs vary across different types of organizations and how individual RFID success stories can be made replicable.

The first step to better understanding the potential of RFID in healthcare is, thus, to create evaluation tools through which the applications experts highlighted as most promising can be assessed and better understood, a task that Chapter 3 undertakes.
Chapter 2 showed that among RFID’s wide spectrum of uses in healthcare as of 2009, four application types stood out as promising, according to expert opinion, with respect to their capacity to positively affect the quality and cost-efficiency of healthcare delivery in the U.S. over the next five to ten years:

- Real-time portable hospital asset tracking and management solutions
- Hospital Emergency Department (ED) process support and workflow management solutions
- Hospital Operating Floor (OF) process support and workflow management solutions
- Hospital Medical Floor (MF) and medication management solutions.

Yet Chapter 2 also highlighted the substantive and methodological limitations of the published empirical studies on RFID’s impacts, limitations that render our current understanding of RFID applications fragmented. The most notable of these are:

- the lack of a critical amount of comparable evidence on the different RFID applications
- the general absence of an evaluation framework that coherently captures the full range of benefits and costs brought on by RFID applications in healthcare delivery
- the lack of a consistent use of parameters, measures, and, occasionally, constructs across existing evaluations of healthcare RFID applications.

Chapter 2 further captured experts’ agreement on the critical need to develop a coherent evaluation approach — i.e., a system of consistently used cost and benefit constructs, variables, and measures — that can be used to comprehensively assess the impacts of RFID applications. Once such an approach is developed, it will be possible to collect more-robust data on the benefits and costs of healthcare RFID and to evaluate the effects of this technology on U.S. healthcare quality and cost.

To address these critical obstacles to understanding the potential that healthcare RFID holds for improving healthcare delivery, in Section 3.1, I leverage the results of the literature review and expert interviews I conducted (see Chapter 2 for methodology) to define the range of organizational benefits and costs associated with each promising application type (and their variability given the degree of the applications’ sophistication). These are summarized in cost and benefit frameworks. Identifying how specific benefits are related to the operational purposes that an RFID solution is capable of supporting, I hence address one of the substantive gaps left unanswered in the current literature: How does RFID create value?
In Section 3.2, I describe how I built on the results of Section 3.1 and current HIT evaluation practices to develop cost-benefit evaluation tools (evaluation structures) tailored to each of the four RFID applications that the experts highlighted as promising. Ready-to-use, and without a present alternative, the four structures provide healthcare RFID adopters, sponsors, and independent evaluators with a set of constructs, variables, and measures that can be used to systematically assess the impacts of RFID applications on the quality and cost-efficiency of the processes they are expected to improve. Each of these evaluation tools is also intended to support the further collection of more-robust evidence on RFID’s potential in healthcare. Implemented on a larger scale, the structures can support the meaningful comparison of RFID applications of different kinds and sophistication, as they are based on the same evaluation approach and use a common set of metrics.

Because each of the four promising healthcare RFID applications supports inpatient healthcare delivery at the hospital or department level, I developed both the cost and benefit frameworks (Section 3.1) and the cost-benefit evaluation structures (Section 3.2) from the point of view of the care delivery organization, or hospital. In other words, I address the questions: What benefits and costs do hospitals experience when they adopt a specific RFID application type? How can these be systematically assessed? I chose this analytic perspective because none of the assessed RFID application types is meant to be owned or operated by a single healthcare provider, and none of their costs and benefits accrues directly to a single care-providing agent.

3.1 **Identifying promising RFID’s range of impacts on healthcare quality and cost-efficiency: benefits and costs**

3.1.1 **Methodology used to establish promising RFID’s benefits and costs**

This section summarizes the methodology and analytic approach I used to capture the range of organizational benefits and costs associated with each of the four RFID application types that were singled out by the experts as promising — i.e., most likely to improve the quality and reduce the cost of healthcare delivery in the U.S. over the next five to ten years.

The RFID taxonomy I proposed and used in Chapter 2 to document the universe of RFID uses in healthcare (see Section 2.1.1) addressed the confusion affecting a large share of the peer-reviewed and grey-source literature on healthcare RFID as to what is the distinction between healthcare RFID’s baseline engineering tasks, operational purposes, and overarching goals. It did not, however, define how specific RFID systems function. More importantly, it left open the question of how differences in the engineering and operational functions of specific healthcare RFID applications affect the benefits and the costs of those applications.

A first step to understanding the potential of RFID in healthcare thus entails defining what a “portable asset tracing and management” or an “ED process and workflow” solution is (i.e., what it does) and what costs their implementation brings about.

To define the benefits and costs that healthcare delivery organizations experience when they adopt a promising RFID application (and how these vary given the degree of an application’s sophistication, otherwise understood as the range of operational purposes that an application serves), as well as to understand how RFID creates value, I conducted a secondary content-and-frequency analysis of the literature review and expert interview data I used to document the range and impacts of RFID use in healthcare (Section 2.1) and to rank-order identified applications in

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65 The case of the not-for-profit care delivery organization is not explicitly considered, since the single critical difference this perspective shift would impose is the relative weight placed on the total net cost or net benefit of the system — an issue relative to the conclusions drawn from the analysis, not to the framework used to conduct it.
terms of their impacts on care delivery cost and quality and their market readiness (Section 2.2). This secondary analysis comprised the following steps:

- First, abstract the cost and benefit variables, cost and benefit groups in which these variables were placed (the cost and benefit constructs), and measures that studies reporting measurement information used when assessing each of the four promising application types (these data were abstracted from the evidence table originally created for the RFID impact analysis described in Chapter 266) and:
  - draft a table listing the cost and benefit variables that peer-reviewed and grey-source literature used for each promising RFID application type, and record how frequently a variable was used across studies
  - similarly, derive a frequency table of the constructs that studies associated with these variables
  - identify the cost components and benefit recipients that sources associated with each cost and benefit variable, respectively, as well as the operational purposes that they associated with each benefit.

- Next, use keyword-density and prominence-of-expression analyses to screen the expert interview responses on:
  - currently outstanding care quality and cost-efficiency issues that RFID solves — both in theory and from their own personal experience with HIT and healthcare RFID solutions
  - important areas for RFID application in healthcare delivery, and how RFID can make a difference in them
  - main drivers of demand for healthcare RFID
to identify the cost and benefit constructs, variables, and measures that the interviewees referred to when discussing the four RFID application types they highlighted as promising and to determine whether any of these were repeatedly mentioned by more than one interviewee.

- Finally, combine the literature-derived and interview-derived tables on the cost and benefit metrics of interest, and the operational purposes with which these are associated, to:
  - determine which constructs, variables, and measures were most frequently used for each of the four promising RFID types across information sources — i.e., which metrics can be regarded as having higher validity
  - establish the range of organizational benefits and costs associated with each of the four promising RFID applications
  - identify how the benefits and costs of each application type vary according to the application’s level of sophistication (i.e., the spectrum of operational purposes it is capable of supporting).

The literature sample drawn on for this analysis was a reduced 39-study evidence table that identified:

- RFID application reviewed

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66 The evidence table is in Appendix 3. It summarizes the 45 studies that, as a minimum, reported information on the measures they used.
• author of the study, when the study was published, and whether the study appeared in a peer-reviewed or grey-literature source

• country of origin

• implementation setting in which the application was used and evaluated (e.g., a 300-bed hospital covering 500,000 ft²)

• type of study (e.g., pre/post pilot evaluation, proof of concept)

• measures used (e.g., percentage change in share of rented portable assets that the biomedical engineering department cannot locate to be returned at the end of the lease period)

• when the data were collected

• outcomes the study reported.

Of these 39 studies:

• Fourteen discussed portable asset tracking and management solutions

• Nine focused on ED workflow management solutions

• Eight assessed OF and OR workflow management solutions

• Eight evaluated RFID medication management solutions (hospital wide, n=4; at patient’s bedside only, n=4).

Overall, five studies provided cost data only, 23 provided benefit data only, and 11 provided both cost and benefit data. Of all the information sources, 97% evaluated RFID applications in the U.S. All 15 expert interviews were included in the analysis.

3.1.2 The costs of advanced inpatient RFID applications

Based on this secondary analysis of the literature sources and expert interviews, two aggregate cost constructs were identified as relevant for all promising inpatient near-term and currently market-ready healthcare RFID applications: direct application costs and induced costs.

Direct application costs include one-time and ongoing financial and non-financial costs associated with the purchase, implementation, and maintenance of an RFID system. Induced costs are those involved in the transition from the pre-RFID to the post-RFID process structure, such as those associated with a temporary decrease in end-user (e.g., care provider) productivity.

Hence, a common cost framework for the four promising RFID application types can be developed. Such is presented in Table 27, which summarizes the types of costs incurred by healthcare delivery organizations when adopting any of the four application types.

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67 This distinction is also identified with respect to EMRs, as discussed by Wang et al. (2003).

68 These largely overlap with the costs associated with other HIT solutions.
Table 27: Promising RFID's organizational costs identified in the literature sample and expert interviews

<table>
<thead>
<tr>
<th>Cost constructs</th>
<th>Cost variables</th>
<th>Cost variable components</th>
<th>Peer-reviewed studies (n=6)</th>
<th>Grey-literature studies (n=10)</th>
<th>Interview respondents (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct application costs</td>
<td>Software cost</td>
<td>software</td>
<td>6</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>middleware</td>
<td>3</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Hardware cost</td>
<td>tags</td>
<td>6</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>readers</td>
<td>6</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wiring</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>server(s)</td>
<td>2</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Implementation cost</td>
<td>application tailoring*</td>
<td>3</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>installation cost</td>
<td>1</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>process redesign cost*</td>
<td>5</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Training cost</td>
<td>initial training</td>
<td>4</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>booster sessions*</td>
<td>2</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Maintenance cost</td>
<td>staff time for repair*</td>
<td>1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hardware</td>
<td>1</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>help line*</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Software annual lease</td>
<td>-</td>
<td>3</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Induced application costs</td>
<td>Temporary productivity loss [end-users]</td>
<td>-</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

* Sources described application tailoring cost as the cost associated with the need to tailor the RFID application to the specific needs of the adopting organization, typically the staff; process redesign cost as what an organization incurs (typically in the form of high-ranking staff’s time) to conduct baseline process mapping and process re-design to ensure the effective introduction of an application into existing organizational practices; booster sessions cost as the cost of staff training intended to re-familiarize staff with the application and to introduce newly hired staff to it; staff time for repair cost as that associated with the maintenance of RFID applications; help line cost as the cost of staff time that the department designated as application owner within the facility spends to help other end-users in the organization navigate the application.

Due to the inconsistent use of parameters across studies, and the small size of the literature sample, the expert responses were instrumental for establishing the uniformity of cost constructs, variables, and variable components across the four promising RFID types.

Expert interviews also played a role in verifying the reliability of the documented spectrum of costs. For example, some of the cost variable components in Table 1 (middleware, installation...
cost, process redesign cost, staff time for repair) and one cost variable (software annual lease) were seldom discussed in grey sources but were frequently referenced by the experts.\textsuperscript{69}

Finally, it is interesting to note that both the sources and the experts tended to lump “software cost” and “hardware cost” in a single cost category, initial application cost. I left this category out of the table to preserve the same level of detail across all cost variables. No variability in the costs associated with implementing a promising RFID application based on application sophistication (i.e., differences in the range of applications’ operational purposes) was identified.

Compared to the range of organizational costs described in Table 27, currently existing evaluations of the cost of RFID systems typically include only the initial application cost and the annual software lease of the system. The key reason why this produces a skewed picture is that system design can be critical to the success of the RFID application’s implementation. As such, system design is associated with the staff time needed to determine the functional requirements that the application should meet, which is also likely to be more than a one-time event. In addition, due to their complex, back-office nature, RFID systems require ongoing maintenance and support. Recurring staff training and re-training are a cost that RFID shares with other HIT systems, and to the extent that most inpatient facilities are tightly staffed and consider staff time as one of their key operational expenditures, any system-related impacts on staff availability and productive time use should be considered. These reasons also are what motivates technology adopters’ interest in understanding the induced costs of implementing any technology.

\subsection{The benefits of advanced inpatient RFID applications}

In contrast with the lack of correlation between applications’ costs and the functions they perform, I found a clear difference in the benefits delivered by promising RFID application types of different sophistication levels. Specifically, the expert interview analysis suggested that several different “subtypes” of applications can be distinguished within each of the four promising application classes — solutions that perform comparable functions but, due to differences in their range of operational purposes, produce different benefits. Such variability in same-class systems is also documented in the literature, but there has been no attempt to organize applications according to their operational purpose range (and resulting benefits). Due to the inconsistent use of parameters across studies and the small size of the literature sample, the expert responses were instrumental for establishing the validity of the applications’ benefit range (as they were for the applications’ costs) that emerged from the literature.

The next four subsections (3.1.3.A through 3.1.3.D) sequentially present my analytic results on the range of benefits experienced by healthcare delivery organizations when they adopted each of the four types of promising healthcare RFID. These results are summarized in four separate benefit frameworks, which identify how the operational purposes of each application type are related to the benefits that are elicited. The frameworks also highlight which key stakeholder in a typical hospital is the benefit’s key recipient. To my best knowledge, no such benefit and system mapping has been previously advanced. These assumptions are tested in the case studies of actual RFID system implementations discussed in Chapter 4.

I illustrate how I derived the integrated benefit frameworks in the first subsection, which presents the results on the benefit range of portable asset management RFID applications. The following three subsections then discuss the ED, OF, and MF workflow management applications. Finally,

\textsuperscript{69} This is not to say that the literature sources did not also contribute to the comprehensiveness of the analysis. For example, “temporary productivity loss” was identified as an organizational cost component by only a few experts, but was discussed in two out of six peer-reviewed sources, as well as in three grey sources.
in Section 3.1.3.E, I outline the range of quality and cost issues that advanced RFID applications can be used to address.

### 3.1.3.A Advanced RFID portable asset management applications: benefits range

To identify the organizational benefits that portable asset management applications carry, I first determined the benefit constructs, variables, and impacts that the information sources and interview respondents associated with portable asset management RFID applications, along with the number of sources that referenced each of the identified parameters of interest. This information is summarized in Table 28, which shows the organizational benefits that the peer-reviewed sources, grey-literature sources, and expert respondents identified as originating from the implementation of portable asset management applications. Table 2 also gives the hospital units (i.e., stakeholders) that were identified as the recipients of the benefits.

**Table 28: Identifying the benefits associated with portable asset management RFID applications based on literature review results**

<table>
<thead>
<tr>
<th>Benefit constructs</th>
<th>Reported benefits</th>
<th>Reported beneficiaries</th>
<th>Peer-reviewed studies (n=4)</th>
<th>Grey-literature studies (n=10)</th>
<th>Interview respondents (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital outlay reduction</td>
<td>Reduction of accidental asset loss avoidance/theft</td>
<td>Biomedical engineering department (Biomed)</td>
<td>1</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Capital outlay reduction</td>
<td>Reduction in share of portable assets (out of total fleet) that are not actively used</td>
<td>Management</td>
<td>4</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Capital outlay reduction</td>
<td>Ability to repeatedly carry out preventive maintenance, prolonging assets’ useful life</td>
<td>Environmental services department (ES)</td>
<td>1</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Non-labor operating cost reduction</td>
<td>Faster asset location for servicing, annual preventive maintenance, or recall</td>
<td>Biomed</td>
<td>4</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Patient safety; Non-labor operating cost reduction</td>
<td>Better regulatory compliance due to ability to repeatedly carry out preventive maintenance of full asset fleet</td>
<td>Biomed</td>
<td>3</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Patient safety</td>
<td>Ability to identify assets used on infectious patients, reducing the spread of contagious and hospital-acquired infections</td>
<td>All departments; patients</td>
<td>0</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Benefit constructs</td>
<td>Reported benefits</td>
<td>Reported beneficiaries</td>
<td>Peer-reviewed studies (n=4)</td>
<td>Grey-literature studies (n=10)</td>
<td>Interview respondents (n=15)</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>-----------------------------</td>
<td>-------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Patient-centered care</td>
<td>Reduced patient waiting time at point of care (through reduced asset search time)</td>
<td>Patients</td>
<td>0</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Increase of productive staff time; Care coordination improvement</td>
<td>Drop in time needed to respond to a nurse call for patient transport within hospital</td>
<td>ES</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Increase of productive staff time</td>
<td>Ready-for-use assets easy to locate when needed for patient care</td>
<td>Nursing</td>
<td>3</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Increase of productive staff time</td>
<td>Reduction in staff time spent on search rounds across facility for asset servicing, preventive maintenance, recall</td>
<td>Biomed</td>
<td>2</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Increase of productive staff time</td>
<td>Reduction in staff time spent looking for assets in routine roundup and monthly inventory</td>
<td>ES</td>
<td>3</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Increase of productive staff time</td>
<td>Reduction in number and duration of routine search rounds across facility to collect used assets for sterilization</td>
<td>Central sterile department (CSD)</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Next, I recorded the specific operational purposes with which each identified benefit was associated in each information source and interviewee’s response. Given the relative weight that interview data played in the analysis, to increase the reliability of these results, I cross-referenced interviewees’ responses on the following two interview questions:

- Are there important areas for RFID applications in healthcare, and if so — what are they?
- Can RFID applications address any of the outstanding quality or cost-efficiency issues in healthcare, and how exactly do these applications achieve this?

Table 29 presents the results of this analysis, listing the operational purpose (i.e., function) that generates each of the identified benefits according to the different sources.
Table 29: Establishing a link between the benefits of portable asset management RFID applications and the operational purposes from which those benefits arise based on literature review results and expert opinion

<table>
<thead>
<tr>
<th>Application's operational purpose</th>
<th>Reported benefits</th>
<th>Peer-reviewed studies (n=4)</th>
<th>Grey-literature studies (n=10)</th>
<th>Interview respondents (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detect asset transition through chokepoints</td>
<td>Reduction of accidental asset loss avoidance/theft</td>
<td>1</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Identify asset location continuously (zonal)</td>
<td>Faster asset location for servicing, annual preventive maintenance, or recall (utility loss due to lack of information on status)</td>
<td>4</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Faster asset location for immediate use (utility loss due to lack of info on status; can lead to repeated hoarding)</td>
<td>2</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Drop in time needed to respond to a nurse call for patient transport within hospital</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Identification of assets used on infectious patients, reducing the spread of contagious and hospital-acquired infections and improving safety of patient care</td>
<td>0</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Register asset status</td>
<td>Capital outlay and operation costs reductions through better understanding of asset utilization patterns and facility needs</td>
<td>4</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Substantial staff time reduction in search rounds across facility for asset servicing, annual preventive maintenance, or recall</td>
<td>2</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Ability to repeatedly carry out preventive maintenance of full asset fleet, hence improving regulatory compliance</td>
<td>3</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Ready-for-use assets easy to locate when needed (reducing nurses’ unproductive time)</td>
<td>3</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Substantial reduction in staff time spent looking for assets in routine roundup and monthly inventory</td>
<td>3</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Ability to repeatedly carry out preventive maintenance, thus prolonging assets’ useful life</td>
<td>1</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Reduction of patient waiting time at point of care (through reduced asset search time)</td>
<td>0</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Reduction in number and duration of routine search rounds across facility to collect used assets for sterilization</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Finally, I used interviewees’ responses on three open-ended questions to establish how portable asset application systems can be categorized in terms of their level of sophistication based on the range of operational purposes they perform (see Table 30).

### Table 30: Identifying the variability in portable asset management RFID applications’ sophistication based on expert opinion

<table>
<thead>
<tr>
<th>Portable asset management RFID applications’ operational purposes</th>
<th>Expert responses (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>A “basic” RFID ED management application:</td>
<td></td>
</tr>
<tr>
<td>Detects asset transition through chokepoints</td>
<td>14</td>
</tr>
<tr>
<td>An “advanced” RFID ED management application:</td>
<td></td>
</tr>
<tr>
<td>Detects asset transition through chokepoints</td>
<td>14</td>
</tr>
<tr>
<td>Identifies asset location continuously (zonal)</td>
<td>14</td>
</tr>
<tr>
<td>A “comprehensive” RFID ED management application:</td>
<td></td>
</tr>
<tr>
<td>Detects asset transition through chokepoints</td>
<td>14</td>
</tr>
<tr>
<td>Identifies asset location continuously (zonal)</td>
<td>14</td>
</tr>
<tr>
<td>Registers asset status</td>
<td>14</td>
</tr>
</tbody>
</table>

The flow chart below summarizes how the information presented in the three preceding tables was used in the remaining parts of the analysis.
In this manner, I arrived at an integrated benefit framework for portable asset management applications (see Table 31) that maps the range of benefits arising from RFID applications designed to support the location and management of mobile assets in the inpatient environment. The framework associates each benefit with the system’s operational purpose from which it arises (based on information derived form the literature review and expert interviews). It thus links the range of documented asset management RFID system benefits to the three levels of application sophistication described by the interviewed experts as basic, advanced, and comprehensive, reflecting the number of operational functions a system is capable of performing. Table 5 also identifies which benefits are primarily associated with which key stakeholders (unit, professional group, etc.) in a typical hospital.

Table 31 (and Tables 32 through 34, which present the benefit frameworks for ED, OF, and MF RFID workflow management applications) is best read using the color-coded key on its right side, which indicates whether a specific operational purpose — and the benefit(s) associated with it — is typical of only a basic, an advanced, or a comprehensive (abbreviated as “comp.”) system. As structured, the tables can also be read as color-coded inverted pyramids in which more-advanced operational purposes build and expand on the more basic ones.

---

70 Expert interview respondents were asked to explain how the benefits they ascribed to specific healthcare RFID applications arise. In doing so, they frequently referred to a “basic,” an “advanced,” and a “comprehensive” system’s functions, encompassing specific engineering functionalities. The overlap in expressed opinions regarding the link between certain engineering functions and certain benefits and the attribution of types of engineering functions to different levels of system sophistication created the basis for the benefit evaluation frameworks presented here.
Table 31: Benefits of RFID mobile asset management applications that are dependent on system sophistication

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Advanced” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detect asset transition through chokepoints</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less accidental asset loss/theft</td>
<td>Biomedical engineering department (Biomed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify asset location continuously (zonal)</td>
<td>Biomed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faster asset location for servicing, annual preventive maintenance, or recall (utility loss due to lack of information on status)</td>
<td>Nursing; Environmental services (ES)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faster asset location for immediate use (utility loss due to lack of info on status; can lead to repeated hoarding)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drop in time needed to respond to a nurse call for patient transport within hospital</td>
<td>ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification of assets used on infectious patients, reducing the spread of contagious and hospital-acquired infections and improving safety of patient care</td>
<td>All departments; Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Register asset status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in capital outlay and operation costs through better understanding of asset utilization patterns and facility needs</td>
<td>Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substantial staff time reduction in search rounds across facility for asset servicing, annual preventive maintenance, or recall</td>
<td>Biomed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to repeatedly carry out preventive maintenance of full asset fleet, hence improving regulatory compliance</td>
<td>Biomed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ready-to-use assets easy to locate when needed (reducing nurses’ unproductive time)</td>
<td>Nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substantial reduction in staff time spent looking for assets in routine roundup and monthly inventory</td>
<td>ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to repeatedly carry out preventive maintenance and infection control of full asset fleet, thus prolonging assets’ useful life</td>
<td>ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in patient waiting time at point of care (through reduced asset search time)</td>
<td>Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in number and duration of routine search rounds across facility to collect used assets for sterilization</td>
<td>Central sterile department (CSD)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Using the same analytic steps I used for the portable asset management applications (see Section 3.1.1 for the steps; see Section 3.1.3.A for the findings for the portable asset management applications, and the flow diagram for the analytical steps I used), I derived a benefit framework for the second of the three most-promising RFID types of applications: the ED process and workflow management applications. Table 32 shows how the applications’ level of sophistication (i.e., the variability in the operational purposes that they can support) relates to the range of benefits that can be achieved. Again, as with the other tables, key stakeholders who would be the recipients of these benefits in a typical hospital are noted, and the table is best read using the color-coded key on the right.

Table 32: Benefits of RFID ED process and workflow management applications that are dependent on system sophistication

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Advanced” system</th>
<th>“Comp. ” system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Register bed/room status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic identification of bed/room as occupied/free/for-cleaning, leading to improved room turnaround rate and faster patient throughput</td>
<td>ED; ES</td>
<td>Ed</td>
<td></td>
</tr>
<tr>
<td>Automatic identification of bed/room as occupied/free/for-cleaning, reducing staffs’ patient placement coordination burden</td>
<td>ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Detect patient location continuously (room-level)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous identification of patient whereabouts, saving staff time for patient location</td>
<td>ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous identification of patient whereabouts, reducing phone calls needed for location and thus creating a quieter environment</td>
<td>ED nursing and clinical staff; Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability for relatives to follow patient’s movement without having to request information from staff</td>
<td>Patients’ relatives; ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Identify patient status continuously (room-level)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display of patient’s status (e.g., infectious, at risk of falling, allergies) at room level, increasing ease of care coordination across providers and reducing latent patient safety threats</td>
<td>ED nursing and clinical staff; Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Integrate patient charts, lab, and radiology result notification</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced frequency of chart and result checks/pulls</td>
<td>ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ready availability of critical and updated information on each patient, enabling appropriate diagnostic and treatment plan</td>
<td>ED clinical staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved patient throughput, leading to reduced patient re-routing and walkouts</td>
<td>ED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved ease of care coordination and patient placement, leading to improved staff work satisfaction and reduced turnaround</td>
<td>ED</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Application operational purposes, Benefits, and Beneficiaries (cont.)

<table>
<thead>
<tr>
<th>Application</th>
<th>Benefits</th>
<th>“Basic” system</th>
<th>“Advanced” system</th>
<th>“Comp. ” system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Register asset location and status</td>
<td>Ease of location of ready-for-use assets when needed (reducing nurses’ unproductive time)</td>
<td>ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asset availability, combined with faster patient throughput and care coordination, leading to decreased patient waiting time and LOT</td>
<td>ED; Patients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detect care-provider location continuously (room-level)</td>
<td>Combination of patient and care-provider movement allows identification of bottlenecks and re-design of processes, leading to improved department performance</td>
<td>ED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process and event audit trail created by the high-granularity event data generated and analyzed</td>
<td>ED</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 3.1.3.C Advanced operating floor workflow and perioperative process management RFID applications: benefits range

Just as Tables 31 and 32 did for the first two types of applications, Table 33 illustrates the range of benefits that can be achieved with RFID OR and perioperative process and workflow management applications, how these benefits depend on the system’s degree of sophistication, and which key stakeholders in a typical hospital are the key recipients of specific benefits. Operational purposes that carry benefits at more than one level (e.g., to departmental nursing as time savings and to the department overall as audit trail creation) are identified at both levels.
<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Adv.” system</th>
<th>“Comp” system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detect pre- and post-operative bed/room availability</strong></td>
<td>OF nursing; ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic identification of occupied/free/for-cleaning rooms,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reducing staffs’ patient placement coordination burden and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>improving room readiness (reducing staff unproductive time)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Track large mobile assets used on OF and their status</strong></td>
<td>OF nursing; ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease in locating assets when needed for use or servicing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(reducing staff’s unproductive time)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positively (passively) identify patient at all stages of</strong></td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive identification of patient identity at any stage,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>decreasing risk of same-name patient mixup or wrong</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>patient/medication/procedure mistakes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive identification of each patient, allowing integration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of data from patient’s EMR, laboratory, and radiology results,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and making them readily available for patient preparation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Association of patient’s admission and pre-operative records</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and delivery of positive patient identification to avoid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wrong patient/wrong procedure/medication mistakes at pre-op</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>initiation stage and to avoid re-entering administrative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positively (actively) identify patient at all stages of</strong></td>
<td>OF nursing;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the peri-operative process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous identification of room-level patient location and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>communication of that location to staff and family in tablet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>format (reducing information requests burden on staff and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>saving staff time for patient location)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to feature a pre-, intra-, and post-operative stage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>team communication system that allows better patient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>throughput and easier communication</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positively (actively) detect staff at all stages of</strong></td>
<td>OF nursing;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the peri-operative process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creation of a real-time room-level virtual map of the OF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>identifying patient and staff location and status, and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>laboratory and radiology result notification for staff,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>improving ease of care coordination and patient throughput</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration of patient and staff identification, patient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>admission and OF records, EMR, and laboratory and radiology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>results establishes pre-operative OR team role-based</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>decision-support system, improving adherence to clinical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>guidelines and evidence-based medicine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface of active patient identification and staff</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tracking software with surgical schedule, nurse call, and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wireless telephony creates centralized workflow portal,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>eliminating need for manual status entries and inclusion in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>department schedules, improving patient care coordination,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>throughput, and safety, and staff work satisfaction</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>and clinical staff; Patients</td>
<td>and clinical</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>staff; OF</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>department;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application operational purposes, Benefits, and Beneficiaries (cont.)</td>
<td>“Basic” system</td>
<td>“Adv.” system</td>
<td>“Comp.” system</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Combination of information on patient vitals, pre-operative medications, tests, scans, and executed pre-operative checks creates permanent record of patient’s pre-operative experience that can be used as an error prevention and audit tool</td>
<td>OF nursing; OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capture of data from incoming patient vitals and pre-operative record can be used to detect OR procedure milestones (inferring higher-level events from basic data — e.g., anesthesia onset) and identify medically significant events, enabling better error prevention and creating a permanent record of the surgical process</td>
<td>OF nursing; OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Based on the above, establishment of a permanent record of patient’s pre-, intra-, and post-operative experience that can be used as a process improvement tool</td>
<td>OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Track location of small assets and inventory outside the OR suite</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to enable evidenced decontamination cycle of surgical trays</td>
<td>ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface of active patient and staff identification and equipment tracking software with surgical schedule, nurse call, and wireless telephony, improving care coordination and staff work satisfaction</td>
<td>OF nursing and clinical staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Track location of small assets and inventory within the OR suite</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of location of ready-for-use assets when needed</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to scan for accidental left-ins (sponges, tools) in addition to conducting post-surgical manual inventory counts</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Passively identify medications and high-value inventory on the OF</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to detect use of medications on each RFID-identified patient, confirming treatment plan compliance and issuing error prevention alarms</td>
<td>OF nursing; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to detect use of high-value inventory (e.g., stents) and medications on each patient at any stage of the care process for better cost capture and better stocking</td>
<td>OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Register haematological products status on the operating floor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous monitoring of products’ safekeeping conditions</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to match blood products to each RFID-identified patient at any stage of the care process, improving haemovigilance and patient safety</td>
<td>OF nursing; Patients</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.1.3.D Advanced medical floor and medication management RFID applications: benefits range

Table 34 presents the benefits framework for the MF and medication management applications. It illustrates how the variability in the sophistication of MF workflow and medication management applications relates to the range of benefits that can be achieved through them. As with the earlier, similar tables, it uses color coding for ease of reading and notes key stakeholders.

### Table 34: Benefits of RFID medical floor and medication management applications that are dependent on system sophistication

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Adv.” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detect patient location continuously (room-level)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous identification of patient whereabouts, saving staff time for patient location</td>
<td>MF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic identification of occupied/free/for-cleaning room status, leading to improved room turnaround rate and faster patient throughput</td>
<td>MF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Integrate patient charts, lab and radiology result notification</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display of patient’s status (e.g., infectious, at risk of falling, allergies) at room level, increasing ease of care coordination across providers and reducing latent patient safety threats</td>
<td>MF nursing and clinical staff; Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced frequency of chart and result checks/pulls</td>
<td>MF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Register asset location and status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of location of ready-for-use assets when needed (reducing staff’s unproductive time)</td>
<td>MF nursing; ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Identify care-provider</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secure, automatic nurse and clinician log-in (saving time and dis incentivizing/preventing workarounds)</td>
<td>MF nursing and clinical staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Identify patient (bed-level accuracy)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive identification of patient at any point, decreasing risk of same-name patient mix-up or wrong patient/medication/procedure mistakes</td>
<td>MF nursing; Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easier performance of 2-factor patient authentication — patient RFID scanned without line of sight, no label wrinkling, no 2-hand read requirement (speeding process, preventing workarounds, and reducing physical patient touches and disturbance)</td>
<td>MF nursing; Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Detect inventory/medication</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV bag identification — not possible with other auto ID (e.g., barcode) due to fluid content</td>
<td>MF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced motivation for workarounds in medication administration process (e.g., height of IV pole makes it difficult to read barcode, or having to multiple-scan</td>
<td>MF nursing; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved inventory management and re-stocking, critical for high-value short-life medication/inventory</td>
<td>MF nursing; MF department</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Application operational purposes, Benefits, and Beneficiaries (cont.)

<table>
<thead>
<tr>
<th>Link patient and care giver ID, EMR, and real-time data on administered medication</th>
<th>“Basic” system</th>
<th>“Adv.” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification and prevention of “Five Rights” violations in medication administration (right patient, right medication, right time, right dosage, right route), issuing STOP NOW signals prior to drug administration that cannot be overridden</td>
<td>MF nursing; patients; MF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatically creates previously nonexistent documentation on near-miss and adverse events, thus overriding the need for the introduction of stand-alone voluntary or mandatory medical error reporting systems</td>
<td>MF nursing; MF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seamless process and event data capture for better cost recording and reimbursement while reducing nurses’ administrative burden</td>
<td>MF nursing; MF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Readily available management reports, facilitating process improvement</td>
<td>MF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to enhance patient EMRs with care process information that can be captured with system: patient ID, caregiver ID, IV bag ID, lab specimen ID, blood transfusion ID, EMR with allergies information and advanced directive, dietary tray ID, device and implant ID, medications reconciliation</td>
<td>MF nursing and clinical staff; MF department</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 1.3.1.E Identify the range of quality and cost issues advanced RFID applications can be used to address

The above-described range of enterprise-level care benefits associated with advanced RFID applications suggests that promising healthcare RFID can be used to address outstanding issues both in the quality and in the cost-efficiency of care delivery (see Table 35). It also highlights the difference between the benefit spectrum of advanced healthcare RFID solutions and the benefits of other types of HIT (noted in Chapter 1).

Healthcare RFID has a direct, positive impact on the capital and operational (including non-labor) costs of healthcare delivery and directly affects patient throughput and revenue. It also supports continuous quality improvements with its functions of process and event management and audit trail creation. In contrast, the benefits of other HIT lie primarily in improving patient safety, making care more patient-centered, and reducing staff time spent on non-care-related tasks.\(^{71}\)

Finally, the four promising RFID application benefit frameworks presented above are a unique attempt to define what a portable asset management, ED, OF, and MF RFID process and workflow solution is.

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\(^{71}\) See Shekelle et al., 2007, and Hillestad et al., 2005, for detailed expositions on the benefits of HIT.
Table 35: The benefits of advanced inpatient RFID applications

<table>
<thead>
<tr>
<th>Benefit domain</th>
<th>Aspect of care RFID addresses</th>
<th>How promising RFID applications add value</th>
</tr>
</thead>
</table>
| Continuous quality improvement | - Creates audit trails for processes and events  
                             | - Provides “control dashboards” visualizing critical process and workflow information, thereby facilitating management and redesign  
                             | - Improves staff’s work satisfaction                                                                                                         |
| Patient-centered care                             | - Makes patient status continuously observable  
                             | - Decreases patient wait time at point of care by supporting better workflow design and faster patient throughput  
                             | - Makes care more patient-centered, improving patient satisfaction                                                                                                                                           |
| Improved care coordination                  | - Makes care delivery more timely  
                             | - Provides real-time visibility into processes and facilitates care process planning  
                             | - Improves auxiliary services coordination                                                                                                          |
| Improved patient safety                  | - Increases the accuracy of care delivery: avoids wrong patient/wrong medication/wrong procedure errors  
                             | - Reduces the risk of hospital infection dissemination  
                             | - Improves organizational compliance with asset preventive and corrective maintenance  
                             | - Enables the fast and reliable recall of assets, medications, and biomedical inventory                                                                                                                      |
| Improved patient placement                  | - Reduces workflow obstacles  
                             | - Decreases leave without treatment (patient diversion)  
                             | - Increases patient throughput                                                                                                                      |
| Increase in productive staff time                  | - Decreases staff time spent on non-care-essential activities (scheduling phone calls, patient or asset location) |                                                                                                                                                      |
| Reduced capital outlay reduction                  | - Reduces capital spending on asset acquisition  
                             | - Improves the utilization of available physical space, making expansion less pressing                                                                                                                     |
| Reduced non-labor operating cost                  | - Reduces insurance premiums by improving hospital’s regulatory compliance  
                             | - Improves management’s forecasting capacity                                                                                                          |
Developing enterprise-level cost-benefit evaluation tools for promising RFID: evaluation structure

Section 3.1 addressed the substantive question: What benefits and costs do healthcare delivery organizations experience when they adopt a specific type of a promising healthcare RFID application?

But how can healthcare delivery organizations know that they are accomplishing what they set out to do with these RFID applications — i.e., that they are reaping the benefits they sought to achieve? And how can they assess whether they are better off having adopted the application? As previously indicated, the review of current literature on RFID in healthcare failed to identify an evaluation framework or approach that healthcare adopters or independent evaluators can use to assess the success of their systems. A review of AHRQ's National Resource Center on HIT and AHRQ's National Health IT Survey Compendium\(^\text{72}\) indicated that at present there are no publicly available evaluation tools for healthcare RFID technology. A search of HIT assessment tools available on the websites of the Institute for Prospective Technological Studies (IPTS), American Medical Informatics Association (AMIA), HIMSS, Institute for Healthcare Improvement (IHI), and American Society for Healthcare Engineering (ASHE) further confirmed this finding.

In this section, I address this methodological gap by proposing a series of cost-benefit evaluation tools (evaluation structures), one for each promising RFID application type, along with an evaluation approach developed to meet the practical evaluation needs of RFID implementers and evaluators and to create a stepping stone for future research into RFID's potential in healthcare.

The methodology and analytic approach I used to create these evaluation structures are described next.

### 3.2.1 Analytic approach used to create the RFID evaluation structure

One of the analytic steps I used to establish the cost and benefit frameworks presented in Section 3.1 entailed identifying the variables, variable measures, research designs, and analytic approaches used by existing studies on the impacts of promising healthcare RFID applications.\(^\text{73}\)

With this information readily available, I began to develop the RFID evaluation tools I sought to create by investigating the research designs and analytic approaches that existing studies used. I wanted to identify useful building blocks that I could further develop. This review showed that over 90% of all published impact assessments or evaluations of healthcare RFID over-emphasized hard returns (e.g., increased revenue, capital cost outlay avoidance). Soft returns (e.g., staff time and increased satisfaction) were frequently omitted altogether. This is particularly problematic because a substantial proportion of the benefits hypothetically associated with the adoption of an RFID application are soft benefits. Furthermore:

- While soft benefits can be expected to ultimately filter, at least to a degree, into hard returns (e.g., improved staff productivity leading to less staff overtime costs; or improved patient safety leading to decreased liability claims paid by the organization), the speed at which different types of soft benefits are transformed into hard returns can vary greatly, and the transformation function is neither linear nor necessarily unbreakable.\(^\text{74}\)


\(^{73}\) This information was sourced from the evidence table (provided in Appendix 3).

\(^{74}\) One can easily imagine how an adverse patient-safety event might not transform into a liability claim but still negatively affect patients and care providers, for example.
Complex organizations, such as healthcare delivery entities, are a black box due to the multitude of interrelated processes that take place in them, and causal attribution of organization- or even department-level net revenue outcomes to any single practice/technology change without a close evaluation and elimination of other potential candidate explanations for the occurring change is prone to difficulty.

Understanding how different interventions affect soft benefits, such as care delivery efficiency and care quality, is invaluable, since increasing employee productivity is, in fact, the key tool for achieving long-term cost reduction (as opposed to one-time cost cuts), and changes in employee productivity and process efficiency produce exponential impacts on hard returns over time. Similarly, care quality parameters are receiving increasing weight in facilities’ ratings, financing, and insurance.

Thus, I concluded that existing RFID evaluation approaches did not contain a research design or evaluation approach I could develop further.

I next conducted a review of peer-reviewed and grey-literature evaluation approaches and tools developed for HIT in general. This search identified an expansive body of literature that included both actual evaluations and theoretical evaluation models. Of these sources, three proved particularly useful for my work:

- a cost-benefit analysis of EMRs by Wang et al. (2003), which provided an example of a cost-benefit analytic model
- an HIT evaluation toolkit by Cusack and Poon (2007), which contained a rich set of exemplary measures that can be used by HIT adopters to evaluate their projects
- Intel’s Health IT Business Value Tool (2007), which provided an example of an Excel-based end-user-ready HIT evaluation tool.

Based on available empirical HIT impact evaluations (most notably Wang et al., 2003; but also Buccoliero et al., 2008, Stroetman, 2007, and Robinson et al., 2005), I identified cost-benefit analysis as the analytic approach best suited to the organizational objectives that hospitals aspire to when adopting advanced healthcare RFID applications. I further determined that given the profit-maximizing objective of most care-delivery organizations, the primary outcome parameter of a cost-benefit analysis is the net financial cost or benefit for the organization that results, during the application’s meaningful lifespan, from adopting an RFID application. As such, I defined a five-year horizon: while technology life span can differ across RFID application types, it can be generalized to five years, which is the currently proven optimal battery lifespan of active RFID tags and the lifespan of most key types of portable assets.

Yet the creation of an RFID cost-benefit evaluation tool requires consideration not only of how costs and benefits could be parametrized (explored in Section 3.1.1, above), but also of how they could be measured consistently across healthcare providers, and how the non-cost elements might be tackled.

While some related low-level benefits (e.g., reduced staff turnover) are measurable through routinely collected data on staffing levels, retention data, and capacity utilization indicators, a key question in the case of RFID is how to obtain a reliable and valid estimate of the baseline process and any benefits that were not monitored prior to the technology’s implementation (since the detailed process data that RFID applications produce can be used to evaluate their performance over time). For example, employee productivity can be measured at two levels: process improvements and task improvements. The former are at the macro level; the latter are at the micro level. While base-case data may be available for the task level, pre-implementation process-level data may be much harder/costlier to collect.

The paucity of empirical data on RFID that the literature review identified, in addition to representing a substantive knowledge gap, should be thought of in terms of the inherent difficulty it imposes on any effort to measure productivity and process efficiency changes and attribute
them to specific technologies. This is a well-known issue in both health economics and technology assessment, and applies to other HIT as well.

Traditional approaches to capturing productivity-related benefits use time-motion studies and random assignment of employees in laboratory situations to produce an estimate of employee productivity gain for specific IT solutions. However, in the case of advanced healthcare RFID applications, capture can be complicated if the introduced RFID system led to a restructuring of tasks (e.g., removal of a task that a person performs) and/or a reduction in the number of end-user processes needed to achieve the same goal (e.g., the automatic scheduling functionality of advanced ED workflow and process management applications). One way to create a workaround to this challenge is to use gains in head-count efficiencies or effectiveness as a proxy for baseline process efficiency.\(^75\)

Another challenge is the valuation of benefits and costs that occur in non-monetary units. For example, staff time, through which a number of benefits can be measured, can be valued at the ongoing staffer’s annual wage multiplied by the total amount of time a given staff member spends annually performing the RFID system-related activity.\(^76\)

My next goal was to determine whether the theoretical and empirical HIT evaluation literature contained any tested benefit measures applicable to the costs and benefits of the four promising RFID applications (identified in Section 3.1). With respect to costs, I did not identify a useful reference for expanding the measurement component of the cost framework I developed (see Section 3.1). The majority of the documented RFID costs and cost variables were, however, both unambiguous and readily monetized. Thus, based on the RFID cost framework I developed and the evidence table on which it builds, I expanded the range of exemplary low-level measures that can be used to capture the identified higher-level cost parameters (see Table 36) and identified potential information sources from which metrics data can be obtained. I also used the evidence table to establish whether these data need to be monetized before they can be used for a cost-benefit analysis.

\(^{75}\) For example, the benefit is \((\text{number of employees affected}) \times (\text{time}) \times (\text{average burden rate for region and job type}) \times 50\%\) (Sward, 2006).

\(^{76}\) Time spent on the activity can be calculated on the basis of staff activity/invoice logs, for example, or time-motion studies. It can be arrived at by multiplying (average duration of task) \(\times (\text{number of times task is performed for a given period}) \times (\text{prorated wage of a single employee involved in the task})\). Regardless of the measurement approach taken, however, it needs to be replicable, valid, and consistently used through the evaluation.
Table 36: Measuring the costs of advanced inpatient healthcare RFID applications — general case valuation considerations

<table>
<thead>
<tr>
<th>Top- and mid-level measures</th>
<th>Exemplary low-level measures</th>
<th>Already monetized?</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct application costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial application cost</td>
<td>RFID readers, antennas, wiring, designated end-user stations</td>
<td>Yes</td>
<td>Contract with technology vendor</td>
</tr>
<tr>
<td>Implementation cost</td>
<td>Staff time dedicated to designing system</td>
<td>No</td>
<td>Time motion study and payroll data</td>
</tr>
<tr>
<td>Training cost</td>
<td>Staff time dedicated to training</td>
<td>No</td>
<td>Time motion study and payroll data</td>
</tr>
<tr>
<td>Software annual lease</td>
<td>n/a</td>
<td>Yes</td>
<td>Contract with technology vendor</td>
</tr>
<tr>
<td>Annual maintenance and support</td>
<td>Staff time needed to locate dead readers, respond to help requests</td>
<td>No, for labor</td>
<td>Time motion study and payroll data</td>
</tr>
<tr>
<td>Induced application costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporary productivity loss</td>
<td>Slowdown in staff routine due to new system</td>
<td>No</td>
<td>Time motion study and payroll data</td>
</tr>
</tbody>
</table>

Two primary sources of benefit measures were:

- Cusack and Poon, 2007, on patient throughput, safety, satisfaction, and timeliness benefit variables
- Carayon et al., 2003, on reducing workload and increasing patient safety through work and workspace design.

Using the variable measures provided by these two sources, I created valuation tables for each promising application. These tables offer a low-level measure for each benefit variable identified in Section 3.1 for each of the applications. Table 37, provided here, is the valuation table for the ED management RFID application; the three remaining valuation tables are included in Appendix 7. These tables are built on a common set of evaluation metrics and can support the meaningful comparison of RFID applications of different kinds and sophistication levels. Further, they outline:

- the potential sources for baseline and post-RFID-system implementation measurement data (baseline information sources were identified based on Cusack and Poon, 2007, data for comparable metrics)
- a guide to how costly it would be to obtain such baseline measurement data (based on information Cusack and Poon provide for comparable metrics), and post-implementation measurement data
- the data bias that evaluators should consider, and whether the information will need to be monetized before it can be used in a cost-benefit analysis (based on valuation approaches proposed in Cusack and Poon, 2007; Wang et al., 2003; Buccoliero et al., 2008; Stroetman, 2007; Robinson et al., 2005; and Sloan, 1995).
Table 37: Measuring the benefits of inpatient RFID applications: ED management example measures and valuation considerations

<table>
<thead>
<tr>
<th>Suggested Benefits</th>
<th>Quality/cost domain</th>
<th>Exemplary low-level measures</th>
<th>Baseline data source</th>
<th>Baseline measurement cost</th>
<th>Post-implementation measurement cost</th>
<th>Can measure be monetized?</th>
<th>Possibility for other confounders</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Improved room turnaround rate</strong></td>
<td>Cost (increased patient placement)</td>
<td>Time needed to identify room as dirty, clean, and make available to new patient</td>
<td>Billing and administrative data</td>
<td>Medium to high</td>
<td>Low</td>
<td>Yes, using average revenue associated with admitted ED patients per patient type</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Faster patient throughput</strong></td>
<td>Cost (increased patient placement); quality (care coordination improvement)</td>
<td>Case-adjusted patient throughput in ED (admission and release)</td>
<td>Billing and administrative data</td>
<td>Medium</td>
<td>Low</td>
<td>As above</td>
<td>Medium (control for concurrent interventions and natural high/low)</td>
</tr>
<tr>
<td><strong>Reduced patient diversion</strong></td>
<td>Cost (increased patient placement); quality (patient-centered care and patient safety improvement)</td>
<td>Number of hours ED is placed on ambulance divert/is closed to new patients</td>
<td>Administrative data</td>
<td>Low</td>
<td>Low</td>
<td>As above</td>
<td>As above</td>
</tr>
<tr>
<td><strong>Reduced number of patients who leave without treatment (LWOT)</strong></td>
<td>As above</td>
<td>LWOT</td>
<td>As above</td>
<td>Low</td>
<td>Low</td>
<td>As above</td>
<td>As above</td>
</tr>
<tr>
<td><strong>Reduced nurse unproductive time</strong></td>
<td>Cost (increase in staff’s productive time)</td>
<td>Number of hours per day an ED nurse spends locating patients</td>
<td>Time-motion studies; direct observation</td>
<td>High</td>
<td>Low</td>
<td>Yes, based on regular and overtime pay per employee category</td>
<td>Low</td>
</tr>
<tr>
<td>Suggested Benefits</td>
<td>Quality/ Cost domain</td>
<td>Exemplary low-level measures</td>
<td>Baseline data source</td>
<td>Baseline measurement cost</td>
<td>Post-implementation measurement cost</td>
<td>Can measure be monetized?</td>
<td>Possibility for other confounders</td>
</tr>
<tr>
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</tr>
<tr>
<td>Increasing ease of care coordination across providers</td>
<td>Cost (increase in staff's productive time); quality (care coordination improvement)</td>
<td>Average number of steps needed to place new patient; number of phone calls needed to move patient</td>
<td>Time-motion studies; direct observation</td>
<td>High</td>
<td>Low</td>
<td>Yes, as above</td>
<td>Low (reliability of measurement and lack of intermittent policy changes)</td>
</tr>
<tr>
<td>Easy identification of latent patient safety threats (e.g., fall, allergies)</td>
<td>Quality (patient safety improvement)</td>
<td>Ability to pinpoint from nurse's desk all patients at risk for allergic reactions</td>
<td>Time-motion studies; direct observation</td>
<td>Medium</td>
<td>Low</td>
<td>Partially, using estimates on economic burden of adverse-event types</td>
<td>Medium (control for concurrent interventions and natural high/low)</td>
</tr>
<tr>
<td>Reduced frequency of chart and result checks/pulls</td>
<td>Cost (increase in staff's productive time)</td>
<td>Number of steps needed to view results</td>
<td>Direct observation; staff search of logs</td>
<td>Medium to high</td>
<td>Low</td>
<td>Yes, based on regular and overtime pay per employee category</td>
<td>Low</td>
</tr>
<tr>
<td>More timely diagnostic and treatment plan formulation</td>
<td>Quality (patient-centered care and patient safety improvement)</td>
<td>Time clinical staff spends waiting for result delivery</td>
<td>Time-motion studies; direct observation</td>
<td>Medium to high</td>
<td>Low</td>
<td>Partially, through economic burden of waiting-time-attributable adverse events and complications</td>
<td>Medium</td>
</tr>
<tr>
<td>Decreased patient waiting time at point of care</td>
<td>Quality (patient-centeredness; timeliness)</td>
<td>Patient wait time for transport</td>
<td>Time-motion studies; direct observation</td>
<td>Medium to high</td>
<td>Low</td>
<td>Partially, through economic burden of waiting-time-attributable adverse events and complications</td>
<td>High</td>
</tr>
<tr>
<td>Suggested Benefits</td>
<td>Quality/ Cost domain</td>
<td>Exemplary low-level measures</td>
<td>Baseline data source</td>
<td>Baseline measurement cost</td>
<td>Post-implementation measurement cost</td>
<td>Can measure be monetized?</td>
<td>Possibility for other confounders</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>----------------------</td>
<td>------------------------------</td>
<td>----------------------</td>
<td>---------------------------</td>
<td>--------------------------------------</td>
<td>--------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Reduced patient waiting time in ED</td>
<td>Quality (patient-centered care and safety improvement); cost (non-labor operating cost reduction)</td>
<td>Case-adjusted average door to triage, and post- triage patient waiting time at ED</td>
<td>Administrative data</td>
<td>Medium</td>
<td>Low</td>
<td>Partially, through economic burden of waiting-time-attributable adverse events and complications</td>
<td>High</td>
</tr>
<tr>
<td>Event and process audit trail creation</td>
<td>Quality (continuous improvement); cost (non-labor cost reduction)</td>
<td>Reduction in steps/processes to create an audit trail with system</td>
<td>Administrative data</td>
<td>Medium to high</td>
<td>Low</td>
<td>Partially, through impact on facility's accreditation and insurance premiums</td>
<td>Low</td>
</tr>
<tr>
<td>Continuous improvement of department performance enabled by high-granularity process and event data</td>
<td>Quality (continuous quality improvement); cost (all)</td>
<td>Integration of system data in formal process improvement loop</td>
<td>Administrative data; time-motion studies; surveys</td>
<td>High</td>
<td>Low</td>
<td>Not directly; indirectly, though comparison of pre/post net revenue</td>
<td>Low to medium (over time, through multivariate statistical analysis)</td>
</tr>
<tr>
<td>Improved staff work satisfaction</td>
<td>Quality (continuous improvement)</td>
<td>Staff job satisfaction</td>
<td>Surveys</td>
<td>Medium</td>
<td>Medium</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Reduced staff turnaround</td>
<td>Cost (increase in productive staff time)</td>
<td>Number of nurses leaving within first annual quarter</td>
<td>Human resources log</td>
<td>Low</td>
<td>Low</td>
<td>Yes, based on avg length of training period per staff type, and pay</td>
<td>High</td>
</tr>
<tr>
<td>Improved patient satisfaction</td>
<td>Quality (patient-centeredness)</td>
<td>Patient satisfaction with care episode</td>
<td>Surveys</td>
<td>Medium</td>
<td>Medium</td>
<td>No</td>
<td>High</td>
</tr>
</tbody>
</table>
Finally, I translated the cost and benefit frameworks (developed in Section 3.1) and the cost and benefit valuation tables (discussed above) into four Microsoft Excel workbooks, one for each type of promising RFID application. Integrating them with the cost-benefit perspective I chose for the model, I created the four promising RFID evaluation structures presented next.

3.2.2 A description of the RFID cost-benefit evaluation structures and guidance on how to use them

Each of the four Excel-based cost-benefit evaluation structures consists of the following:

- **Tab 1**: Instructions for using the structures
- **Tab 2**: Costs:
  - an Excel-based version of the cost framework presented in Section 3.1, containing the cost variables and measures identified as common to the four promising RFID application types
  - evaluators can use this first cost sheet to identify which variables will need to be measured
- **Tab 3**: Cost measures:
  - an Excel-based version of the cost valuation table presented in Section 3.2.1.
- **Tab 4**: Benefits:
  - an Excel-based version of the benefit framework presented in Section 3.1, containing the benefit variables and measures identified for each of the four promising application types
  - end-users can select the operational purposes their RFID application performs to identify the range of benefits associated with these functions and to tailor the evaluation matrix to their needs (this can be done using a built-in list function in the Excel sheet)
  - evaluators can use this first benefit sheet to identify which variables will need to be measured
- **Tab 5**: Benefit measures:
  - an Excel-based version of the benefit valuation table presented in Section 3.2.1.
- **Tab 6**: Five-year cost-benefit analysis:
  - a separate sheet on which individual cost and benefit data are fed from the cost and benefit tabs; pre-programmed functions allow the user to choose whether the cost-benefit analysis should be based on the averaged measure value or on the measures' extremes; the tab is further programmed to sum benefits on an annual basis and to derive the net benefit of the system, based on a 5% discount rate (which end-users can change).

The evaluation structures were developed to assess the annual benefits and costs of implemented applications. Thus, even though information on system performance is likely to occur in different time units, users should ensure that all variable measures are calculated in comparable time units (e.g., all measures are computed monthly and then summed for all months).  

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77 In beginning this task, I found the cost-benefit model developed by Wang et al. (2003) and Intel's Excel-based HIT value tool (2007) particularly helpful as starting points.
of the year). To heighten evaluators’ attention to the potential need to transform the scale in which measures were originally recorded, all benefits and costs not naturally occurring in annual units are color-flagged. Additionally, there is a link between the costs tab and the cost valuation tab and between the benefits tab and the benefit valuation tab to allow users seeking more information on a cost or benefit measure to jump to the valuation table row that discusses that measure. Benefit and cost measures that do not occur in monetary units are also color-flagged to alert evaluators to the need to first monetize the collected data (guidance on how this can be done is available in the valuation tabs). The evaluation tools assume a five-year useful life horizon for each application type.  

Table 38 shows the costs tab, illustrated for the ED management application class. In it, users can choose to enter either the variation across departments/units documented for each variable measure or the averaged value. For cost measures that take a concrete value, the variation column is marked with “n/a” (not applicable) to eliminate confusion.

Table 38: Costs tab of evaluation structure file for ED management RFID applications

Table 39, in turn, shows the benefits tab of the evaluation structure for the RFID ED management application, exemplified for a comprehensive system.

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78 A technology life span of two to seven years can be used to test the sensitivity of the net financial costs or benefits for the organization to this assumption. Two years is the minimum amount of time needed to establish an RFID application and diagnose a need for substantial changes in it; seven years is currently the maximum battery life span of active RFID systems (with five years being the optimal battery life span).
Finally, Table 40 shows the cost-benefit analysis tab of the ED management application.

To calculate the RFID application’s net benefit for its adopter, evaluators need to first calculate the present value (consistently monetized, if necessary, and estimated for each individual year in the analysis horizon) of all costs and benefits associated with the technology’s introduction into the organization. Once this information is fed into the costs tab and benefits tab of the evaluation structure, the application’s present benefit and net value are automatically calculated by the evaluation tool (through pre-programmed functions). The individual costs and benefits outlined above are then adjusted to a common base year (compensating for currency inflation/deflation), discounted by a 5% rate to account for the present value of future incoming and outgoing payment streams incurred by the organization as a direct result of the adoption of the RFID system, and summed up over the application’s lifespan. The program then arrives at the application’s net value by subtracting the application’s monetized costs from its monetized benefits for each year of the application’s useful life.
Finally, the flow chart presented below summarizes the individual steps that RFID evaluators must follow when using the four promising RFID evaluation structures. Although the evaluation structures are programmed to deliver a “single number” — the annual net application benefit — evaluators should refrain from over-emphasizing this number when assessing the application’s impacts on their organization. Instead, they should view the evaluation structures primarily as tools to use to continuously assess how the RFID application they have adopted affects different aspects of the organization’s performance.
### 3.3 Summary of key findings and implications

This chapter has described how I furthered my investigation into the capacity of healthcare RFID technology to positively affect the quality and cost-efficiency of care delivery by addressing the key substantive and methodological gaps that were highlighted (see Chapter 2) as affecting the current knowledge on RFID’s potential in healthcare and our capacity to expand it. I have attempted in this chapter to:

- Identify what types of benefits and costs healthcare delivery organizations experience when they adopt one of the four RFID applications highlighted by the experts as leading in their ability to improve the quality and/or reduce the cost of healthcare delivery in the U.S. in the next five to ten years.
- Define how promising RFID applications operate.
- Determine how differences in the engineering and operational purposes of specific promising healthcare RFID applications affect the benefits that can be derived from these applications and their costs.

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#### Using an RFID evaluation structure

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>User uses the costs tab (Tab 2) to identify cost constructs and variables that should be considered in the evaluation</td>
<td>Using the cost valuation table (Tab 4) user selects specific cost variable measures to be used, and identifies the information sources from which data on each measure can be retrieved</td>
<td>User estimates and enters the average monetary value and variance of each cost measure in the costs tab of the structure (Tab 2) for each year of the application’s useful life</td>
<td>4.1. Structure imports results of costs and benefits tabs in cost-benefit evaluation tab (Tab 6)</td>
</tr>
<tr>
<td>User uses the benefits tab (Tab 3) to identify benefit constructs and variables that should be considered in the evaluation given the degree of sophistication (functionality range) of the application</td>
<td>User selects the benefit variable measures specific to this application type from Tab 5 and identifies baseline (pre-implementation) data sources for each measure</td>
<td>User estimates and enters the monetized average value and variance of each benefit measure in the benefits tab of the structure (Tab 3) for each year of the application’s useful life (see Tab 5 for directions on how each benefit measure can be monetized)</td>
<td>4.2. User chooses whether analysis should be completed on the basis of averaged annual values, annual minimum values or annual maximum value</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>4.3. Structure computes the total monetized annual cost and total monetized annual benefit for each year of analysis by summing costs and benefits that occurred during the same year</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.4. Structure computes the net benefit of the application for each year of its useful life by subtracting the annual costs (in the cost section of the table) from the annual benefits of the application (listed in the benefit section of the table)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.5. Structure computes present value of net application benefit by subtracting the present value of the application’s annual costs from the present value of the application’s annual benefits</td>
</tr>
</tbody>
</table>
• Identify where the value of promising RFID for improving the quality and cost-efficiency of healthcare delivery lies.

• Develop ready-to-use, customizable evaluation constructs for each of the promising RFID application types. These tools are to address RFID adopters’ and evaluators’ need for a consistent set of constructs, variables, and measures, and for an evaluation approach, that can be used to assess the impacts of RFID applications on the quality and cost-efficiency of the processes they are expected to improve.

The analysis revealed that although healthcare delivery organizations incur the same types of costs when adopting a promising healthcare RFID application, the benefits obtained may differ substantially across application types. Benefits are also strongly correlated with an application’s sophistication level. Regardless of these differences, however, the analytic results indicated that all four promising application types have a capacity to directly bear on the capital and operational costs incurred by healthcare delivery organizations (thus relating strongly to dollars saved) and to enhance an organization’s ability to engage in continuous quality improvement — two benefits that set promising RFID solutions apart from other HIT solutions. Finally, the proposed RFID evaluation structure provides a stepping stone for further research into RFID’s potential in healthcare.

But how do the identified benefits and costs compare to actual impacts experienced by healthcare delivery organizations that have adopted a promising healthcare RFID application? Are the proposed RFID evaluation constructs reliable? Can they be implemented in real life? Finally, are there critical factors (including privacy and interference threats, and organizational characteristics) affecting the value that adopters can derive from promising RFID? I explore these questions in Chapter 4.
Chapter 3 described how I developed a new evaluation structure for healthcare RFID, one designed to address the currently outstanding need for a coherent system of constructs, variables, and measures through which more-robust data on the benefits and costs of healthcare RFID can be collected. In this chapter, I present the findings of a case study research design that I used to build on and validate the evaluation tools I developed. The design explored the effects of seven hospitals’ implementations of types of RFID applications that experts had highlighted as promising. By studying and assessing the outcomes from these RFID implementations, and the ways in which they were achieved, I sought to identify the critical factors (including privacy and interference threats, and organizational characteristics) affecting the value that adopters can derive from promising RFID. The case studies represent a first attempt to explore, using a systematic evaluation approach, how the benefits and costs of leading types of healthcare RFID vary with organizational environment and why.

To capture promising healthcare RFID’s spectrum of impacts across a range of hospital settings, I aimed to include as case study sites both for-profit and not-for-profit, and medium-sized and large hospitals. At present, however, only a limited number of healthcare delivery organizations in the U.S. and globally have implemented advanced RFID applications. In order to tap the needed heterogeneity of implementation contexts, I chose to use a combination of U.S. and European hospitals as my case study sites. Because the research objectives focused more on identifying the specific factors that drive RFID’s impacts at the organization level than on deriving absolute size cost and benefit information, the addition of non-U.S. cases did not adversely affect the relevance and validity of the findings.

Section 4.1 outlines the research design, data collection methods, and analytic approach I used for the case studies; it also discusses the case studies’ limitations. Section 4.2 presents the case results on the validity and usability of the RFID evaluation structures, and summarizes the impacts experienced by healthcare delivery organizations after adopting a promising healthcare RFID application. The section further highlights the case study results on factors affecting the value that adopters can derive from advanced RFID in the hospital setting. Finally, Section 4.3 summarizes the conclusions that can be drawn from the eight case studies about the critical issues for successfully adopting, or failing to successfully adopt, a promising healthcare RFID application. Condensed presentations of the individual case studies and the key case-level results, organized per application type, can be found in Appendix 10.
4.1 Analytic approach used in case studies

4.1.1 Research design

To meet the goals I set out for this portion of my research, I used a case study design that involved applying the cost-benefit evaluation structures to study and assess the effects that hospitals (representing a range of organizational contexts) experienced upon implementing and using RFID solutions belonging to the four promising application types. To understand better what the critical factors for RFID adoption and use were, I adopted a multi-case embedded research design\(^79\) that distinguished the experiences that different groups of application users and stakeholders (identified on the basis of the benefit analysis presented in Section 3.1) had with the application in a given hospital. These users included care providers (doctors and nurses), hospital administrators, patients and their relatives, staff, and organizational managers.

Thus, for the purposes of my analysis, I defined a case as an RFID technology as it had been introduced into a healthcare delivery organization and was being used in the delivery of one or more inpatient services as part of regular operations.

In selecting the individual cases that I included in the research design, I aimed to maximize the diversity of contexts of RFID use, institutional frameworks, and perceived degrees of application success. Additional selection criteria included:

- level of integration (at department and/or hospital level): multi-function and multi-purpose RFID applications
- expected bearing on the quality and the cost-efficiency of care delivery
- application maturity
- availability of (financial) data on the application
- institution’s willingness to participate in the study and to provide access to information.

My objective was to capture information on the validity of the evaluation structures, on the impacts of advanced RFID applications, and on the factors influencing those applications in a range of implementation contexts that I could then use for pattern matching and explanation building. The seven analytic themes that I examined in each case study, and which formed the embedded structure of the research design, were:

- institutional context
- technical description of the application
- application costs
- application benefits
- adoption process facilitators
- adoption process obstacles
- perceptions of hospital staff expected to use the system.

As mentioned earlier, in an effort to tap the needed heterogeneity of implementation contexts, I chose as case study sites a number of U.S. and European healthcare facilities.\(^80\) This decision came about because the present number of facilities that have implemented advanced RFID

\(^79\) For more information on the multi-case embedded research design approach and its uses, see Yin, 1994.

\(^80\) Covered systems include full national health systems, systems that have recently introduced more market-oriented elements, and fragmented private-insurance dominated systems.
applications is limited, both in the U.S. and globally.\textsuperscript{81} Because the research objectives focus more on identifying relationships than on deriving absolute-size cost and benefit information, the inclusion of non-U.S. cases does not adversely affect the relevance and validity of the findings.\textsuperscript{82} Furthermore, the European case studies provide an opportunity to test the internal validity and usability of the evaluation structures for the RFID emergency department (ED), operating floor (OF), and medical floor (MF) application types — structures that, by design, are useful for studying the benefits and costs of RFID in the U.S.\textsuperscript{83}

The case studies included in the analysis were:

- **Real-time portable asset management solutions**
  - *Wayne Memorial Hospital (WMH), U.S.* This is a hospital-wide portable assets and equipment tracking and management RFID application. It was implemented in 2007 with the objective of addressing the low asset visibility that WMH was experiencing. WMH is a private, medium-sized, acute care community hospital, the majority of whose facilities were built between 1970 and 1992.
  
  - *Royal Alexandria Hospital (RAH), U.K.* This is a hospital-wide portable assets and equipment tracking RFID application. It was implemented in 2007 to reduce the amount of time that clinical and technical staff spent locating portable devices. RAH is a large district general hospital; it was built in 1986.

- **Emergency department process and workflow management solution**
  - *Caravaggio Treviglio Hospital (OTC), Italy.* This is a stand-alone application for tracing orthopedic patients in and between the ED and the x-ray department. It was implemented in 2005 with the objective of preventing nursing staff from being overwhelmed by requests for information updates on patients' whereabouts. OTC is a medium-sized general regional hospital with a new ED built in 2004. In 2004, OTC replaced several small hospitals; since then, its ED patient volume has risen by 10% to 12% annually. Orthopedic patients constitute on average 4% of all ED patients and are the largest patient group treated by the ED.

- **Operating floor process and workflow management solutions**
  - *Birmingham Heartlands Hospital (BHH), U.K.* This is a passive, real-time RFID pre-operative decision support system fully integrated with core clinical systems used in five BHH ear, nose, and throat (ENT) department wards. It was implemented in 2007 to automate the pre-operative process by having a digital operating list, enabled by automated patient recognition, through which wrong site/side surgeries can be prevented, hospital efficiency can be increased, and BHH's exposure to litigation costs can be decreased. BHH is a large, urban,

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\textsuperscript{81} Finding U.S. hospitals that were using these RFID application types, were willing to participate in the study, and had sufficient historical data was a priority. However, U.S. hospitals meeting these conditions could not be identified, despite repeated negotiations. For example, negotiations with two U.S. hospitals that could have provided two more case studies of ED workflow management RFID applications were unsuccessful. In one case, the implemented application was discovered to be a mixed RFID-infrared system, rendering its results of questionable value for the analysis. In the second case, site visits could not be made because other evaluations were taking place.

\textsuperscript{82} It can also be argued that to the extent that the U.S. healthcare system is almost unique, adding information from non-U.S. systems is beneficial, since it allows us to investigate whether any of the constraints characterizing the U.S. system critically affect healthcare RFID's impacts and adoption.

\textsuperscript{83} The evaluation structure is useful for studying the benefits and costs of RFID in the U.S. because it was developed on the basis of evaluation approaches used in the U.S. to assess HIT, U.S. experts’ opinions on RFID, and analysis of literature that is representative of current RFID practice in the U.S.
acute care hospital with approximately 800,000 ENT surgical patient admissions annually; it belongs to one of U.K.’s best-performing hospital trusts.

- **Amsterdam Medisch Centrum (AMC), The Netherlands.** This solution comprises three passive/active RFID operating room (OR) RFID applications — OR theater person identification, OR material and medication tracing, and OR blood product tracing — focused on reducing materials waste, improving patient safety, and providing better OF and OR workflow visibility. It was implemented in 2005 to explore such questions as, “Is this a technology that works?” and “What is RFID’s added value?” It was abandoned in 2006. AMC is a large teaching hospital; the largest part of its infrastructure was built in the 1980s.

- **Medical floor and bedside medication management solutions:**
  - **Hôpitaux Universitaire de Genève (HUG), Switzerland.** This is an RFID-based computerized chemotherapy preparation and administration application. It was implemented in 2005 to centralize the preparation of all chemotherapies administered at HUG, to integrate them into the e-prescription process, and to improve chemotherapy patients’ safety by matching care giver, patient, and medication to ensure the “Five Rights” (right patient, right medication, right time, right dose, right route). It was abandoned in 2007. HUG is a large regional teaching hospital consortium spread over five campuses, the majority of which was built in the 1980s.
  - **Universitätsklinikum Jena (UHJ), Germany.** This is an RFID system for unit-dose medication commissioning and bedside medication preparation and administration for patients in the intensive care unit (ICU). It was implemented in 2006 to identify, track, and match medications accurately and in real time, from the hospital’s pharmacy to administration to ICU patients. It was abandoned in 2008. UHJ is a large teaching hospital that is also a regional acute care center; its ICU, built in 2004, has 72 beds, 30 of which were included in the initial RFID implementation.

The eighth case study was an RFID hospital-wide inventory (garment) management application that one of the study sites also supported (Hôpitaux Universitaire de Genève). This system, implemented in 1995, manages the daily collection, ironing, and redistribution of staff and patient garments across four hospital sites and seven garment distributors.

The dependent variables of interest in the case study analyses were the costs and benefits identified in the RFID evaluation structure presented in Chapter 3 for each of the four application types. I selected specific cost and benefit variable measures for each RFID application class using the Excel-based tools.

As independent variables of interest (i.e., sources of the witnessed effects), I used:

- technology characteristics of the RFID application itself (e.g., reliability and performance, system quality and information quality)
- features of the institutional context (e.g., hospital size, patient population, health system financing mechanisms)
- characteristics of the technology implementation process (e.g., how the application was integrated in the application setting)

84 Although I assume sole responsibility for the design of the case studies’ methodology, site selection, and the analysis, I am thankful to my RAND Europe team for their help in the preliminary data collection for some of the European case studies. Parts of these case studies also fed a separate RAND Europe study that investigated healthcare RFID’s potential in the European context.
the degree of the technology’s diffusion (e.g., the proportion of intended users that actually use the application, use it appropriately, and perceive it as useful).

These variables were identified on the basis of adaptive structuration theory application to HIT (the theory and the analysis supporting the identification are presented in Appendix 8). Using these independent and dependent variables, I conducted eight case studies of the promising types of healthcare RFID.85 More details on the research design are available in Appendix 9.

4.1.2 Data collection and analysis

To increase the internal validity of the findings, I sourced information on the dependent and independent variables of interest from multiple information sources in each case study. These included:

- face-to-face and/or telephone interviews with the developers and users of the applications
- pre- and post-implementation data, both financial and operational, on the cost of implementing the applications and their impact on the processes and workflows they support
- existing evaluations of the applications (if any)
- direct observations during site visits.

To organize each site visit, and to identify the specific incumbents that should be contacted with an invitation for an interview or a data request, a key contact person was identified and asked to act as the main liaison in each participating institution. Typically, this person was the organizational RFID pilot leader or the Vice President (VP) of Operations. Table 41 shows the information sources I examined in each case to identify the seven analytic themes.

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85 The eight case studies presented here are an expansion of a more simplified (cost outcome only) analysis previously published by van Oranje et al. (2009). I was responsible for developing the multi-case research design and for selecting, conducting, and analyzing both sets of case studies. I am grateful for help I received from my RAND Europe colleagues during the data collection and initial brainstorming stages of the European case studies.
Table 41: List of case study information sources per analytic theme

<table>
<thead>
<tr>
<th>Information sources</th>
<th>Institutional context</th>
<th>Application description</th>
<th>Costs</th>
<th>Benefits</th>
<th>Adoption facilitators</th>
<th>Adoption obstacles</th>
<th>User perceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Interviews</td>
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<td>1.1. Chief</td>
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<td>√</td>
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<td>1.2. RFID Pilot</td>
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<td>1.6. Nurses</td>
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<td>1.7. Other</td>
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<td>incumbents (e.g.,</td>
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<td>Sr. Pharmacists,</td>
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<td>Managers)</td>
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<td>2. Document review</td>
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<td>financial data and</td>
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<td>implementation</td>
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<td>2.3. Previous</td>
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<td>evaluations of the</td>
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<td>RFID application</td>
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<td>2.4. Technical</td>
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<td>descriptions of the</td>
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<td>3. Direct observation</td>
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<td>√</td>
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</tbody>
</table>

All interviews (in person and by phone) lasted around 50 minutes and used open-ended questions to capture information that interviewees could provide on the seven analytic themes of analysis based on their role in the development, implementation, and use of the applications. In lieu of using Human Subjects Protection Committee (HSPC) procedures, oral consent was obtained from all respondents prior to an interview, both for participation and for recording or note-taking of the conversation. Follow-up interviews were conducted as well. In lieu of using HSPC regulations, no data identified by case study participants as proprietary were procured.

During data collection and analysis, I placed primary emphasis on testing alternative causal explanations for the impacts of the implemented applications. To this end, I sought to procure detailed direct and indirect cost and benefit data and to use interviews with multiple stakeholders to establish the reliability of reported information on how the costs and benefits of the application were realized.

After data collection was completed, analyses were first done on a within-case basis (as required by this research design). Patterns of similarity and difference, revealed by comparing the cases on common variables, were then used to reach between-case, cross-application conclusions.
Raw information was not pooled across studies.\textsuperscript{86,87} Case-level results on the seven analytic themes were summarized in concise case study presentations and can be found in Appendix 10.

To test the validity of the four RFID evaluation frameworks I developed in Chapter 3, during the data collection and analysis stages of each case study, I assessed:

- the degree of overlap between the benefits and costs identified in the case studies and those identified in the evaluation structures as relevant to an RFID application having operational purposes similar to those of the implemented applications (i.e., having a similar level of sophistication); in other words, I assessed:
  - how accurately the evaluation structure for each RFID type and functionality level captured the benefits and costs that hospitals actually experienced
  - the portion of the benefits and costs identified for each application type and sophistication level that was documented in each case study)
- the degree to which the benefit component of the evaluation structures correctly identified the operational purposes that produced individual application benefits
- the degree to which the benefit component of the evaluation structures correctly identified the organizational stakeholder that was the recipient of a specific application benefit
- the portion of the baseline information sources suggested in the evaluation structures that was in fact useful for obtaining the benefit and cost variable measures needed for the analysis (per organizational stakeholder)
- the portion of the exemplary variable measures suggested in the evaluation structures that had face validity (i.e., could be used in practice to capture the cost and benefit variables of interest in each case)
- the portion of the valuation approaches suggested in the evaluation structures that was in fact useful for monetizing variable measures prior to their inclusion in a cost-benefit analysis
- whether the majority of the costs and benefits produced by the application occurred at the care delivery organization level (not the single care provider level) — i.e., whether the hospital was the appropriate unit of analysis for the evaluation structures
- whether the majority of the costs and benefits produced by the application could be monetized — i.e., whether cost-benefit analysis was the appropriate analytic approach for the evaluation structures
- the user-friendliness (as opposed to proneness to error) of the Excel-based version of the evaluation structures (specifically, how easy it was to navigate the files and input data, and how reliable the cost benefit analysis performed by these tools was in comparison to an independent cost benefit analysis of the data).

This analysis suggested that the evaluation frameworks are valid and useful for assessing the net benefit that organizations can reap through RFID. Section 4.2 presents illustrations of these results.

\textsuperscript{86} To arrive at the assertions and generalizations arising from the group of purposefully selected case studies, within-case theme analysis was used first to arrive at the key themes emerging from each case study. A cross-case theme analysis was then used to contrast the similarities and differences between the themes of the individual cases (for more details see Creswell, 2007).

\textsuperscript{87} For more information on the analytic approach options for multi-case embedded design case studies, see Yin, 1994 and 1993.
To identify the organizational benefits and the costs of the evaluated applications, I:

- collected detailed data on the cost and benefit variable measures identified in each cost-benefit evaluation structure
- monetized the variables, whenever necessary, using the valuation approach suggested in the structures
- used the monetized data to conduct a cost-benefit analysis of the net financial benefit achieved by hospitals with the applications they adopted (using the Excel-based versions of the evaluation structures and an alternative approach to test the tools’ reliability).

The cross-case findings of this analysis are presented in Section 4.2. Individual, case-level results on the benefits and costs of the eight applications can be found in the application summaries contained in Appendix 10.

Finally, to identify the critical factors (including privacy and interference threats, and organizational characteristics) affecting the value that adopters can derive from promising RFID, and the ultimate success or failure of the RFID implementations, I sought to identify patterns of similarity and difference across the eight cases by comparing them on the factors that led to the successful adoption of each application or to its failure. These are presented in Section 4.3.

### 4.1.3 Case study limitations

The cases studies demonstrated that healthcare delivery organizations currently seldom approach the implementation of an RFID application as a process that will require ex-post evaluation and analysis, largely due to the additional effort and cost such an approach would require.

Three of the case studies did not provide comprehensive and detailed empirical baseline (i.e., pre-RFID implementation) process and event data. For some cases (most notably, the OTC case and the inventory application at HUG), this applied to only a few of the benefit variables included in the RFID cost-benefit evaluation structure. Other sites were more seriously affected (AMC, UHJ). This limitation constrained my ability to evaluate the magnitude of the full spectrum of benefits that hospitals reaped after implementing the applications. In three of the studies, the adopters abandoned their applications after the pilots (AMC, HUG, UHJ; see Section 4.3 for a detailed explanation), so benefit data for these cases are limited to the pilot stage. In addition, detailed empirical cost and benefit data could not be obtained for three of the cases because of confidentiality agreements between the hospital and vendor or because the hospital regarded the data as proprietary (AMC, OTC, BHH). The sites provided only high-level estimates of the benefits and costs resulting from the RFID applications (i.e., variability across units or over time was not available).

The HUG and UHJ applications also did not provide comprehensive cost data, due to multiple challenges that emerged during their implementation, including substitutions in RFID technology vendors and multi-vendor involvement in which some of the costs were borne by the vendor alone. This meant that anecdotal and snapshot information had to be emphasized in considering these applications’ costs.

Two cases not affected by any of these limitations were the WMH and RAH portable asset management applications.

Despite these limitations, the evidence cumulatively delivered by the case studies on RFID’s costs and benefits is thin but sufficient to meet the goals I posed for the case studies.
It should be noted that collection of cost and benefit data for the purposes of extrapolation to broader-scale impacts at the U.S. health system level was not an objective of the case studies. Instead, the objective was to collect evidence on the costs and benefits experienced by hospitals after adopting one of the four RFID types that the experts had highlighted as promising in order to test the reliability and usability of the new RFID evaluation tools I developed.\(^8\) This structure is, by design, useful for studying the benefits of RFID in the U.S. because it was developed on the basis of evaluation approaches used in the U.S. to assess HIT, U.S. experts’ opinion on RFID, and analysis of literature representative of current RFID practice in the U.S.

4.2 Results on testing the evaluation structures and on the costs and benefits of promising RFID

4.2.1 The validity of the proposed RFID cost-benefit evaluation structures

Using the analytic approach outlined in Section 4.1.2, I assessed how valid each evaluation structure is with respect to:

- the spectrum of costs and benefits it identifies for each of the four promising application classes (per sophistication level/operational functions)
- the data sources, measures, and valuation approaches it proposes
- the benefits it attributes to hospital stakeholders.

Table 42 shows how the RFID application costs that I identified in each of the eight case studies correspond with the cost evaluation framework developed in Section 3.1.1. (Overlaps are highlighted in green; the case-level cost data on which these results are based are available in Appendix 10.)

As the table suggests, the case study findings on the types of costs that healthcare delivery organizations incur when adopting advanced RFID solutions validated the cost evaluation framework developed in Section 3.1.1 as accurate in its proposed cost parameterization.

\(^8\) See Yin, 2003 on the limitations which affect the external validity of absolute impact-case study results in general.
Table 42: Overlap between costs identified in the eight case studies and RFID cost evaluation structure from Chapter 3 (overlap in green)

<table>
<thead>
<tr>
<th>Cost constructs and variables</th>
<th>Variable components/measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct application costs</strong></td>
<td></td>
</tr>
<tr>
<td>Initial application cost</td>
<td>Total software cost</td>
</tr>
<tr>
<td></td>
<td>Total middleware cost</td>
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<td></td>
<td>Total cost of tags</td>
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<td>Total cost of readers</td>
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<td></td>
<td>Total cost of collectors</td>
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<tr>
<td></td>
<td>Total wiring cost</td>
</tr>
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<td></td>
<td>Total cost of server(s)</td>
</tr>
<tr>
<td></td>
<td>Total cost of designated workstations/PDAs</td>
</tr>
<tr>
<td>Implementation cost</td>
<td>Total cost of staff time spent on designing the application</td>
</tr>
<tr>
<td></td>
<td>Total application installation cost</td>
</tr>
<tr>
<td></td>
<td>Total cost of staff time spent on initial mapping and redesigning of processes affected by the application</td>
</tr>
<tr>
<td>Training cost</td>
<td>Total cost of staff time spent on initial training</td>
</tr>
<tr>
<td></td>
<td>Total cost of staff time spent annually on booster training sessions</td>
</tr>
<tr>
<td>Annual maintenance and support costs</td>
<td>Total cost of staff time spent annually on system servicing/repair</td>
</tr>
<tr>
<td></td>
<td>Total annual cost of hardware replacements</td>
</tr>
<tr>
<td></td>
<td>Annual total staff time spent responding to help requests from other institutional users</td>
</tr>
<tr>
<td>Software annual lease</td>
<td>Total cost of software lease</td>
</tr>
<tr>
<td><strong>Induced application costs</strong></td>
<td>Percentage change in patient throughput during first month of application use</td>
</tr>
</tbody>
</table>

Tables 44 to 47 show how the case study data on the benefits that hospitals achieved with their implemented RFID applications overlap each of the benefit evaluation frameworks developed in Section 3.1.2 for the four application types that experts highlighted as promising. As the tables suggest, the case study findings on the types of benefits that healthcare delivery organizations incur when adopting advanced RFID solutions indicated that the benefit evaluation frameworks are accurate in terms of the operational purpose/benefits/ beneficiaries assumptions they make and the measures they suggest. The data collected during the case studies further supported the validity of the benefit construct measurement and valuation components of the RFID evaluation structure. How documented benefits correspond with anticipated benefits for each of the four application types is shown in the tables. (Overlaps are highlighted in green; the benefit data on which these results are based are listed under each case study in Appendix 10.)
Table 43 shows how the WMH case study data on the operational purposes, benefits, and beneficiaries of the hospital’s adopted application for portable asset tracking and management overlap (green highlighting) those identified in the portable asset RFID evaluation structure. As can be seen, the only benefit in the evaluation structure that was not borne out by the case study data is the reduction in number and duration of routine search rounds performed by central sterile department (CSD) staff to collect used assets for sterilization. The reason why this benefit did not occur at WMH was the CSD staff’s low level of system use (see detailed WMH case presentation in Appendix 10 for more details).

Table 43: Overlap of the WMH portable assets benefit results (comprehensive system) and the portable asset benefit evaluation structure from Chapter 3 (overlap in green)

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Advanced” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detect asset transition through chokepoints</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Less accidental asset loss/theft</td>
<td></td>
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<tr>
<td>Biomedical engineering department (Biomed)</td>
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<tr>
<td><strong>Identify asset location continuously (zonal)</strong></td>
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<tr>
<td>Faster asset location for servicing, annual preventive</td>
<td></td>
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<tr>
<td>maintenance, or recall (utility loss due to lack of information on status)</td>
<td>Biomed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faster asset location for immediate use (utility loss due to lack of info on status; can lead to repeated hoarding)</td>
<td>Nursing; Environmental services (ES)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drop in time needed to respond to a nurse call for patient</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>transport within hospital</td>
<td>ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to identify assets used on infectious patients,</td>
<td></td>
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<tr>
<td>reducing the spread of contagious and hospital-acquired</td>
<td></td>
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<tr>
<td>infections and improving safety of patient care</td>
<td>All</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>departments;</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Register asset status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in capital outlay and operation costs through better understanding of asset utilization patterns and facility needs</td>
<td>Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substantial staff time reduction in search rounds across</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>facility for asset servicing, annual preventive maintenance,</td>
<td>Biomed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or recall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to repeatedly carry out preventive maintenance of full asset fleet, hence improving regulatory compliance</td>
<td>Biomed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ready-for-use assets easy to locate when needed (reducing nurses’ unproductive time)</td>
<td>Nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substantial reduction in staff time spent looking for assets in routine roundup and monthly inventory</td>
<td>ES</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 44 shows how the OTC case study data on the operational purposes, benefits, and beneficiaries of the hospital’s adopted application for tracking ED–radiology department patients overlap (green highlighting) those identified in the ED workflow management RFID evaluation structure. In this case, the overlaps are limited to benefits arising from room-level patient location, which is this system’s only operational purpose. (For more information on this system, see the detailed OTC case presentation in Appendix 10.)

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Advanced” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to repeatedly carry out preventive maintenance and infection control of full asset fleet, thus prolonging assets’ useful life</td>
<td>ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of patient waiting time at point of care (through reduced asset search time)</td>
<td>Patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in number and duration of routine search rounds across facility to collect used assets for sterilization</td>
<td>Central sterile department (CSD)</td>
<td></td>
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</tr>
</tbody>
</table>

**Table 44: Overlap of the OTC ED patient tracing benefit results (basic system) and the ED workflow management benefit evaluation structure from Chapter 3 (overlap in green)**

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Advanced” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Register bed/room status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic identification of bed/room as occupied/free/for-cleaning, leading to improved room turnaround rate and faster patient throughput</td>
<td>ED; ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic identification of bed/room as occupied/free/for-cleaning, reducing staff’s patient placement coordination burden</td>
<td>ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Detect patient location continuously (room-level)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous identification of patient whereabouts, saving staff time for patient location</td>
<td>ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous identification of patient whereabouts, reducing phone calls needed for location and thus creating a quieter environment</td>
<td>ED nursing and clinical staff; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability for relatives to follow patient’s movement without having to request information from staff</td>
<td>Patients’ relatives; ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Identify patient status continuously (room-level)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display of patient’s status (e.g., infectious, at risk of falling, allergies) at room level, increasing ease of care coordination across providers and reducing latent patient safety threats</td>
<td>ED nursing and clinical staff; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application operational purposes, Benefits, and Beneficiaries</td>
<td>“Basic” system</td>
<td>“Advanced” system</td>
<td>“Comp. ” system</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
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<td>-----------------</td>
</tr>
<tr>
<td><strong>Integrate patient charts, lab, and radiology result notification</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced frequency of chart and result checks/pulls</td>
<td>ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ready availability of critical and updated information on each patient, enabling appropriate diagnostic and treatment plan</td>
<td>ED clinical staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved patient throughput, leading to reduced patient re-routing and walkouts</td>
<td>ED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved ease of care coordination and patient placement, leading to improved staff work satisfaction and reduced turnaround</td>
<td>ED</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Register asset location and status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of location of ready-for-use assets when needed (reducing nurses’ unproductive time)</td>
<td>ED nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asset availability, combined with faster patient throughput and care coordination, leading to decreased patient waiting time and LOT</td>
<td>ED; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Detect care-provider location continuously (room-level)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination of patient and care-provider movement allows identification of bottlenecks and re-design of processes, leading to improved department performance</td>
<td>ED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process and audit trail created by the high-granularity event data generated and analyzed by the application</td>
<td>ED</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 45 shows how the BHH case study data on the operational purposes, benefits, and beneficiaries of the hospital’s adopted RFID preoperative decision support system overlap (green highlighting) those identified in the ED workflow management RFID evaluation structure. Because the application did not include inventory tracking and management, the operational purpose and benefits associated with this function were not observed in the case study. (For more information on this system, see the detailed BHH case presentation in Appendix 10.)
### Table 45: Overlap of the BHH OF workflow management benefit results (advanced system) and the ED application benefit evaluation structure from Chapter 3 (overlap in green)

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Adv.” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detect pre- and post-operative bed/room availability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic identification of occupied/free/for-cleaning rooms, reducing staff’s patient placement coordination burden and improving room readiness (reducing staff unproductive time)</td>
<td>OF nursing; ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Track large mobile assets used on OF and their status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease in locating assets ready when needed for use or servicing (reducing staff’s unproductive time)</td>
<td>OF nursing; ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positively (passively) identify patient at all stages of treatment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive patient identification at any stage, decreasing risk of same-name patient mixup or wrong patient/medication/procedure mistakes</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive identification of each patient, allowing integration of data from patient’s EMR, laboratory, and radiology results, and making them readily available for patient preparation</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Association of patient’s admission and pre-operative records and delivery of positive patient identification to avoid wrong patient/wrong procedure/medication mistakes at pre-op initiation stage and to avoid re-entering administrative data</td>
<td>OF nursing and clinical staff; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positively (actively) identify patient at all stages of the peri-operative process</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous identification of room-level patient location and communication of that location to staff and family in tablet format (reducing information requests burden on staff and saving staff time for patient location)</td>
<td>OF nursing; patients’ relatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to feature a pre-, intra-, and post-operative stage team communication system that allows better patient throughput and easier communication</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positively (actively) detect staff at all stages of the peri-operative process</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creation of a real-time room-level virtual map of the OF identifying patient and staff location and status, and laboratory and radiology result notification for staff, improving ease of care coordination and patient throughput</td>
<td>OF nursing; OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration of patient and staff identification, patient admission and OF records, EMR, and laboratory and radiology results, establishes pre-operative OR team role-based decision-support system, improving adherence to clinical guidelines and evidence-based medicine</td>
<td>OF nursing and clinical staff; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface of active patient identification and staff tracking software with surgical schedule, nurse call, and wireless telephony creates centralized workflow portal, eliminating need for manual status entries and inclusion in department schedules, improving patient care coordination, throughput, and safety, and staff work satisfaction</td>
<td>OF nursing and clinical staff; OF department; Patients</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Application operational purposes, Benefits, and Beneficiaries

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Adv.” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combination of information on patient vitals, pre-operative medications, tests, scans, and executed pre-operative checks creates permanent record of patient’s pre-operative experience that can be used as an error prevention and audit tool</td>
<td>OF nursing; OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capture of data from incoming patient vitals and pre-operative record to detect OR procedure milestones (inferring higher-level events from basic data — e.g., anesthesia onset) and identify medically significant events, enabling better error prevention and creating a permanent record of the surgical process</td>
<td>OF nursing; OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Based on the above, establishment of a permanent record of patient’s pre-, intra, and post-operative experience that can be used as a process improvement tool</td>
<td>OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Track location of small assets and inventory outside the OR suite</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to enable evidenced decontamination cycle of surgical trays</td>
<td>ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interface of active patient and staff identification and equipment tracking software with surgical schedule, nurse call, and wireless telephony, improving care coordination and staff work satisfaction</td>
<td>OF nursing and clinical staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Track location of small assets and inventory within the OR suite</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of location of ready-for-use assets when needed</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to scan for accidental left-ins (sponges, tools) in addition to post-surgical manual inventory counts</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Passively identify medications and high-value inventory on the OF</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to detect use of medications on each RFID-identified patient, confirming treatment plan compliance and issuing error prevention alarms</td>
<td>OF nursing; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to detect use of high-value inventory (e.g., stents) and medications on each patient at any stage of the care process for better cost capture and better stocking</td>
<td>OF department</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Register haematological products status on the operating floor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous monitoring of products’ safekeeping conditions</td>
<td>OF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to match blood products to each RFID-identified patient at any stage of the care process, improving haemovigilance and patient safety</td>
<td>OF nursing; patients</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 46 shows how the HUG and HUJ case study data on the operational purposes, benefits, and beneficiaries of the hospitals’ adopted RFID medication preparation and bedside administration systems overlap (green highlighting) those identified in the ED workflow management RFID evaluation structure. Because patient tracking (except for close-range identification), patient EMR and RFID system integration, and asset and inventory tracking and management were not included in this application, the operational purpose and benefits associated with these functions were not observed in the case study. Furthermore, because both applications were ultimately abandoned by the two hospitals — HUJ because of the pilot’s high cost, and HUG because of technical issues — the benefits were identified on the basis of the pilot
results. (For more information on this system, see the detailed HUG and HUJ case presentation in Appendix 10.)

Table 46: Overlap of the HUG/HUJ bedside medication administration benefit results (advanced systems) and the MF management benefit evaluation structure from Chapter 3 (overlap in green)\textsuperscript{89}

<table>
<thead>
<tr>
<th>Application operational purposes, Benefits, and Beneficiaries</th>
<th>“Basic” system</th>
<th>“Adv.” system</th>
<th>“Comp.” system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detect patient location continuously (room-level)</td>
<td>MF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous identification of patient whereabouts, saving staff time for patient location</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Automatic identification of occupied/free/for-cleaning room status, leading to improved room turnaround rate and faster patient throughput</td>
<td>MF nursing; ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrate patient charts, lab, and radiology result notification</td>
<td>MF nursing and clinical staff; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display of patient’s status (e.g., infectious, at risk of falling, allergies) at room level, increasing ease of care coordination across providers and reducing latent patient safety threats</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced frequency of chart and result checks/pulls</td>
<td>MF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Register asset location and status</td>
<td>MF nursing; ES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ready-for-use assets easy to locate when needed (reducing staff's unproductive time)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify care provider</td>
<td>MF nursing and clinical staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secure, automatic nurse and clinician log-in (saving time and disincentivizing/preventing workarounds)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Identify patient (bed-level accuracy)</td>
<td>MF nursing; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive identification of patient at any point, decreasing risk of same-name patient mix-up or wrong patient/medication/procedure mistakes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easier performance of 2-factor patient authentication — patient RFID ID scanned without line of sight, no label wrinkling, no 2-hand read requirement (speeding process, preventing workarounds, and reducing physical patient touches and disturbance)</td>
<td>MF nursing; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detect inventory/medication</td>
<td>MF nursing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV bag identification — not possible with other auto ID (e.g., barcode) due to fluid content</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Reduced motivation for workarounds in medication administration process (e.g., height of IV pole makes it difficult to barcode-read, or having to multiple-scan)</td>
<td>MF nursing; patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved inventory management and re-stocking, critical for high-value short-life medication/inventory</td>
<td>MF nursing; MF department</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{89} The incomplete overlap between the evaluation structure and the results is due to the fact that the applications were tailored to support bedside administration and preparation of medications and did not include medical workflow management.
### Application operational purposes, Benefits, and Beneficiaries

<table>
<thead>
<tr>
<th><strong>Link patient and care giver ID, EMR, and real-time data on administered medication</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification and prevention of &quot;Five Rights&quot; violations in medication administration (right patient, right medication, right time, right dosage, right route), issuing STOP NOW signals prior to drug administration that cannot be overridden</td>
</tr>
<tr>
<td>Automatic creation of previously non-existent documentation on near-miss and adverse events, thus overriding the need to introduce stand-alone voluntary or mandatory medical error reporting systems</td>
</tr>
<tr>
<td>Seamless process and event data capture for better cost recording and reimbursement while reducing nurses’ administrative burden</td>
</tr>
<tr>
<td>Readily available management reports, facilitating process improvement</td>
</tr>
<tr>
<td>Ability to enhance patient EMRs with care process information that can be captured with system: patient ID, caregiver ID, IV bag ID, lab specimen ID, blood transfusion ID, EMR with allergies information and advanced directive, dietary tray ID, device and implant ID, medications reconciliation</td>
</tr>
<tr>
<td><strong>“Basic” system</strong></td>
</tr>
<tr>
<td>MF nursing; patients; MF department</td>
</tr>
<tr>
<td>MF nursing and clinical staff; MF department</td>
</tr>
</tbody>
</table>

The above-presented results suggest that the proposed RFID evaluation structures accurately capture the range of benefits and costs associated with each of the four leading near-term market-ready types of RFID and the mechanisms through which they arise. Moreover, while the results indicate, as highlighted in Chapter 3, that the evaluation structures are able to identify the range of benefits associated with promising RFID application classes, they do not suggest that all organizations will in fact achieve the full range of benefits. Nevertheless, although the eight case studies did not capture any benefits or costs not identified by the evaluation structures, it is possible that additional not-yet-identified benefits may exist. The structures also correctly identify which hospital stakeholder is the recipient of specific benefits. The case-level data collection and analysis further show that the data sources, measures, and valuation approaches proposed in the evaluation structures can in fact deliver useful guidance for RFID evaluators. The next section illustrates the results of applying these tools to assess the net benefit that WMH reaped from the hospital-wide portable asset tracking and management application it implemented.

#### 4.2.2 An example of applying the RFID portable assets evaluation structure

Figure 14 demonstrates the cost-benefit analytic result for the WMH case. I achieved this result by feeding the raw case study data I collected (available in Appendix 10) into the Excel version of the RFID portable asset management evaluation structure I developed (see Chapter 3). To ensure the reliability of the result, I conducted a separate cost-benefit analysis of these data and found that the results overlapped.

Unfortunately, due to the limited baseline information and the proprietary nature of the data in the other case studies, I could not repeat this experiment for the remaining RFID application types.
However, because the principles on which the separate Excel files were built are identical, and the case study results indicated the accuracy of the benefit and cost parameterization and valuation approaches I used in the evaluation structure, the results of the WMH experiment are sufficient for concluding that the Excel-based tools in the RFID evaluation structure can reliably assess the monetized value that the adopted RFID system brings to the healthcare delivery organization.

The evaluation structure (both the tools and the approach) thus can be regarded as reliable and can be implemented in real life as a ready-to-use customizable evaluation tool. In addition, the structure can support the evaluation needs of both care delivery organizations that implement RFID and independent evaluators in the research community that wish to collect more-robust data on the costs and benefits of advanced healthcare RFID.

![Figure 14: Cost-benefit analysis tab of WMH portable asset management RFID application evaluation matrix file](image)

Although the WMH analysis shown is incomplete, it demonstrates that the hospital reaped a significant net benefit during the first year in which the portable asset management application was implemented. In contrast, during its second year of use, the hospital registered a net loss. A closer look at the data and the implementation history for this case reveals that WMH faced high annual maintenance and support costs during that second year because the active tag batteries failed unexpectedly. (Subsequent review showed that the tag batteries were being exhausted quicker than expected because they were emitting signals more frequently than necessary.) In addition, the hospital leveraged the data provided by the application during the application’s first year of use to reconsider the preliminary budget set aside for purchasing and renting infusion pumps, but did not conduct a similar analysis for different types of portable assets during the second year. These findings suggest that even if an RFID application is successfully adopted
and leads to cost-efficiencies, it needs to continue to be put to meaningful use if it is to deliver inventory reduction related capital and operational cost savings. Its passive employment in routine care delivery can help an organization ensure its care delivery processes are efficient (including by providing readily available performance metrics), but it may not cover the application's operating costs (once an initial improvement in the utilization levels of specific assets and an initial reduction in their fleets is achieved).

4.2.3 Further case study results on the costs and benefits of the four RFID types

Due to the scarcity of detailed empirical baseline and post-adoption data and the fact that three of the RFID implementations were unsuccessful, the evidence that the case studies cumulatively deliver on RFID's costs and quality-of-care benefits is thin. However, when combined, the results of the eight case studies show that promising healthcare RFID applications, if successfully implemented, can improve healthcare delivery in the hospital setting, delivering operational benefits in terms of care quality enhancement and healthcare delivery cost containment.

Most notably, the results suggest that the aspects of care most substantially impacted by the promising RFID applications are, in order of magnitude:

- Cost of care:
  - patient placement
  - productive staff time
  - capital outlays
  - non-labor operating costs

- Quality of care:
  - care coordination
  - patient-centeredness
  - continuous quality improvement
  - patient safety.

A large portion of the benefits realized by the studied RFID applications relate strongly to money saved (as hypothesized in the cost-benefit evaluation frameworks developed in Chapter 3). These first-order benefits arose from:

- better ED patient pathway coordination, leading to more-efficient patient placement and reduced numbers of patients leaving without treatment (OTC case)
- more-streamlined perioperative patient care coordination, which is associated with more-efficient patient throughput and reduced staff time spent on non-care-essential tasks (BHH case)
- more operational and capital cost savings due to reduced portable asset fleets (WMH case)

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90 Case-level evidence on these results is available in Appendix 10.
• better auxiliary services coordination, leading to labor savings (OTC, WMH, BHH, RAH, HUG cases)
• a reduction in clinical staff’s non-patient-essential activities (e.g., re-entering administrative information, locating patients or assets) (OTC, BHH cases)
• better retrieval of clinical information at the patient level and detection of potential adverse patient safety events, reducing the likelihood of medical errors (BHH case)
• better clinical process support, enhancing adherence to clinical guidance and protocol-based care (e.g., verifying that all pre-operative checks are carried out) (BHH case).

In addition, the case studies reveal that promising RFID applications, through their event and process capture and their audit functions, can support a continuous loop of healthcare process quality improvement at the organization level (as in the WMH, HUG, and BHH cases).

Furthermore, the availability of reliable empirical evidence provides care delivery organizations with a way to identify process segments whose alteration can critically improve overall process outcomes and to test how different process changes impact overall outcomes. Finally, advanced RFID applications can function as a tool to quickly identify and respond to critical situations by providing hospital administrators with real-time information on critical performance metrics (e.g., pre-surgical antibiotics administration time, as in the BHH case).

4.2.4 Findings on the factors that affect the costs of advanced RFID in the hospital setting

Due to the scarcity of detailed empirical baseline and post-adoption cost data, the case studies did not supply strong evidence on how RFID implementation and ongoing costs vary across RFID application types and levels of sophistication. Nevertheless, the cases provided sufficient data to suggest that:

• RFID systems’ technological composition varies greatly even across same-type solutions, and so do their hardware and software costs
• The total implementation and operational costs of different RFID applications also differ greatly, from insignificant (e.g., the OTC case) to prohibitive (e.g., the HUG case).

Available data also indicated that an advanced RFID application’s implementation costs are strongly correlated with how well an implementation is thought through and carried out, and whether the adopted RFID application is:

• proprietary (as in the AMC case) vs. open source (as in the OTC case)
• commercial (the WMH case) vs. developed in-house (the UHJ case).

Several other cost-related conclusions can also be drawn on the basis of the collected evidence:

• Implementation hardware and training costs are likely to vary most substantially with facility size and application scope (e.g., the differences in the implementation costs of the WMH and RAH portable asset applications).92

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91 RFID asset-related and hospital logistics applications are the most successful (i.e., in terms of providing sound ROI evidence) of the four classes of healthcare RFID solutions deemed promising by the experts.

92 The limited comparability of cost data across cases, which stemmed from critical differences in engineering design (e.g., zonal-level vs. room-level signal coverage) and in data availability (e.g., detailed data being treated as proprietary information), made it impossible to establish a quantitative relationship.
For hospitals, the largest cost component of application adoption is staff time spent during the pre-launch, design phase of RFID implementations — mapping the processes to be altered and identifying desired system functionalities. This cost is correlated with hospital size and application scope, ranging between one and two years for most applications, of which one to six months are devoted to studying existing departmental processes and activities (OTC was at one end of the spectrum with one year of concept-to-pilot time; BHH and UHJ, with over two years, were at the other end).

Conversely, system software and maintenance costs (labor and hardware) appear not to be as responsive to facility size (as shown in the WMH and RAH portable asset cases). Therefore, the implementation costs for advanced healthcare RFID applications can be characterized as having scale efficiencies with respect to hospital size. This does not apply to their maintenance costs.

4.2.5 Findings on the factors that affect the benefits of advanced RFID in the hospital setting

The case study results on the benefits of the advanced healthcare RFID systems that were highlighted by the experts as promising showed that:

- The benefits of advanced RFID applications are highly dependent on how successful hospitals are in identifying whether RFID is the technology that can best address the issues they are being confronted with, and what engineering options and operational functions the RFID system should have to successfully meet its goals. For example, system engineering design problems were leading factors motivating AMC, UHG, and UHJ to abandon their RFID applications; in contrast, they facilitated the pilot-to-hospital-wide use scaling of the WMH application.93

- Even if advanced RFID systems belong to the same application class, they produce different benefits when implemented in different healthcare delivery organizations, as their effects depend on how the system’s information is used and the process of implementation. The AMC and BHH OF process and workflow management applications serve as two good examples. In the AMC case, data derived from the application were not used for process analysis or redesign, and the application was ultimately deemed to be of limited value to the organization for different reasons, including the fact that staff buy-in was never achieved for the implementation (see Section 4.3 for more details). At BHH, the RFID application is used for continuous process analysis, staff adoption was ensured by addressing any emergent concerns on the technology, and staff adoption is high, leading to significant benefits for BHH.94

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93 Section 4.3 presents more details on the factors that emerged from the cases as influencing adoption success and adoption failure.

94 For details on the role these factors played in the success and value that hospitals attributed to the applications they adopted, see the detailed case descriptions in Appendix 10.
The case studies also indicated that while some types of market-ready RFID solutions may be beneficial to healthcare organizations of all magnitudes (e.g., pre-operative milestone decision support systems, medication management solutions), other RFID applications are likely to deliver the greatest added value to medium-sized and large organizations (e.g., portable asset tracking and management systems, ED workflow management systems). This relative distinction is driven by the source of the identified benefits. As the WMH, RAH, and OTC cases showed, portable asset and ED management solutions are applications whose returns are associated with:

- facility scale (e.g., RAH’s reduction in unproductive staff time spent searching for portable assets for routine inventory)
- patient volume (e.g., OTC’s reduction in unproductive staff time spent responding to requests for information from patients’ relatives)
- lack of visibility in complex and busy environments (e.g., WMH’s reduction in unproductive staff time spent searching for portable assets for immediate use).

Analysis of the distribution of each type of RFID application across small, medium-sized, and large U.S. hospitals in the HIMSS Analytics 2009 data supported this finding. As Figure 15 shows, in early 2009, patient tracking, portable asset management, and inventory management applications (the benefits of which are strongly correlated with the three factors outlined above) had diffused more widely across large hospitals than across medium-sized and small facilities. The same statistically significant differences held for applications under implementation. Laboratory, radiology, pharmacy, and medication administration RFID systems were, in contrast, more widely diffused across small facilities (see Figure 16), which also tended to be more likely to experiment with other types of HIT.95 Large and medium-sized hospitals appeared to be closing this gap, ramping up ongoing implementations of such applications.

Figure 15: RFID application types in use as of January 2009, share of same-size hospitals

![Diagram showing the distribution of RFID application types in use as of January 2009, share of same-size hospitals.](image)

95 Fonkych, 2005.
The fact that a proportionally larger share of medium-sized and large hospitals adopted high-value inventory management, portable asset management, and patient tracking RFID applications, however, hints that the added value of applications for inventory/asset/patient management and tracking is particularly high for busier or larger enterprises in which the visibility of work, process, and patient flows is limited yet critical. Limited IT budgets and the need to prioritize investment decisions may be the driving factors behind this distribution. This hypothesis, however, could not be substantiated with causal analysis due to the small data sample sizes.

A more-detailed analysis further revealed that facilities simultaneously operating more than two RFID applications tended to be of medium and large size. One large urban hospital was identified as the owner of the maximum number of concurrent RFID systems: seven. This finding corroborates the hypothesis that while small hospitals actively experiment with healthcare RFID, the majority of them invest in stand-alone department-level solutions. Unfortunately, no data were available in the database on the integration of adopted RFID solutions with other HIT systems.

4.3 Identified critical issues for successful adoption of advanced healthcare RFID applications

This section discusses the factors that emerged from the case study interviews and data analysis as primary drivers of adoption failure and success based on the information collected on the seven analytic themes that I examined in each case study (as discussed in Section 4.1.2). Detailed descriptions of the case-level findings of this analysis can be found in the “Implementation success enablers/barriers” section of each case study presentation in Appendix 10.

96 Compared with the share of large and medium-sized hospitals having adopted RFID applications for patient registration only, and in their pharmacy, radiology, and laboratory departments — i.e., more isolated, stand-alone applications with departmental coverage.
4.3.1 **Observed adoption failure factors**

Of the eight case studies included in my research design, three were ultimately abandoned: AMC, UHJ, and UHG (chemotherapy preparation application).

The factors that motivated the hospitals to abandon these applications can be subjectively summarized as follows:

- **Not addressing staff concerns and securing buy-in:**
  - Not answering staff’s skepticism during application design is likely to be an issue. For example, AMC staff were not convinced that RFID technology would be the right solution to reduce the administrative burden and produce a flawless measurement of processes, particularly given that wireless communication was not available in the OR. To prove their point, they experimented with the electromagnetic interference that RFID can cause, and their experiments were ultimately successful in showing that under extreme circumstances, RFID could interfere with several types of clinical equipment, including external ventilators and syringe pumps (these findings were published in van der Togt et al., 2008). As a result, one of three pilots was not conducted as originally planned.
  - Not responding to staff’s privacy concerns during implementation can pose problems. For example, AMC staff were concerned about the way in which individual-level performance data collected through the RFID system would be used. Although the worker’s council did not find the aims of the application in conflict with staff privacy protections, AMC staff were allowed the choice of wearing or not wearing an ID badge. Half of the OF staff chose not to wear a badge, adversely affecting the value of the information delivered by the application.

- **Attempting to create in-house an RFID application designed to improve the safety of clinical care by integrating RFID components provided by multiple vendors.** This can be a very complex and error-prone approach, resulting in a system that does not resolve the problems it was supposed to address:
  - Integrating in-house technology components from different vendors is likely to pose significant challenges. For example, at HUG, labels were sometimes printed erroneously, and printer software did not notify the user when errors occurred, resulting in diminished confidence in the printing process. At UHJ, the physical size of the RFID tags prevented them from being attached to ampoules, a problem discovered after the components for the pilot were purchased. The pilot tags were also of poor quality and were discovered to be overly expensive compared with alternative tags that could have been used. In the UHJ case, such integration ultimately resulted in up to 2% of all signal reads being unsuccessful, which was enough to deem the system completely unreliable. (Staff subsequently tried to repeat the interference tests carried out at AMC. They were not able to replicate the interference but decided anyway to abandon the system due to its unreliability and high pilot cost.)
  - Errors in overall system design can make the system non–user friendly and stifle its adoption by staff. For example, the automatic sleep mode of screens at HUG made it necessary for staff to execute emergency re-booting of the entire system; and in one case, this additional task delayed the scanning process by three to five minutes. Furthermore, staff had to remove patient wristbands for certain routines and found components of the RFID application very easy to lose, leading to staff resistance to the application.
Cumulatively, the AMC, HUG, and UHJ cases show that it may be more challenging to successfully implement RFID applications primarily aimed at patient safety than to successfully implement the three other promising types of RFID applications. One root cause of failure for these systems lies in errors in their adoption process — e.g., inadequate consideration of the application’s full range of organizational impacts during the planning stage. Other causes stem from the technology itself — unlike logistics applications, these applications require nearly 100% signal reliability, which has to be achieved by working around the complexity of hospital environments. In-house design of such systems may be unsuccessful when technology from multiple vendors is used (although the BHH case shows that in-house systems can be designed to meet a high standard of system and information quality). These findings suggest that until more data and best practices on RFID are collected, implementation failure will remain a credible threat for advanced healthcare RFID adopters.

4.3.2 Observed adoption success factors

Unlike the three applications that were ultimately abandoned, five of the applications included in my research design were successfully adopted: those at WMH, RAH, OTC, BHH, and UHG (garment management application).

The factors which facilitated the successful adoption of these applications can be subjectively summarized as:

- Investing heavily in system design and integration. To identify what functions an advanced RFID application should perform, how it can be integrated into existing organizational processes and workflows and how it can be used to re-design them, WMH, BHH, HUG, and OTC translated the processes/workflows they sought to improve into electronic form, formalized different stakeholders’ knowledge (e.g., terminology used by different staff to refer to specific activities/locations) and conducted several rounds of working sessions with all prospective users of the applications in order to achieve agreement on how the applications are to function and what their objectives will be. All of this demanded a considerable investment of time and human resources.

- Understanding and addressing, in the design phase of the application, the full range of concerns that staff expected to use the application may have. For example, in addition to providing data drill functions for the more-advanced users, WMH included a touch-screen function to make the application less intimidating to staff with limited computer and overall literacy.

- Designating an institutional “owner” of the application that oversees the functioning and maintenance of the RFID application after it is introduced. WMH did this.

- Sharing the process quality and efficiency results that different units or departments have achieved by using the application widely across the organization in order to create incentives for units/departments not making effective use of the application to put more effort into doing so (and in this way integrating the application in the hospital’s continuous quality improvement plan). WMH and BHH both did this.

- Matching the RFID system with the organizational complexity/variability and the institutional context by involving institutional stakeholders, end users, and system support staff early in the application’s design process. WMH and HUG did this.

- Working with technology vendors that are vested in the success of the pilot and willing to tailor it to the needs and requirements of the adopting facility. This was done by WMH, RAH, and BHH.
When combined, the experiences of the five successful RFID adopters suggest that successful implementation of RFID applications, and of other types of HIT, demands a thorough understanding of the special requirements of a hospital environment and cannot be accomplished using generic, non-customized applications. Thus, simple replication of RFID systems and their impacts cannot be easily achieved. The combined experiences further show that RFID patient and staff tracking functionalities tend to bring out initial resistance from these user groups, which can be overcome if addressed on time with education (and, for staff, inclusion in the application’s design). It was also found that the RFID applications involving staff and patient tracing do not pose a threat to individual privacy or data security, since they typically carry only an ID number and are restricted to covering actors only in their professional realm of action. Finally, the combined experiences indicate that the value of an RFID system is truly achieved, and sustained, only by analyzing on a regular basis the granular time-stamped data these applications produce, sharing the insights resulting from the data analysis across stakeholders, and using those insights for process/workflow refinement.

### 4.4 Summary of key findings and implications

The case studies had three main aims:

- to validate the cost-benefit evaluation structure I proposed
- to collect evidence on actual RFID benefits and costs in different organizational environments
- to identify the critical factors affecting the value that adopters can derive from promising RFID applications.

The key findings arising from the eight case studies for each of the three aims are:

- The evaluation structure (tools and approach) can be implemented in real life as a ready-to-use customizable evaluation tool. The structure accurately captures the benefits and costs associated with each of the four leading near-term market-ready types of RFID and the mechanisms through which they arise. The cost and benefit construct, measurement, and valuation components of the four separate evaluation structures can be used to capture and assess the applications’ impacts. The Excel-based tool in which the structures are built can reliably assess the monetized value that the adopted RFID system brings to the healthcare delivery organization.

- Thus, the evaluation structure can support the evaluation needs of both care delivery organizations that implement RFID and independent evaluators in the research community that wish to collect more-robust data on the costs and benefits of advanced healthcare RFID.

- Although the collected quantitative data were limited, they were sufficient to suggest that the group of four promising RFID applications can positively affect both the cost (e.g., efficiency) and the quality (e.g., timeliness, capacity for continuous improvement) of care delivery. The majority of the benefits achieved by hospitals with successfully implemented RFID solutions are also directly related to money saved (occurring as direct capital and operational cost savings). The technology-related implementation problems that were faced by adopters of quality-focused applications (the two medication management applications) imply that the patient safety gains associated with advanced RFID may be more difficult to achieve than other quality and cost-related gains.
The benefits of portable asset and ED management RFID applications are positively correlated with facility scale and patient volume and thus are likely to deliver greatest added value only to medium-sized and large organizations. The benefits of OF and MF applications are less strongly related to these factors and can thus be assumed to occur regardless of hospital size. These findings are supported by the analysis of the diffusion level of the different applications across small, medium-sized, and large U.S. hospitals in January 2009.

The critical factors affecting RFID’s potentially positive impact on healthcare quality and cost-efficiency are similar to those affecting HIT in general (e.g., need of leadership involvement in change management, organizational culture and norms). Yet some are RFID specific. These include managing the integration of RFID-generated data, proactively identifying and addressing staff’s privacy concerns, managing RFID scalability, willingness to incur high upfront system design and implementation costs, willingness of RFID application suppliers to tailor solutions to adopter’s needs, and errors in RFID system design and integration.

The experiences of the three hospitals that ultimately abandoned their RFID systems showed that even organizations that had previously succeeded in implementing other types of HIT were confronted with RFID adoption challenges they could not successfully resolve but that other case study sites successfully overcame. This, along with the finding that the majority of studied hospitals did not approach the implementation of an RFID application as a process requiring ex-post evaluation and analysis, suggests that there is a need for more-rigorous evaluation of RFID implementation and outcomes in healthcare. Such evaluations would allow best practices to be collected for this technology class — valuable information not now readily available to RFID adopters.

The case studies also show that because of the critical factors affecting RFID’s potentially positive impact on healthcare quality and cost-efficiency (given above), the individual and organizational impacts of identical RFID applications will not be the same in every hospital. Although the benefits of such applications are highly dependent on an application’s potential benefit spectrum, they also depend on the solution’s design (the quality of the system and of the information it produces) and on information use, context of use, user’s satisfaction, and the process of implementation (as is the case with other HIT). Thus, the overall value and success of healthcare RFID applications are likely to also depend on the adopting organization’s capacity to self-innovate, which is assumed to include the ability to successfully identify areas for improvement and for defining relevant improvement measures, as well as the ability to provide strategic leadership for implementation. Given the existing evidence on the multiple difficulties of HIT diffusion, this implies that not all institutions that adopt an RFID system will succeed in introducing the technology in their environment, and that not all organizations will be able to derive the maximum potential value of RFID applications.
CHAPTER 5 Summary of Results, Study Conclusions and Policy Implications

Having already presented the results of the analysis I conducted to address the first three research aims I formulated in Chapter 1 as specific objectives for my dissertation, in this chapter I summarize the key findings of Chapters 2 through 4. In addition, I highlight the study’s contributions to knowledge and address the final research aim of my thesis: To derive conclusions about the merit of public policy action on the use and further diffusion of RFID in healthcare. The chapter concludes by outlining the key directions for further research on RFID use in healthcare.

5.1 Objective, results and contributions of this dissertation

The key policy question my dissertation sought to answer was: What are the most-promising means by which RFID can address currently outstanding issues in the quality and cost-efficiency of healthcare delivery over the next five to ten years, and are any policy actions on healthcare RFID needed?

To answer this question I pursued four specific research aims:

5. Describe today’s universe of RFID use in healthcare, and identify the RFID applications expected to have the largest positive impact on healthcare delivery over the next five to ten years.

6. Develop a set of cost-benefit evaluation tools that can be used to understand the impact of the identified RFID applications on the quality and cost of healthcare delivery at the healthcare organization level.

7. Conduct case studies of actual healthcare RFID implementations to validate the evaluation tools, to collect evidence on actual RFID benefits and costs in different organizational environments, and to identify the critical factors affecting the value that adopters can derive from promising RFID applications.

8. Derive conclusions about the merit of public policy action on the use and further diffusion of RFID in healthcare.

Chapters 2, 3, and 4 addressed the first three of these aims. The next paragraphs summarize the analytic approaches, key results and contributions to knowledge of each chapter.

Chapter 2 presented my attempt to conduct an original comprehensive review of RFID uses in healthcare as of April 2009. Through analysis, I found that the universe of ways in which RFID is being used today to support healthcare delivery is expansive. It includes applications designed for use in the inpatient setting, applications tailored to the needs of care delivery in the outpatient...
setting, and applications for use in patients’ homes. I also found that anecdotal quantitative information on the benefits and costs of different types of RFID applications was abundant and indicated that existing types of RFID have successfully been used to address some of the outstanding issues related to the quality and cost-efficiency of healthcare delivery.

Yet rigorous quantitative data on the benefits and costs of RFID applications was available in only 6% of the 436 information sources captured in my analysis. In addition, the data shed light only on some benefits and some costs for some RFID application types. In consequence, it was impossible to conduct a comparative analysis of the potential of different types of RFID to positively affect the quality and cost-efficiency of care delivery.

To circumvent this problem, and to distill a priority list of “promising” healthcare RFID applications — i.e., those likely to have a sizable positive impact on the quality (safety, timeliness, continuity, effectiveness) and the cost (staff time/resource efficiency, cost-efficiency) of healthcare delivery over the next five to ten years — I then conducted an original study of experts’ opinions. In interviews with 15 RFID experts identified in the course of my literature review as representing the key healthcare RFID stakeholder groups, four types of healthcare RFID applications were highlighted as leading in their capacity to improve the quality and/or reduce the cost of healthcare delivery in the U.S. over the next five to ten years:

- portable hospital asset tracking and management solutions
- hospital emergency department (ED) process support and workflow management solutions
- hospital operating floor (OF) process support and workflow management solutions
- hospital medical floor (MF) and bedside medication management solutions.

I also used the experts’ opinions to understand the range of views different stakeholders may hold on two issues relevant to RFID’s diffusion:

- the surveillance threat and potential privacy intrusion associated with healthcare RFID
- the lack of RFID industry standards ensuring RFID’s non-interference with other clinical systems or biomedical implants.

Interviewees uniformly identified both of these issues as non-credible, in the first case because of the strict privacy laws governing personal health information and the technological limitations prohibiting ubiquitous monitoring of RFID-identified objects; in the second, because the one RFID interference experiment currently available in the peer-reviewed literature cannot be replicated.

The interviewees did, however, highlight the critical need for a coherent system of cost and benefit constructs, variables, and measures that can be employed to comprehensively assess the costs and benefits associated with implementing different healthcare RFID solutions in healthcare delivery organizations. According to one respondent, “Without such evaluation tools, more objective information of the real-life outcomes and costs associated with deploying RFID solutions in healthcare will not become available, and it will remain unclear how RFID impacts the quality and cost-effectiveness of healthcare delivery and what value do specific RFID applications bring to different types of organizations.”

In Chapter 3, I described the first step I took to gain a better understanding of RFID’s potential in healthcare: developing my four proposed cost-benefit evaluation structures — one for each type of RFID application the respondents had identified as promising. The structures address two critical questions that RFID adopters and evaluators need to have answered:

- What benefits and costs do healthcare delivery organizations experience when they adopt a specific RFID application type?
- How can these be systematically evaluated?
To develop these structures, I conducted a secondary analysis of the literature and interview data I had collected, focusing on the specific benefits and costs that the information sources associated with each of the four promising application types. The goal of this analysis was to identify the benefits and costs associated with each application type, the RFID operational purpose that produces each reported benefit, and how application types can be categorized by the range of operational purposes they perform (using frequency-of-information cross-referencing across sources as an indicator of the information’s face validity). This analysis showed that:

- same-type applications have varied degrees of sophistication — i.e., functionality layers
- the size and range of RFID benefits are strongly proportional to system sophistication
- cost dimensions do not vary across inpatient RFID application types
- unlike benefits, the majority of costs are already monetized.

I created a separate benefit framework for each application type, and a common cost framework for all four application types. These frameworks offer a unique way to:

- identify the types of benefits and costs experienced by healthcare delivery organizations when they adopt one of the four RFID applications highlighted by the experts as leading in their ability to improve the quality and/or reduce the cost of healthcare delivery in the U.S. in the next five to ten years
- define how promising RFID applications operate
- determine how differences in the engineering and operational purposes of specific promising healthcare RFID applications affect the benefits that can be derived from these applications and their costs
- identify where the value of promising RFID for improving the quality and cost-effectiveness of healthcare delivery lies.

Using the information I captured in the benefit frameworks, I was able to outline the types of outstanding care quality and cost issues that can be addressed with promising RFID. These include:

- quality of care:
  - limited process and event visibility and data to support continuous quality improvement
  - limited ability to center care on the patient (limited patient-centeredness)
  - difficulties in coordinating patient care
  - patient safety challenges

- cost of care:
  - outstanding issues in patient placement and throughput associated with workflow inefficiencies
  - unproductive use of staff time
  - capital outlay growth due to low utilization of available infrastructure and resources
  - growth in non-labor operating costs.

Turning to existing empirical and theoretic studies and evaluation frameworks for HIT, I next identified tested measures that can be used to capture the identified RFID benefit and cost variables, sources for baseline data for each variable, and valuation approaches that can be used to monetize these variables. I summarized these data in valuation tables for each promising RFID type and then transferred the benefit and cost frameworks and the valuation tables into four
separate Excel files, one for each promising application type. In these files, I created a cost-benefit analysis tab in which cost and benefit data available from the preceding tabs are transferred and used to estimate the net financial impact that the application’s adoption will have on the organization. Ready-to-use, and without a present alternative, these four evaluation structures provide healthcare RFID adopters, sponsors, and independent evaluators with a set of constructs, variables, and measures that can be used to systematically assess the impacts of RFID applications on the quality and cost-effectiveness of the processes they are expected to improve. Each of these evaluation tools is also intended to support the further collection of more-robust evidence on RFID’s potential in healthcare. Implemented on a larger scale, the evaluation structures can support the meaningful comparison of RFID applications of different kinds and levels of sophistication, as they are based on the same evaluation approach and use a common set of metrics.

In Chapter 4, I presented the between-case cross-application results of eight case studies I conducted to validate the evaluation structures, to assess the actual benefits and costs experienced when hospitals implemented each of the four promising RFID types, and to identify the critical factors affecting the value that adopters can derive from promising RFID applications. Conducted in seven hospitals in the U.S. and Europe, these case studies represent an original attempt to use a systematic evaluation approach to explore how the benefits and costs of leading types of healthcare RFID vary with organizational environment and why. Because the primary objective of the case studies was not to derive absolute-size cost and benefit information, but to test the validity and usability of the evaluation structures (developed on the basis of U.S. experience with RFID) and identify the critical issues in RFID use, the inclusion of non-U.S. cases did not adversely affect the relevance and validity of the case study findings. Moreover, because three of the eight RFID applications were ultimately abandoned by their adopters, the case selection allowed me to determine which factors facilitate adoption failure and which facilitate adoption success.

The individual case studies focused on seven analytic themes:

- institutional context (e.g., hospital size)
- RFID technological characteristics (e.g., passive tags)
- implementation adoption facilitators
- implementation adoption obstacles
- application costs
- application benefits
- degree of staff adoption and perceptions.

Primary data were collected through:

- face-to-face and/or telephone interviews with the developers and users of the applications
- pre- and post-implementation financial and operational data on the cost of implementing the applications and on the impacts they have had on the processes and work flows they support
- existing evaluations of the applications (if any)
- direct observations during site visits.

During data collection and analysis, my primary emphasis was on testing alternative causal explanations for the impacts of the implemented applications. To this end, I sought to procure
detailed direct and indirect cost and benefit data and to use interviews with multiple stakeholders to establish the reliability of reported information on how the costs and benefits of the application were realized.

After data collection was completed, analyses were first done on a within-case basis, as required by this research design (the raw case-level results on the seven analytic themes are summarized in Appendix 10). Patterns of similarity and difference, revealed by comparing the cases on common variables, were then used to reach between-case, cross-application conclusions.

The case study analysis showed that my four proposed RFID evaluation structures offer valid assumptions on:

- the spectrum of costs and benefits they identify for each of the four promising application types (per sophistication level/operational functions)
- the data sources, measures, and valuation approaches they propose
- the unit of analysis they are based on
- the cost-benefit evaluation approach they leverage.

Although the evidence is thin — because of the proprietary nature of some of the hospitals’ performance data, the absence of detailed empirical pre- and post-implementation benefit data, and complicated implementation processes (in which implementation, process redesign, and training cost data were fragmented) — the results from the successfully implemented case studies indicate where the benefits of the promising RFID applications lie. These studies — two portable asset management applications, one OF workflow management application, one ED workflow management application, and one inventory-management application — indicate that the benefits arise from reducing operational and capital expenditures by increasing process efficiency and increasing the utilization level of available resources, and increasing revenue by improving patient throughput (as opposed to the strong emphasis on quality-of-care benefits delivered by other types of HIT). The data collected in these cases further show that logistics and workflow-management applications deliver benefits that are correlated with patient volume, i.e., hospital size. This correlation did not hold for the applications’ costs, however, the bulk of which is associated with the design stage (lasting one to two years) and organizational process mapping and re-design (lasting one to six months), which are relatively independent of facility size (as opposed to hardware cost). Combined, the cost and benefit results on these systems suggest that busy medium-sized and large hospitals stand to benefit most from adopting such applications. This hypothesis was borne out by the results of an analysis I conducted, using January 2009 data (obtained from the 2009 annual HIMSS Analytics HIT U.S. Hospital Sector Survey), on the diffusion of different types of RFID across hospitals of different sizes, profit status, and location (urban vs. rural).

The findings from the successful implementations also showed that, like other HIT, RFID’s value comes with process redesign. Yet unlike other HIT, some RFID applications make process redesign mandatory, not optional — for example, in the case of portable asset management applications or patient tracking applications that completely substitute for pre-existing processes. Other observed success factors in the five successful implementations included:

- investing in system design and integration, and bringing all stakeholders into the design process early
- designating an organizational “owner” of the application
- choosing an RFID provider committed to growing this segment.

In contrast, the RFID implementations that were abandoned — two bedside medication management applications and one OF workflow management application — brought to light two key factors likely to lead to implementation failure:
• failing to address staff concerns and to secure buy-in early in the adoption process (including, for example, concerns about the capacity of RFID technology to perform the task for which it is being implemented and concerns about its privacy implications)

• attempting to create in-house an RFID application that is expected to deliver very high information reliability by integrating RFID components provided from multiple vendors (an approach that can result in system error rates surpassing the acceptable threshold, and pilot budget overrun).

These cases also showed that even hospitals that have successfully implemented other types of HIT can fail in their attempt to adopt advanced RFID applications, and that part of that risk can be attributed to the limited information available on best practices for this technology cluster.

5.2 Key conclusions emerging from the study’s results, and the case for policy action on RFID

The combined results of the analyses described in Chapters 2 through 4 highlight four key policy-related conclusions:

• Currently existing types of healthcare RFID technology aimed at workflow redesign have the potential to improve the quality and cost-efficiency of healthcare delivery in the inpatient setting. However, the existing evidence on the size of the impacts that these applications can have is thin.

• The benefits delivered by advanced RFID applications appear to relate strongly to dollars saved (through reductions in operational and capital expenditures and increases in hospital revenue). Thus, if the business case for investing in these applications can be demonstrated (through more-robust data on the impacts they produce) and the risk of implementation failure can be minimized (through a collection of best practices on RFID design and adoption), hospitals are likely to adopt these technologies without special regulatory support.

• Healthcare RFID does not now pose a privacy threat, since confidential patient data are not stored on RFID tags (which are the system component most vulnerable to unauthorized reading) and staff identification is used to support only professional activities. Thus, no policy actions are needed for healthcare RFID to diffuse safely. This may change, however, as outpatient types of RFID that involve embedding RFID tags directly into humans or storing sensitive data on tags in systems shared across facilities mature in the medium-to-long run.

• Healthcare RFID success depends on the collection of a critical amount of best practices for implementation and more-robust evidence on impacts. Proof-of-concept funding may thus be merited, especially funding tied to systematic evaluation and reporting of adoption strategies and outcomes, so that more evidence can be collected on the impacts of different RFID application types and best practices on adopting and extracting value for RFID. Given the large number of under-performing hospitals (frequently, large public hospitals) likely to benefit greatly from the improvements these applications can deliver — but also highly likely to be unable to successfully implement these applications due to insufficient innovation management capacity — the case for proof-of-concept funding to collect more evidence on benefits and best practices with healthcare RFID is even stronger.

Finally, the study produced a set of tested, ready-to-use, customizable RFID evaluation tools that can be used by hospitals investing in RFID, funding agencies, and independent evaluators to
5.3 **Directions for further research**

Given the critical need for more and more-robust data on the benefits and costs of individual types of healthcare RFID, further assessment of successful and unsuccessful RFID implementations should be considered a priority for further research. Collecting comparable and reliable data on the benefits and costs of different RFID application types through the evaluation structures will also enable the research community to answer the question that naturally follows from this thesis: What quantitative effects will their further diffusion in healthcare have on the quality and cost-effectiveness of care delivery at the national level?

A second important direction for further research is establishing an evidence base on best practices for RFID use in healthcare. As noted above, the existence of such data is a critical precondition for making healthcare RFID more accessible to under-performing hospitals. Understanding how hospitals can use specific RFID applications to re-organize their existing processes in order to resolve specific care delivery challenges they face will further stimulate the diffusion of healthcare RFID. In the medium term, the availability and analysis of such data can also help to identify specific policy changes through which the Centers for Medicare and Medicaid Services (CMS) can improve overall organizational performance among healthcare delivery organizations and can incentivize the provision of more-efficient and better care at the healthcare system level.

As a rapidly developing technology, healthcare RFID is likely to continue to evolve fast in the coming years. Changes in the functional range of already advanced applications can be expected, as can the emergence of altogether new solutions. Currently promising but not yet market-ready solutions — such as RFID solutions for the management of home-based intelligent medication regimens and for subcutaneous implant supporting healing and clinical management — are likely to mature and start diffusing in their relative markets. Simultaneously, currently leading healthcare RFID applications are likely to see wider adoption across U.S. hospitals. These anticipated changes create a third domain for further research on healthcare RFID: assessing how newly emerging RFID application types bear on process and outcome care quality and care cost, as well as on patient and staff privacy, data security, and the potential wireless-band saturation. What diffusion paths these technologies are likely to face would be a relevant question.

Finally, RFID’s capacity to automate workflows and processes leads to another topic worthy of further research: How RFID’s use in the logistical processes surrounding care delivery can affect the cost and/or quality of healthcare by altering the supply chains of medications, assets, or inventory. One example of much-needed work in this domain is determining the impact of using RFID vs. barcodes for evidencing the origin of pharmaceutical products (their e-pedigree) in an effort to reduce the use of counterfeit drugs.
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Appendixes
Appendix 1: Healthcare RFID technology, brief reader

As outlined in Chapters 1 and 2, although RFID is frequently referred to as a wireless chip-and-reader technology, in the context of healthcare delivery it is a system of interfaced hardware, software and middleware providing unique identification and geolocation (and in the case of active RFID – continuous geolocation, or tracing; see Figure 1 below). Other engineering tasks healthcare RFID applications perform include carrying pre-recorded data and time-stamping tag-reader interactions, an underlying factor in which is machine-to-machine communication occurring between the hardware, software and middleware components of an RFID system. As such RFID applications comprise five to six key components that can be grouped in two main categories: hardware (including RFID tags, readers – portable and fixed, collectors and servers) and software (middleware and system applications). Hardware components are tasked with the unique wireless identification, and physical location (proximity to designated landmarks) at the item/person level, and the collection and transportation of this high-granularity data to a host server where the software components of a system transform it into meaningful and useable information fed into different web-based applications. RFID systems can operate on a stand-alone network of RFID readers and collectors, or can be embedded into a hospital’s WiFi or WLAN infrastructure.

Figure 1: Healthcare RFID system components
As used in healthcare, RFID can be classified across a number of dimensions, among others depending on:

i) whether the RFID tag is battery-powered and emits its own signal, or not – i.e. active and passive tags, which also determine the size and strength of the signal (maximum distance currently stands at 100 feet;

ii) what frequency on which the data is transmitted – e.g., low frequency, high frequency, ultra wide band

iii) whether the transmitted data operates within a single application only (closed-loop system), or is shared across applications, and possibly across institutions (open-loop systems)

Of these, currently the most frequently used differentiation is that between active and passive tag RFID applications. Passive RFID tags are machine-readable tags which use radio frequency to collect data from a distance, instead of the close proximity required by barcode label. A passive RFID tag only transmits its tag ID via RF when a passive RFID reader energizes the tag. The advantages of passive RFID tags are longer read ranges, the ability to read multiple tags at once, fast tag reads and small physical size. The drawbacks of passive RFID include read accuracy problems at longer distances and higher tag costs. Also, like barcode and traditional ID tagging to track IT assets, passive RFID tagging is labor intensive and batch oriented. Passive tags are relatively small and inexpensive; each tag costs between $0.50 and $1 (see Figure 2 for visual examples of the two types of tags). Active RFID tags are always “on.” They are constantly transmitting information to an active RFID reader. Their big advantage lies in their ability to simultaneously offer real-time communications, extremely long read ranges, and highly accurate processing. Active RFID tags have the concept of online or offline. This means the asset the tag is attached to is constantly monitored, just like connection status on a TCP/IP network. The larger tag size and higher upfront tag cost - an active RFID tag can cost $30 to $80 - are sometimes thought of as a drawback to this particular approach. However, they have a fast ROI.

Figure 2: Healthcare RFID tags – passive (left panel) and active (right panel)

According to Nagy et al (2006) RFID applications can be further differentiated across on the basis of three other specifications:

iv) the tag-to-reader or air-to-interface protocol (tags can operate in a wide range of frequencies, from 128 KHz to 5.8 GHz. The choice in frequency is dependent upon the distance between the tag and the reader, the resolutions required, and the data rate needed)
v) the communication from the reader to the host system (this specification can vary from a serial RS-232 cable connection to a computer all the way to WiFi 802.11 wireless protocols.)

vi) the software format of the content of the information being delivered. (for example, some of those standards are ISO 11784, ISO 1785, ISO 14223, and ISO 14443)

Table 1 below provides further details on the differences between the different classes of healthcare RFID technology, and those between RFID and other auto ID solutions.

**Table 1: Overview of passive and active RFID technology**

<table>
<thead>
<tr>
<th>Source</th>
<th>Low Frequency (LF)</th>
<th>High Frequency (HF)</th>
<th>Ultra High Frequency (UHF)</th>
<th>Microwave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Range</td>
<td>&lt;135 kHz</td>
<td>13.56 MHz</td>
<td>Passive: 860-930 MHz, Active: 433 MHz</td>
<td>2.4GHz</td>
</tr>
<tr>
<td>Standards</td>
<td>ISO 18000-2</td>
<td>ISO 14443, ISO 15693, ISO 18000-3</td>
<td>Passive: Auto-ID Class 0, Auto-ID Class 1, EPCglobal Gen 2, ISO 18000-6, Active: 18000-7</td>
<td>ISO 802.11, ISO 18000-4</td>
</tr>
<tr>
<td>Data Capacity</td>
<td>Low data capacity from 64 bits to 2k bits</td>
<td>From 512 bits to 8k bits</td>
<td>From 32 bits to 4k bits</td>
<td>From 128 bits to 32kbit</td>
</tr>
<tr>
<td>Read-write Capability</td>
<td>Read-only or read/write tags</td>
<td>Both read-only or read/write tags</td>
<td>Both read-only or read/write tags</td>
<td>Read-only or read/write tags</td>
</tr>
<tr>
<td>Data transfer</td>
<td>Low data transfer less than 1 kbits/s</td>
<td>25kbps</td>
<td>28kbps</td>
<td>up to 1 Mbps</td>
</tr>
<tr>
<td>Time to Read</td>
<td>0.5 second quite slow</td>
<td>0.002 second</td>
<td>0.002 second</td>
<td>0.3 second</td>
</tr>
<tr>
<td>Range</td>
<td>Passive: 0.5m, Active: 2m</td>
<td>Passive: 1.2m</td>
<td>Passive: 2-5m, Active: 100m</td>
<td>Passive: 2-5m, Active: 30m</td>
</tr>
<tr>
<td>Power Source</td>
<td>Inductive coupling (Near field) of variety of tag forms</td>
<td>Inductive coupling (Magnetic or Near field)</td>
<td>Backscatter (Electric or Far field)</td>
<td>Backscatter (Electric or Far field)</td>
</tr>
<tr>
<td>Some Applications</td>
<td>Manufacturing, Large vehicle container, Access Control, Animal</td>
<td>Airline baggage, Library Laundry</td>
<td>Asset tracking, Supply Chain Logistics</td>
<td>Vehicles, Factory, Access control, Road tolling</td>
</tr>
</tbody>
</table>


The large-scale deployment of wireless LANs/WiFi in healthcare environments positions this existing infrastructure as logical for real-time location, just as it moves data and voice. In a typical wireless LAN configuration, clients communicate through an access point where wireless clients gain access to the network. The access point has connectivity to other clients associated with it or to the wired LAN. The basic service area (BSSID) is the area of RF coverage provided by an access point, also known as a cell. Adding an access point can extend the BSSID, enable the addition of wireless devices, and extend the range of an existing wired system. It attaches to the
Ethernet backbone and allows communication between all devices on the Ethernet backbone and those in the cell area. These remote devices communicate with the access point, not directly with each other. If one cell does not provide enough coverage, the range can be extended by adding cells - an extended service area (ESSID). It is recommended that coverage overlap 10-15 percent to allow remote users to roam without losing "RadarFind" connections. The recommended amount of overlap between cells is different, however, if voice over WLAN (VoWLAN) is deployed. However, a number of factors affect WLAN coverage, including the selected data rate, channel selection, power level, antenna type (dipole, omnidirectional, directional, or wall mount), and environment.\textsuperscript{97} Wireless installations are complicated by the fact that healthcare facilities often are built using a combination of different materials, thereby making RF behavior in these varying environments highly unpredictable. Additionally, there are areas surrounded by lead shielding or other substances that RF signals cannot penetrate. Consequently, it is strongly recommended that healthcare facility deployments always include a professional physical site survey. A survey is also warranted to verify the lack of potential technology signal collisions. Frequently, medical environments use equipment that shares the industrial, scientific, and medical unlicensed RF bands that 802.11b/g at 2.4-GHz and 802.11a at 5-GHz occupy. Therefore, it is recommended that when a healthcare facility is surveyed for installation of an 802.11a/b/g wireless infrastructure, a full RF spectrum analysis also be conducted. At a minimum, this analysis should cover the 2.4-GHz and 5-GHz ISM bands. The 433 MHz radio location band has been approved by the Federal Communications Commission (FCC) for more than 60 years, is less congested and not as susceptible to propagation issues as 2.4GHz – from floor hopping to reflection off mobile carts, beds and other items in the healthcare environment. These issues can also affect accuracy.\textsuperscript{98}

Finally, AlMahmood provides historical data on the number of RFID tags sold, and their total volume cost (an indicator of market size) in 2006, 1,022.6 million tags at a total cost of $1,484 million (healthcare accounting for 10 million tags at the value of $5.1 million). More recent projections on RFID’s market size and diffusion are provided by Harrop et al (2008) - who predict that the market for RFID tags and systems in healthcare will rise rapidly from US$120.9 million in 2008 to US$2.03 billion in 2018; and Gartner (2008) according to which the healthcare RFID hardware and software market stood at rough US$100 million in 2007, and can be expected to rise to US$450 million in 2010. Both projections were issued prior to the 2009 economic crisis, and are likely to be over-estimates.

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Appendix 3: Detailed methodology and additional results of systematic literature review

This appendix presents in detail the methodology and results of the comprehensive systematic literature review presented in Chapter 2, and identifies the factors which drive RFID's impacts and dissemination in healthcare.

Methodology

Data sources and search strategy

Given the relative novelty of the technology, to comprehensively, systematically and objectively review available evidence on the deployment range, effects and factors influencing RFID technology in healthcare the review covered both peer-reviewed and studies with limited distribution (grey literature)\(^99\).

The inclusion/exclusion criteria which were applied to both groups of sources are:

- **Focus:** all sources discussing RFID actual or potential use in healthcare, or care delivery, regardless of setting were included; sources discussing the application of RFID to supply chain management in the healthcare industry (including drug e-pedigree\(^100\)) were judged to be outside the scope of the study and were excluded.
- **Publication date:** the review was restricted to cover sources published between 1999 and April 2009, to ensure that discussions pertaining to obsolete RFID technologies are excluded\(^101\).
- **Language:** only studies published in English, Italian, German or French were retained\(^102\).

\(^{99}\) An additional argument for including non-academically reviewed sources in the review is the relative delay characterizing the publication process in academic journals, hence the increased risk for outdatedness of the collected information.

\(^{100}\) The U.S. Food and Drug Administration (FDA) advisory position that all medications be uniquifyable throughout their lifespan - including each prior sale, purchase, or trade of a drug, including the date of those transactions and the names and addresses of all parties to them. E-Pedigree’s primary purpose is to protect consumers from contaminated medicine or counterfeit drugs. As of 2008, most states have enacted some sort of drug pedegree requirement and many have also require e-pedigree.

\(^{101}\) Although it can be argued that a 5-year span would be more relevant to determine the application range and impacts of healthcare RFID, 1999 was chosen as a start date to allow for capturing evidence on any potentially-valuable applications developed prior to 2004.

\(^{102}\) Although the majority of leading medical informatics and health policy journals are published in English, the additional languages were included to avoid the omission of any early-stage or institutional intramural
• Study type: experimental, observational and epidemiologic studies, case studies and case study series, editorials/letters to the editor, healthcare engineering and management studies, and research syntheses were included.

Study design, principal outcome, intervention or population were not used as inclusion/exclusion criteria to avoid compromising the comprehensiveness of the results on the range of RFID use in healthcare and its effects.

For the peer-reviewed sources, a combination of electronic keyword-based mining of bibliographic databases, citation cross-checking ("snowballing"), and hand search of selected journals was used. Mined databases included:

- PubMed/MEDLINE
- ABI/INFORM
- Lexis/Nexis Academic
- Applied Science and Technology Abstracts (ASTA)
- Business and Management Practices (from OCLC/Firstsearch)
- EconLit (from OCLC/Firstsearch)
- Wilson Business Abstracts (from OCLC/Firstsearch)
- Wilson Select Plus (from OCLC/Firstsearch)

The electronic keyword-based mining incorporated two approaches: In the case of PubMed, due to its medical orientation, all articles filtered by ‘RFID’ or ‘Radio Frequency Identification’ were selected for title review. All other databases were searched according to the following search terms and keywords: (RFID OR ‘Radio Frequency Identification’) AND (healthcare OR medicine OR medical OR pharmaceutical OR surgery OR patient OR hospital). The automatic results that were generated by these filters were then narrowed down by selecting only scientific materials or scholarly journals, in order to omit any irrelevant articles or information. For example, only the ‘Scholarly Journals’ from all ABI/INFORM articles were retained, and only the category of ‘Scientific Materials’ in the case of Lexis/Nexis Academic was kept.

Journals which were hand-searched included: International Journal of Healthcare Quality Assurance; Health Affairs; Journal of the American Medical Association (JAMA); International Journal of Electronic Healthcare; Academy of Management; Journal of Evaluation in Clinical Practice; Healthcare Financial Management; Health Management Technology; and Health Data Management.

Articles which appeared highly-relevant to the goals of the literature review were used for citation cross-checking ("snowballing"). Citations identified by this method were screened at duplicate check and title review.

A second set of information sources were obtained from the RFID Journal - an online journal providing daily updates on RFID applications and developments across sectors and from around the world. To systematically identify articles relevant to the study, the journal was searched for health applications since 2005 in the following countries: USA, UK, Germany, Italy, the Netherlands, Switzerland and Sweden. The choice of which countries to focus on was driven by two objectives: 1) to assess RFID applications in a wide variety of healthcare systems, ranging from full national health systems (UK and Sweden), to systems with a strong corporatist nature (Germany) and systems that have recently introduced more market-oriented elements (The Netherlands) to the US model of healthcare; 2) to focus on countries already experimenting with a variety of RFID applications. Using the search feature of the website, a list of healthcare-

research on RFID (as they cover healthcare systems experimenting for a number of years with the technology).
related articles was generated, after which articles meeting the inclusion/exclusion criteria were handpicked. Due to the substantial number of articles generated for Germany and the UK, a more elaborate search strategy was employed to select health-related articles for these countries. Again, using the search feature of the website, seven lists of articles were generated for each country using the following search terms: “country” AND Health; “country” AND healthcare; “country” AND hospital; “country” AND pharmaceutical; “country” AND medical; “country” AND medicine; “country” AND patient.

Finally, through key informants (RAND colleagues, mentors, and external advisors), and searches of the World Wide Web – including Google searches, as well as targeted searches of the websites of The Institute for Prospective Technological Studies (IPTS); the MIT RFID Special Interest Group on RFID; the Health Information and Management Systems Society (HIMSS); the Institute for Healthcare Improvement; and leading healthcare RFID manufacturers – a set of relevant studies with limited distribution was also collected for initial screening. These include commercial reports and industry white papers, industry conference presentations, testimonies, and other documents. The guiding principles applied in the selection of these additional materials were identical to the ones used for the identification of peer-reviewed articles.

Using the data search methods described above, a total of 4,481 citations were collected for initial screening of which 436 sources were selected and obtained for review (see below). Appendix 2 lists all reviewed sources in full.

**Figure 1: Search flow for RFID in healthcare literature**

<table>
<thead>
<tr>
<th>Citations identified from electronic databases (n=4,120)</th>
<th>Citations identified through RFID Journal website search (n=200)</th>
<th>Citations identified through experts (n=40) and hand search (n=121)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citations retrieved (n=4,481)</td>
<td></td>
<td>Duplicate citations (n=61)</td>
</tr>
<tr>
<td>Title review (n=4,420)</td>
<td></td>
<td>Excluded on title review (n=3,784)</td>
</tr>
<tr>
<td>Abstract review (n=636)</td>
<td></td>
<td>Excluded on abstract review (n=188)</td>
</tr>
<tr>
<td>Article review (n=436)</td>
<td></td>
<td>Full text not found (n=12)</td>
</tr>
</tbody>
</table>

**Data extraction and synthesis**

After obtaining all literature sources via the search strategies outlined above, an abstraction protocol (presented in the next section) and narrative synthesis methods were used to compile descriptive summaries of all information sources. These were recorded in a central electronic database, initially Access-based and subsequently exported in Excel, the main goal of which was to succinctly summarize information in the application range and factors impacting the technology. The abstraction protocol comprises the following domains:
Within each domain (except for basic information, economic analysis, market and cost–benefit analysis), an initial set of descriptors was used. To illustrate - for application areas pre-identified descriptors included “patient identification at hospital for surgery” and “infant identification at hospital to forego mismatching”. Additional descriptors were developed to capture the information in the articles as comprehensively as possible.

Once exported in Excel, the structured summaries were used to feed an evidence table (also presented next). Its primary aims were to highlight the outcomes and costs associated with healthcare RFID, and the measures used to capture them, while condensing the information collected through the review. The table further dichotomized the healthcare settings in which RFID is used - distinguishing between in-patient, out-patient and non-medical settings such as patients' homes, and distributed the reviewed sources on healthcare RFID across four research domains:

- engineering-focused – both empirical and conceptual sources primarily concerned with the engineering of RFID solutions;
- standardization-focused – sources primarily concerned with the development of standards for healthcare RFID applications, including operating frequencies, data content and structure, tag types, conformance and performance;
- management issues focused - sources taking a management perspective to analyzing the use and value of RFID solutions in healthcare delivery;
- ethics and privacy issues focused - sources primarily concerned with the ethical and privacy implications arising from the use of RFID applications in the healthcare setting.

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103 The domain descriptors were chosen based on the results of the initial review, confirming Bureau et al.’s (2008) observation on the main domains of research on RFID.

104 Studies covering in depth more than one of these topics were assigned all applicable category descriptors.
Table 1: Abstraction protocol used for systematic literature review

<table>
<thead>
<tr>
<th></th>
<th>Article details</th>
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<tbody>
<tr>
<td>1</td>
<td>Reference</td>
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<tr>
<td></td>
<td>Review date (dd-mm-yyyy)</td>
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</table>

<table>
<thead>
<tr>
<th>2</th>
<th>Data source type and sub-category (use one)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>RFID Journal</td>
</tr>
<tr>
<td></td>
<td>Peer-reviewed journal</td>
</tr>
<tr>
<td></td>
<td>Industry journal</td>
</tr>
<tr>
<td></td>
<td>Grey literature (types identified in drop-down menu)</td>
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<tr>
<td></td>
<td>Book</td>
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<table>
<thead>
<tr>
<th>3</th>
<th>Summary (text box to be filled by reviewer)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Provide succinct review of study.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4</th>
<th>Overall relevance (use one)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Low</td>
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</table>

<table>
<thead>
<tr>
<th>5</th>
<th>Overall focus of the source (check all that apply)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RFID trial/ pilot description</td>
</tr>
<tr>
<td></td>
<td>RFID potential benefits</td>
</tr>
<tr>
<td></td>
<td>RFID obstacles and enablers</td>
</tr>
<tr>
<td></td>
<td>RFID - economic analysis and cost-benefit analysis</td>
</tr>
<tr>
<td></td>
<td>RFID market analysis</td>
</tr>
<tr>
<td></td>
<td>Alternative technologies</td>
</tr>
<tr>
<td></td>
<td>Basic knowledge and general information</td>
</tr>
<tr>
<td></td>
<td>Other (text)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>6</th>
<th>Location of reviewed application/ author's primary affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Europe: (provide country)</td>
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<tr>
<td></td>
<td>Americas: (provide country)</td>
</tr>
<tr>
<td></td>
<td>Asia: (provide country)</td>
</tr>
<tr>
<td></td>
<td>Australia and New Zealand: (provide country)</td>
</tr>
<tr>
<td></td>
<td>Africa: (provide country)</td>
</tr>
</tbody>
</table>
Application areas: setting, where, who and by whom (check all that apply)

**Patient:**
- patient identification at hospitals for surgery
- patient identification (disasters)
- infant identification at hospitals to forego mismatching
- patient tracking and tracing at hospitals for monitoring patient flow
- infant tracking and tracing at hospitals for security/to forego theft
- dementia patients tracking and tracing at elderly homes to forego missing
- other (text)

**Staff:**
- staff identification at hospitals to manage access
- staff tracking and tracing at hospital ER to speed up service
- staff monitoring at hospitals for management purposes
- other (text)

**Asset/ Inventory: (by type)**
- asset identification:
  - sponge identification at hospital to ensure hygiene compliance
  - blood bags identification at hospitals/OR to ensure blood type matching
  - other (text)
- asset tracking and tracing:
  - equipment tracking and tracing at OR to ensure hygiene compliance
  - sponge tracking and tracing at OR to prevent 'left-ins'
  - other (text)
- asset monitoring:
  - blood bags equipped with temperature sensors at hospital to ensure cold chain and efficacy
  - other (text)

**Randomized clinical trials:**
- patient identification at trial
- patient compliance with treatment at trial
- other (text)

**Other:**
- telemedicine:
  - intelligent pillbox to monitor/prompt patient compliance
  - remote monitoring of vital signs at home (extended healthcare)
  - other (text)
8 Policy areas (check all that apply)
- patient safety/quality of care
- improved utilization of resources
- reduce liability-related problems
- e-health
- waste management
other (text)

9 Obstacles/barriers/risks (check all that apply)
information security risk:
- privacy
- security
- data integrity
- other (text)
interference
reliability
interoperability
standards
legal
social/societal (perceptions etc.)
high technology cost
other (text)

10 Enablers (check all that apply)
government legislation (national or local)
government incentive (national or local)
falling tag prices
proven ROI
cost pressures in healthcare system
other (text)

11 Additional/ alternative technologies (check all that apply)
bar code, substituting RFID
bar code, complementing RFID
WIFI, substituting RFID
WIFI, complementing RFID
infrared
other (text)

12 Economic analysis and cost-benefit analysis
Short summary, including methodology and key assumptions. Copy/paste graphics, tables, etc. (mentioning page numbers).

13 Market analysis
Copy/paste graphics, tables, including key assumptions. (mentioning page numbers).

14 Comments/Notes
Text box (without limit)
An evidence table used to collect key information on the use and impacts of RFID in healthcare in the course of the structured literature review. Its general organization is shown Table 2 below.

<table>
<thead>
<tr>
<th>RFID application type</th>
<th>Reference</th>
<th>Country</th>
<th>Type of publication</th>
<th>Setting</th>
<th>Type of study</th>
<th>Measures</th>
<th>Data collected when</th>
<th>Percentage improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable asset tracking</td>
<td>Cohren, 2007</td>
<td>USA</td>
<td>non-peer reviewed industry journal</td>
<td>inpatient, a 300-bed Hospital covering 500,000 feet²</td>
<td>not reported</td>
<td>- percentage change in IV pump usage appropriately billed to patients (share of total usage)</td>
<td>not reported</td>
<td>only 37% of pump usage billed accurately; Reduces unnecessary inventory (by 20%)</td>
</tr>
<tr>
<td></td>
<td>Becker, 2004</td>
<td>USA</td>
<td>peer-reviewed industry journal</td>
<td>inpatient, hospital size not specified</td>
<td>not reported</td>
<td>- percentage change in share of rental equipment which cannot be located to be returned at lease expiration date (valuated at cost per item)</td>
<td>not reported</td>
<td>not reported</td>
</tr>
<tr>
<td>Author, Year</td>
<td>Country</td>
<td>Journal Type</td>
<td>Study Type</td>
<td>Methodology</td>
<td>Key Findings</td>
<td></td>
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<tr>
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<td>------------</td>
<td>-------------</td>
<td>--------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Britton, 2007</td>
<td>UK</td>
<td>peer-reviewed medical journal</td>
<td>inpatient, three wards in a large community hospital</td>
<td>proof of concept</td>
<td>ability to reliably track the movement of iv pumps across wards over a 16-week period, not specified when system failed to detect the device in the correct location at a rate of 12.32%.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Davis, 2004</td>
<td>USA</td>
<td>non-peer reviewed industry journal</td>
<td>inpatient, not specified on wards</td>
<td>not reported</td>
<td>percentage change in annual cost of lost and stolen portable assets not reported not reported</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey, 2007</td>
<td>USA</td>
<td>non-peer reviewed industry journal</td>
<td>inpatient, 700+ beds academic hospital</td>
<td>pre/post outcome evaluation</td>
<td>- percentage change in time nurses spent on equipment searches - percentage change in surgery turnaround time - percentage change in time needed to locate FDA-recalled equipment 2006 50% reduction in lost equipment in selected nursing units</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacheldor, 2008</td>
<td>USA</td>
<td>non-peer reviewed industry journal</td>
<td>inpatient</td>
<td>pre/post pilot outcome evaluation</td>
<td>- percentage change in patient flow (measure unclear) - percentage change in time needed to locate critical devices that can compromise patient flow 2005 expect RTLS will save it $300,000 annually; pilot paid for itself within 15 months</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results
The pages that follow review in detail the results of the structured review. A succinct summary of the key findings and implications of the review is presented at the end.

The information source sample
A total of 436 peer-reviewed and grey information sources on the applications, impacts and facilitators/inhibitors of RFID use in healthcare fed into the structured literature review. Of these, slightly less than a quarter originate from peer-reviewed journals\textsuperscript{105,106}, the largest share being sourced from the RFID Journal (see below).

Table 3: Breakdown of reviewed information sources by type

<table>
<thead>
<tr>
<th>Data source type</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID Journal</td>
<td>165</td>
<td>38%</td>
</tr>
<tr>
<td>Grey literature</td>
<td>112</td>
<td>26%</td>
</tr>
<tr>
<td>Peer reviewed journal</td>
<td>106</td>
<td>24%</td>
</tr>
<tr>
<td>Industry journal</td>
<td>52</td>
<td>12%</td>
</tr>
<tr>
<td>Book</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>436</td>
<td>100%</td>
</tr>
</tbody>
</table>

Studies with limited distribution – grey literature – account for another quarter of all information sources. The bulk of these comprise industry white papers and industry conference presentations, jointly yielding 60\% of grey sources (see below). Non-industry-released white papers, reports and policy memos produced by the Commission of the European Union (EU), and testimonies and government reports account for another 22\% of the retained grey sources.

Table 4: Breakdown of reviewed grey literature by category

<table>
<thead>
<tr>
<th>Grey literature category</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry white papers</td>
<td>43</td>
<td>39%</td>
</tr>
<tr>
<td>Industry conference presentations</td>
<td>24</td>
<td>21%</td>
</tr>
<tr>
<td>EU Commission reports and policy memos</td>
<td>15</td>
<td>13%</td>
</tr>
<tr>
<td>Industry conference proceedings</td>
<td>12</td>
<td>11%</td>
</tr>
<tr>
<td>Working papers</td>
<td>8</td>
<td>7%</td>
</tr>
<tr>
<td>Industry newsletters</td>
<td>8</td>
<td>7%</td>
</tr>
<tr>
<td>Testimonies and government reports</td>
<td>2</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>112</td>
<td>100%</td>
</tr>
</tbody>
</table>

\textsuperscript{105} Of these more than 90\% (n=96) were retrieved through PubMed, with a fraction of duplicates available through other databases.

\textsuperscript{106} While some industry journals do practice peer-review, typically the purpose and rigidity of the process differs from the one used in academic journals. To reflect this, a distinction between academic peer-reviewed and industry journal publications is made.
Eighty nine percent of all reviewed materials were published/released after 2005 (see below; the sharp truncation in 2009 reflecting the fact that only sources published prior to April 2009 entered the review). This time-growth pattern is further confirmed in the graph below which presents a per-type break down of sources’ publication years. It also updates Chao et al.’s (2007) observation about the exponential growth of attention paid to RFID technology in the peer-reviewed literature, expanding it to healthcare RFID solutions in particular and to sources with limited circulation.

**Figure 2: Number of reviewed sources on RFID in healthcare, all types**

![Graph showing number of reviewed sources on RFID in healthcare, all types](image)

**Figure 3: Number of reviewed sources on RFID in healthcare, by type**

![Graph showing number of reviewed sources on RFID in healthcare, by type](image)

Furthermore, roughly two thirds of all implementation and innovation accounts, and research on the use of RFID in healthcare originate from North and South America; with only 5 studies in this group produced in countries other than the U.S.A. (3 from Canada, 1 from Mexico and 1 from...
European-origin studies account for 30% of all reviewed sources, with Asia, Australia and New Zealand supplying the remaining 5%.

Figure 4: Distribution of sources, by region of origin/focus (% total)

Table 5 below lists the seven leading countries of information origin. In addition to these, information on healthcare RFID applications from 27 other countries fed into the analysis. These include: Canada, Brazil, Mexico, Finland, Austria, Spain, Switzerland, France, Luxembourg, Turkey, Japan, India, China and Saudi Arabia. As Table 5 indicates, however, more than 60% of all materials focus on the use of RFID technology within the U.S. healthcare sector.

Table 5: Top 7 country sources of reviewed information

<table>
<thead>
<tr>
<th>Country</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>280</td>
<td>64%</td>
</tr>
<tr>
<td>UK</td>
<td>27</td>
<td>6%</td>
</tr>
<tr>
<td>Germany</td>
<td>26</td>
<td>6%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>13</td>
<td>3%</td>
</tr>
<tr>
<td>Italy</td>
<td>11</td>
<td>3%</td>
</tr>
<tr>
<td>Taiwan</td>
<td>8</td>
<td>2%</td>
</tr>
<tr>
<td>Belgium</td>
<td>6</td>
<td>1%</td>
</tr>
</tbody>
</table>

Regional distribution identification was done on the basis of stated country of RFID implementation – for implemented/piloted RFID systems, and for engineering innovations and conceptual work on RFID - on the basis of stated affiliation of researchers, or first author in case of collaborating teams. This approach to geographic attribution was chosen in order to gain better understanding of how prevalent implemented and piloted/tested healthcare RFID solutions are across different regions and countries, vs. solely understand where evaluation efforts are concentrated (subject to the exclusion criteria governing the source selection).
Finally, the figure below reveals a perhaps superfluous distinction between the trends in the contribution volumes originating from different regions. Namely, a tempering in the number of studies originating from and/or focused on healthcare RFID applications in Europe is observable post 2006. In contrast, in the U.S. the interest in healthcare RFID does not yet appear to have reached a saturation point.\textsuperscript{108}

Figure 5: Distribution of information sources by year and region (N)

Key topics in the literature: management, engineering, standardization and ethics/privacy

The main domains of research on the uses of RFID in healthcare, described in more details below, are: RFID engineering, use of RFID for healthcare delivery management purposes, RFID standardization, and ethics/privacy issues surrounding RFID use in healthcare. These were identified using the protocol-based structured summaries, and conform to the classification proposed by Bureau et al. (2008).

Studies which have an engineering focus - both empirical and conceptual - are primarily concerned with the design of RFID solutions for use in healthcare. They discuss issues such as how RFID applications perform in specific environments (e.g., absence/presence of interference with clinical and biomedical devices, performance in sub-zero or high-pressure environments), and what engineering challenges need to be considered when designing an RFID solution (e.g., reading ranges suited to specific functions, and number of tags per reading zone resulting in RFID signal collisions). Some also report test results of RFID solutions created to solve healthcare-specific challenges, such as testing different RFID tags and adhesives to create an RFID-based solution which will ensure that all surgical tray sets go through the de-contamination process and can be traced and uniquely identified.

Studies which have a management focus tend to center on the benefits or potential benefits that can be achieved through the use of RFID solutions in healthcare, or the process of their adoption. They comprise both conceptual discussion, as well as short “case studies” – cost/outcome presentations for specific application implementations. Including both peer-reviewed and a large share of grey sources, this group of studies largely regards RFID as “a

\textsuperscript{108} This difference has not been tested for statistical significance.
wonderful opportunity\textsuperscript{109}, although the definition of RFID and its purposes are frequently not clarified. In fact, studies belonging to this thematic group often explicitly or implicitly employ wrong or incomplete definitions of what constitutes an RFID solution, and include misunderstandings of what RFID can really do\textsuperscript{110}. For example, RFID is frequently referred to as a wireless chip-and-reader technology when, as discussed in Chapter 1, at least in the healthcare context it is a system of interfaced hardware, software and middleware providing unique identification and geolocation, and in the case of active RFID – continuous geolocation, or tracing. The importance of the difference between the two definitions becomes apparent once comparisons between RFID and barcode technologies are made; in the case of the management-focused literature typically to argue for/against the general supremacy of RFID over barcodes. Since barcodes fundamentally involve a non-unique identified tag and a reader, the shorter “wireless chip-and-reader” RFID definition invites an apples-to-apples comparison between the RFID and barcode – a topic of blanket discussions in many a source belonging to this research domain. The full RFID definition, instead, suggests that the two technologies differ sufficiently to not be directly comparable in the general case and to potentially be suited to fulfilling distinct functional goals (even if specific function-based comparisons between passive RFID and barcodes may be appropriate)\textsuperscript{111}. A portion of the management-focused literature on healthcare RFID also explores its potential in healthcare by examining different typologies/classifications of its functionalities, uses and goals\textsuperscript{112}. Many of these, too, suffer from the definition and capability ambiguities surrounding healthcare RFID, and do not contribute to understanding the value which RFID can add, especially since they frequently mix application functions with deployment goals (e.g., include as entries both “unique patient identification” and “improving quality of care”). A handful of studies offer methodologically sound evaluations of RFID system pilots; but none attempt to value the potential impacts of RFID’s wider dissemination in healthcare, in general or across specific solution types/categories.

A third group of studies concentrate on the standardization of RFID in healthcare – the need for it, and the challenges and approaches to it. This group of sources includes predominantly grey literature, industry journal publications and some peer-reviewed articles. Topics of specific interest include the development of standards for healthcare RFID operating frequencies in different countries, data content and structure industry guidelines, RFID system conformance and performance. Standardization discussions also explore options for developing guidelines on how RFID is used.

The fourth and final domain of research on healthcare RFID includes studies centered on the ethics/privacy issues surrounding RFID’s use in healthcare – the types of data collected through RFID, its uses and protection; as well as individuals’ right to opt out of such systems, and the potential privacy threats that can/cannot be brought on by RFID’s wider dissemination. As in the case of the management-focus group, these studies also frequently explicitly or implicitly employ wrong or incomplete definitions of what constitutes an RFID solution; and involve misunderstandings of what RFID can really do as used in healthcare. An extreme example of both is the portrayal of healthcare RFID as a tool for the Orwellian Big Brother observation of

\textsuperscript{109} See Burau et al. (2008), p 15923.

\textsuperscript{110} Bureau et al. (2008) argue that these problems characterize the entire peer-reviewed literature on RFID in healthcare. Having systematically reviewed this literature, as well as “grey” sources and industry publications (including the RFID Journal), my impression is that sources focused on the engineering or standardization of healthcare RFID are largely not affected by these problems. The management and ethics/privacy strands in the literature (term used broadly), however, are. And these confusions cannot be solely ascribed to any one type of sources (e.g., industry white papers vs. conference presentations, or peer-reviewed articles), making these even more significant problems.

\textsuperscript{111} It is interesting to note that most incomplete or wrong definitions of RFID are brought in the attempt to introduce a broader audience to healthcare RFID (as RFID is frequently dubbed an innovation this group is expected to be the average reader), but remain unexpanded/corrected in the paragraphs that follow. It has been observed across all information type categories included in the review.

\textsuperscript{112} See Vilamovska et al. (2008) for examples of such typologies.
private lives and activities of both patients and care providers. While concerning, such use is unrealisitic due to the strict regulation of patient data privacy and protection, and the physical laws affecting RFID (e.g., lack of endless reading range). This analogy, however, highlights the concern some groups have with RFID in general and healthcare RFID in particular, and the need for it to be addressed through education and regulation.

As indicated by Table 6 below, the above-suggested research domain (i.e. topic) classification captures 72% of all information sources as single-topic papers/presentations, and can hence be considered valid.

<table>
<thead>
<tr>
<th>Number of topics in reviewed source</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single topic</td>
<td>312</td>
<td>72%</td>
</tr>
<tr>
<td>Two topics</td>
<td>115</td>
<td>28%</td>
</tr>
<tr>
<td>Three or more topics</td>
<td>9</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>436</td>
<td>100%</td>
</tr>
</tbody>
</table>

Among the single-topic group of sources, most focused on the management potential of RFID solutions, followed by engineering-related discussions (see Figure 6). Sources dedicated to the potential ethics/privacy issues which can be associated with healthcare RFID constituted the sparest group.

Further investigation in the distribution of discussion topic across setting of interest shows that most engineering-, management- and ethics/privacy-focused sources (in ranked order) revolve around the use of RFID in the hospital setting, with standardization discussions distributed almost evenly across all settings.

For dual-topic sources, dominating themes continue to be management and engineering (a total of 77 sources, accounting for 67% of all dual-topic sources; or 17% of all sources). Second most important dual theme is management and standardization, applicable to 11 articles.
Standardization and engineering is in 3rd place with 8 articles belonging to this group. Other topic combinations include management and ethics/privacy (n=6), engineering and ethics/privacy (n=3), standardization and ethics (n=5).

Healthcare settings covered by the literature

Roughly half (n=238) of all reviewed studies center on the use of RFID applications in the inpatient care (hospital) setting. RFID applications tailored to the out-patient setting (including such geared to use at nursing homes and patients' homes) are the focus of 7% of all studies. And 16% of all information sources analyze RFID applications suited to both the inpatient and out-patient settings. 23% referred to uses of healthcare RFID in other contexts (see below).

<table>
<thead>
<tr>
<th>Application setting</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inpatient care only (hospitals)</td>
<td>238</td>
<td>55%</td>
</tr>
<tr>
<td>Both in- and out-patient care</td>
<td>69</td>
<td>16%</td>
</tr>
<tr>
<td>Out-patient care only (ambulatory care, home care)</td>
<td>30</td>
<td>7%</td>
</tr>
<tr>
<td>Other (e.g., medication supply management)</td>
<td>99</td>
<td>23%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>436</td>
<td>100%</td>
</tr>
</tbody>
</table>

Within the hospital-setting-tailored RFID solutions, most frequently discussed are those employed in the operating room and floor, and in the emergency department (see Table 8 for full list).

<table>
<thead>
<tr>
<th>Inpatient care application setting only</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating room/floor</td>
<td>27</td>
</tr>
<tr>
<td>Emergency department</td>
<td>12</td>
</tr>
<tr>
<td>Medication management (hospital-wide)</td>
<td>2</td>
</tr>
<tr>
<td>General medical floor (endoscopy)</td>
<td>1</td>
</tr>
<tr>
<td>General medical floor (oncology) and clinical trial</td>
<td>1</td>
</tr>
<tr>
<td>Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>Multiple or not detailed</td>
<td>194</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>238</td>
</tr>
</tbody>
</table>

Healthcare RFID applications designed for use at patients' homes account for half of all studied outpatient setting applications; with RFID solutions designed for use at nursing homes ranking second (see below for a full list).
Table 9: Sub-settings of interest for outpatient care applications

<table>
<thead>
<tr>
<th>Outpatient care application setting only</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient's home</td>
<td>15</td>
</tr>
<tr>
<td>Nursing home</td>
<td>8</td>
</tr>
<tr>
<td>Multiple or not detailed</td>
<td>5</td>
</tr>
<tr>
<td>Ambulatory care</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30</strong></td>
</tr>
</tbody>
</table>

Table 10 shows the referencing of healthcare RFID in contexts other than the delivery of healthcare.

Table 10: Sub-settings of interest, other application settings

<table>
<thead>
<tr>
<th>Other application settings</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medication supply chain</td>
<td>15</td>
</tr>
<tr>
<td>Asset and inventory supply chain</td>
<td>6</td>
</tr>
<tr>
<td>Forensic science</td>
<td>1</td>
</tr>
<tr>
<td>Disaster preparedness</td>
<td>1</td>
</tr>
<tr>
<td>Warehouse management</td>
<td>1</td>
</tr>
<tr>
<td>Multiple or not detailed</td>
<td>75</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99</strong></td>
</tr>
</tbody>
</table>

Evaluation frameworks for RFID in healthcare: cost and benefit parametrization

The results reported in the preceding section suggest that RFID technology can be leveraged to achieve a range of operational and functional goals both in the inpatient and outpatient (ambulatory and patient’s home) healthcare setting. Yet, the review also indicates the lack of a common cost and benefit evaluation framework – a system of consistently used constructs, variables and measures – to assess RFID use in healthcare, not least due to the problems affecting existing RFID classification attempts discussed in the beginning of Section 2.1.2 (mix of RFID uses and benefits, use of wrong or incomplete definitions of RFID, and inaccurate representations of its engineering capabilities).

The closest alternatives to a structured approach to assessing the benefits and costs of healthcare RFID are the case studies reported in the management domain of the RFID literature, and the RFID classification attempts within it (those which mix RFID’s range of use with RFID’s benefits). Both of these unfortunately suffer from inaccuracies and/or ambiguities, are frequently conceptually unsound, lack clear and consistently-used impact measures, and generally do not reflect the benefits and costs arising from RFID’s full range of application in healthcare.

In fact, although roughly 70% of all sources highlight in their abstracts (or executive summaries) the source’s focus on the discussed RFID application(s) potential to affect the quality and cost of healthcare (see below), seldom have specific benefit or cost variables and variable measures been used in both the peer-reviewed and limited circulation literature on RFID’s use in healthcare.
Based on the context of discussion the following top and mid-level healthcare quality and cost measure categories can be distilled (see tables below). The tables also list the number each of the mid-level measures is referenced in the quality-only and cost-only literature (i.e. sources which discuss solely quality/cost impacts)\textsuperscript{114}.  

**Safety** is the most-frequently referred to quality mid-level measure (featuring in 89, or 71\% of the reviewed quality-focused sources) and it is used to evaluate RFID solutions developed for/used in the in- and in the outpatient setting alike. It is over-represented in the engineering- and management-focused sources.

| Table 11: Quality mid-level measures emerging in literature (quality-only sources) |
|-----------------------------------|-----|-----|
| **Quality of care** | N | Share |
| Safe | 89 | 71\% |
| Timely | 16 | 13\% |
| Patient-centered | 12 | 10\% |
| Effective (evidence-practice based) | 9 | 7\% |
| **Total** | **126** | **100** |

Across cost mid-level measures, **efficiency** (n=78) is the most-frequently used one. Yet unlike safety (conceptualized as patient and staff safety from medical error and physical/ecological threats), efficiency does not share a common definition across sources: it is discussed in the context of: waste of financial and non-financial resources; staff time; biomedical asset and physical space utilization; and staff productivity. Cost-focused discussions too are concentrated in engineering and management sources, but overwhelmingly feature RFID applications tailored to use in the hospital setting only.

\textsuperscript{113} “Impact measures not applicable” refers to studies which focus on topics other than RFID’s impacts.

\textsuperscript{114} It was not possible to assess how frequently each sub-measure was used in the general pool including articles discussing both costs and quality due to the way source summaries were coded. This latter group, however, is analyzed in more detail in the next sub-section of this chapter.
Table 12: Cost mid-level measures emerging in literature (cost-only sources)

<table>
<thead>
<tr>
<th>Cost of care</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient</td>
<td>78</td>
<td>97%</td>
</tr>
<tr>
<td>Cost-effective</td>
<td>3</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>80</td>
<td>100%</td>
</tr>
</tbody>
</table>

Based on the range of healthcare RFID operational purposes and functional goals, and the benefits discussed in the literature, an evaluation framework for RFID should include the following domains of care quality improvement and cost containment, which healthcare RFID in its full spectrum can be said to support.

**Figure 8: Domains of healthcare which RFID can affect**

<table>
<thead>
<tr>
<th><strong>Healthcare Quality:</strong></th>
<th><strong>Healthcare Cost:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Increasing effectiveness of care via RFID-inclusive clinical innovations (in imaging and post-surgical healing with neuro-stimulation) and at-home patient medication regimen compliance monitoring;</td>
<td>• Increasing cost-efficiency of care by reducing operational and capital outlays in hospitals – e.g.:</td>
</tr>
<tr>
<td>• Increased safety of care via prevention of falls and wrong patient/wrong medication/procedure errors in the in-patient setting; and dementia patient’s physical safety in the out-patient setting;</td>
<td>o reducing labor costs by altogether eliminating the need for or reducing the time spent on making calls to coordinate patient admittance, location, or status updating, looking for assets, doing sponge counts;</td>
</tr>
<tr>
<td>• Increased continuity and patient-centeredness of care via real-time patient record updating through connectivity with hospital clinical, administrative, laboratory and radiology systems, and less intrusive remote patient identification (for medication administration at night or MR/dementia patient tracing);</td>
<td>o reducing risk for some types of medical errors and the additional costs (medical and litigation) associated with rectifying them;</td>
</tr>
<tr>
<td>• Improved timeliness of care achieved by RFID-enabled process reorganization (including process elimination and ability for overall control) and improved workflow and staff time use in busy and complex in-patient environments (ED, OR &amp; OF).</td>
<td>o reducing perishable medication and biomedical inventory expiration in hospital environments;</td>
</tr>
</tbody>
</table>

**Evidence on healthcare RFID benefits and costs**

Despite the increasing attention paid to RFID’s potential in healthcare, as documented by the exponential growth of publications on this topic, less than 6% of all unique studies (27 out of 436)
contain some information on both the benefits and applications costs of healthcare RFID applications/pilots (see below).

**Figure 9: Number of reviewed sources containing information on RFID applications’ benefits and/or costs (N, % total)**

<table>
<thead>
<tr>
<th>Information Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost and benefit information (matching cases)</td>
<td>27, 6%</td>
</tr>
<tr>
<td>Cost information only</td>
<td>48, 11%</td>
</tr>
<tr>
<td>Benefit information only</td>
<td>83, 19%</td>
</tr>
<tr>
<td>Neither cost nor benefit information</td>
<td>278, 64%</td>
</tr>
</tbody>
</table>

Benefits alone are most frequently cited (in 19% of all sources), and stand-alone implementation/maintenance cost information is provided in 11% of all studies. This relative prevalence of information appears to be stable over time (see below).

The major quality benefit shown in the sources discussing healthcare RFID application costs or benefits in isolation is improved safety of care (including decreased medication errors, decreased autologous blood transfusion errors, improved prevention of surgical sponge/instrument retention, and improved capacity to prevent hospital infection spread among others). With respect to cost gains, three key benefits reported are: reduced capital outlays, increased staff productivity and staff time savings.

As cost-effectiveness is a primary consideration whenever healthcare innovations are discussed, and the goal of the analysis is to determine if sufficient data allowing the comparison of individual types of RFID is available, the rest of this section focuses only on the sources containing matching-case benefit and application cost information.
Figure 10: Distribution of cost, benefit and market information content of sources per publication year (1999-2009)

Matching-case benefit and cost information

Of the 27 information sources reporting any data on both the impacts and applications costs of healthcare RFID applications/pilots, 12 do not directly provide quantified cost and impact data, instead referring to return on investment (ROI) ratios, or report only qualitative or anecdotal information. Of the 11 studies that do contain empirical cost and impact data, only 4 (i.e. 1% of the 436 reviewed materials) provide detailed cost, outcome and implementation process information supporting the attributiveness of the reported impacts\textsuperscript{115}.

All 27 sources focus on commercially developed systems created through a collaboration between the implementing institution and the technology providers. 17 of these studies (63% of 27) discuss asset/inventory-focused RFID applications, 10 (4%) - patient-focused, and 7 (3%) - staff-focused RFID solutions. 7 of the described applications are also multi-functional, covering both patients and staff\textsuperscript{116}. All but one assesses the effect of the applications in the inpatient setting, with 7 featuring ED-supporting systems and 3 – perioperative and OR-dedicated systems. The following paragraphs review the RFID costs and benefits these studies document.

Among hospital-wide staff-and-patient focused RFID solutions, Traster (2004) reports a pilot of an RFID application used to positively identify patients and carry their health record during hospital stay. The pilot saved 35 minutes off each nurse’s day, and demonstrate that hospitals can save up to $2 million annually by eliminating costly mistakes and improving efficiency. Another case study describes a 3-month pilot of a patient fall prevention RFID solution which reduced by 67% high-risk patient falls, and cut down by 60% 1:1 patient watches for patients at risk of falling, saving approximately a total of $71,657 in staff time translated back to patient watch time (RTTechnologies, 2008). Additional identified benefits included minimizing staff liabilities and

\textsuperscript{115} While these studies do not explicitly discuss the biases which could have affected the reported results (e.g., internal validity threats such as selection, maturation, history or instrumentation biases), they supply sufficient information to establish an acceptable chain of evidence. None of these, however, involve experimental or quasi-experimental designs.

\textsuperscript{116} None of the studies is concerned with the use of RFID in the conduct of clinical trials.
maximizing patient rights. Project cost (including portable control units and disposable patient pads) was reported to be “a fraction of the cost of 1:1 watches and alarm-equipped beds.” Finally, Dalton et al. (2005) highlight an RFID system for autologous blood transfusions delivered a 41% process accuracy improvement, a 27% increase in productivity, along with an average of 90 minutes in time saved per workday across system users (clinical staff) which covered the system’s cost.

In the operating room (OR) environment, Nagy et al. (2006) note a study of RFID-enabled operating room staff tracing which resulted in a 13 percentage point improvement (57% to 70%) in the utilization of the surgical department. The benefit of avoiding OR staff overtime pay covered the cost of the system. More recently, the 2008 RFID Journal White Paper in RFID in Healthcare reported that similar systems have demonstrated OR utilization improvements by 40%, which given the average cost of $40 per minute for OR time produced “substantial payback.” Evaluating a passive RFID system designed to eliminate instances of retained surgical sponges, Rogers et al. (2007) report that the use of passive-tagged sponges eliminates the occasional errors in the sponge count and thus reduces post-op retention. The study concluded that given the 2 million dollars in malpractice insurance claims paid to patients with retained surgical sponges during a seven-year period, the $5000 dollar cost of an RFID reader is justifiable (the study assumed away the cost of tagging sponges). A more recent analysis of the cost-effectiveness of different strategies for preventing retained foreign bodies (RFB) after surgery demonstrates that the most important factor in determining the optimal RFB prevention strategy is the probability of having an RFB. While for low- and average-risk patients the most cost-effective strategy is to do nothing; for high-risk (e.g., obese) patients it is to use a system as described by Rogers et al. estimated RFID cost per quality adjusted life year for this group was $1,169, vs. $3,023 for counts, $3,933 for imaging, and $10,849 for “do nothing”. The cost of treatment of an RFB was found to be an important determinant of overall cost-effectiveness of the alternative approaches. Finally, Bachelord (2008) reports that an RFID system designed to prevent surgical errors – involving disposable passive RFID tags applied to the site on the patient where the surgery is slated to occur and used during a pre-operative workup by nurses, anesthesiologists and surgeons to document checks and procedures – costs about $50,000 with maintenance support and the RFID-enabled labels are about 15 to 20 cents apiece. According to the manufacturer, this cost still supports a healthy ROI, compared with the frequency of wrong-site surgical errors – said to exceed 170 in Pennsylvania over a 30-month period – and their indemnity cost – starting at $50,000. A real-world example is a case study of an operating floor workflow management system implemented in Providence St. Vincent medical center, Portland, OR (a facility with over 22,000 surgeries annually including 53 pre-op beds, 27 ORs and 27 recovery beds) The challenges it was brought to solve included: optimize communication and workflow to support surgical services; locate patients and equipment easily and quickly; reduce telephone calls and manual interventions to confirm status. At baseline an estimated 11 calls per patient were needed to confirm patient status, of which 75% were to clarify location/status. Amounting to 4.5 hours of staff time per day saved, given daily patient volume of 80-100 patients the RFID systems increased nurse patient face time by roughly 22 minutes. It maximized efficiency to avoid hiring FTEs with unit expansion; improved surgeon and staff satisfaction and reduced staff frustration.

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117 Blood is returned to the same donor.
In the Emergency Department (ED), an industry case study of an RFID/infrared patient-tracing solution reported that by allowing patient visit milestones and movement to be automatically identified and displayed for staff to see in near-real-time, the application decreased pediatric patients length of stay by 37%, same-day-release adult patients stay by 18.5% and admitted adult patients stay by 36%. The application, furthermore, increased cash collections on average by 45% by associating badge return with the discharge process. Leveraging RFID to automatically update patients’ medication profiles and to enable its movement with the patient from one area to the next reduced calls to the pharmacy, OR unit, and nursing units, and improving communication, timeliness and delivery of care. Patient location (or discharge notification) was also used to cut down on the waste involved in preparing meals for patients who are no longer present and in the time required to deliver and retrieve trays. The bed-management capability of the system, deployed hospital-wide, cut room turnover time from 4 to 8 hours to 24 minutes, reducing boarding bottlenecks. The system was further expanded to cover high-value and mobile equipment, through which a reduction in the hospital’s fleet of pumps was achieved, reducing capital and operational outlays. A similar ED patient-tracing application resulted in reduced door-to-care time from one hour and 20 minutes to 9 minutes. The tracking system is interconnected with the hospital’s registration, laboratory, communication and bed tracking system, as well as with its picture archive. Its return on investment has not been formally evaluated, reportedly due to its clear benefits.

Asset tracking and management solutions are the single class of RFID applications for which repeatedly reported information of both costs and benefits, and/or return on investment is available. Industry case studies suggest that positive return on investment for these solutions is achieved within 8 to 15 months after initial implementation, depending on the scale of coverage. Identified savings include “soft” savings – e.g., gains in productivity, improved staff satisfaction, and safety; as well as “hard” savings – reduced capital purchases and renting, and decreased operational costs (on the basis of which ROI is computed). For example, according to Davis (2004) annually lost and stolen equipment costs US hospitals as much as $4,000/bed. Avoiding the up to $50,000 spent yearly by hospitals on misplaced/lost rental equipment, along with staff time savings from easier asset/inventory management and location, Davies argues, can make real-time asset management solution (RTLS) benefits accumulate to $110,000 annually. Davis (2004) reports that the costs for an RFID system can run from $20,000 to over $1 million depending on the size of the area where the technology is deployed and the application. $20,000 can monitor and control patient movement in a small inpatient area. A $1 million system can track thousands of pieces of equipment throughout a hospital facility. The author also reports that ROI for RFID typically occurs in less than one year, and can subsequently reach 450% per year for equipment management. More recently, the 2008 RFID Journal White paper on RFID in Healthcare argued that: “The low-hanging fruit from an ROI perspective really is asset utilization, and the costs of doing preventative maintenance to equipment.” Eighty percent of RFID users are also said to start with asset management (and in particular infusion pumps), consecutively expanding to other RFID applications. Reported benefit range of biomedical equipment tracking for a medium- to large-size hospital is $300,000 to $400,000 per year. A slightly higher range of annual benefits that an average 400-bed healthcare facility can save is given by Cisco (2008) – from $400,000 to $500,000 annually resulting from by reducing short-term equipment leases, loss prevention, fewer purchases, and labor savings.

122 See Versus Technology, 2008c.
123 See Versus Technology, 2008b.
124 Radiance Inc. reports that PinnacleHealth achieved ROI within 12 months of deploying their asset tracking and management solution.
125 By one estimate, hospitals cannot find 15 to 20 percent of the devices they own. Of the eight hours needed to perform preventive maintenance on an intravenous (IV) pump, seven hours are typically spent locating the pump.
One of the most-frequently cited examples of these benefits is the experience of the 747-bed Brigham and Women's Hospital (BWH), Boston, which in 2006 implemented an asset-management real-time location RFID-based solution covering upwards of 10,000 medical devices across all major areas of the hospital's 17 floors – including perioperative and ED departments. The system was expected to achieve its ROI in three year, with a 15 month ROI of $66,000 on $80,000, in addition to a 50% reduction in lost equipment, for the pilot stage of the implementation during which 6,000 assets were followed hospital-wide, however, no recent accounts on its experience have been published. BWH also expected its RTLS will save it $300,000 annually. Reported non-quantified benefits included: increased staff satisfaction and productivity (based on finding equipment quickly), increased workflow efficiency (real-time alerts) and reduced loss of assets, ability to quickly locate FDA-recalled equipment, faster surgery turnaround time by reducing equipment waiting time, and nurses able to focus on patients not equipment searches.

More detailed cost and benefit data is provided by Scott (2007) who estimates that the hardware and software cost for a ultra wide band RFID application in a 300 bed hospital with 500,000 feet² (requiring roughly 1,500 Tags) is $490,000. The benefits such a system can deliver are illustrated through an infusion pump management application adopted by a 950-bed urban hospital: evaluating the data generated by the system the hospital managers determined that only 37% of pump usage was billed accordingly, resulting in over $8 million in unbilled usage annually. Due to inefficient asset tracking the 950-bed hospital also maintained 749 IV pumps in inventory in order to have 600 available, which resulted in $1.4 million in wasted capital expenditures annually (as IV pump rental costs $25/day per pump). In sum, the hospital was able to recoup roughly $9 million annually. The system achieved positive ROI in 6 months, however, no background information on the implementation process is provided. According to Page (2007), the cost of RFID infrastructure can run from $200,000 to $600,000 or more for a facility-wide RFID tracking system in a medium-sized hospital. This almost prohibitive cost can be reduced by substituting RFID-designated reader networks with an existing WiFi network (at the cost of worse granularity and network overload), or by using handheld devices at all times (leading to loss of user-friendliness).

The most informative account of the costs and benefits of an RFID medication management application come from a case study. Pittsburgh’s St. Clair’s Hospital adopted a hybrid RFID-barcode system in order to document outcomes of care (medication errors prevented, process improvement achieved) and to ensure that “5 Rights” violations in medication administration (right patient, medication, right time, right dosage, correct route) are identified and prevented. The RFID solution can also detect if medication has been discontinued by the physician, and captures event time and patient demographics. Based on the average number of errors prevented per week in September 2004 per nursing unit, the system prevented 6,074 errors in 2004; 5,409 in 2005, and 5,358 in 2006. They estimated that before implementing the medication verification system St. Clair was only aware of 12% of all medication errors annually (600, leaving 4400 as unknown). Comparing attempted incorrect medication deliveries per nursing unit per week, pilot participants found that the nurses learned to avoid the opportunity for error by using the system (09/04 rate was 1.41, 1/05 was 0.68). The annual savings resulting from these improvements were calculated to stand at $630,000.

127 billed at $56/day a pump
Finally, a single outpatient study containing both cost-of-system and impact information was identified (O’Connor, 2009). It describes how an assisted-living facility supplemented the need to confine residents at risk for wandering away (70% of all facility residents) to a secured area by using a patient tracing RFID solution based on passive tags sewed into patient’s clothing. The system alerts staff members if a resident suffering from dementia attempts to leave the facility, and can be used by residents to request immediate assistance. It also includes an asset and inventory tracking and a management component which provide the business process benefits making the application financially sustainable. The system is reported to be yielding a positive ROI, and to have resulted in a roughly 50% reduction in the monthly fees of high-risk dementia patients (the price differential for secure section vs. general housing).

Limitations notwithstanding, the information sources show that a number of healthcare institutions have successfully leveraged RFID to improve the quality of care they provide, and/or to reduce the costs they accrue in its delivery. However, while informative, the peer-reviewed and industry publications presented above at best report only some of the aggregate benefits and implementation costs associated with the different RFID systems they discuss.

For example, in-hospital RFID application evaluations seldom account explicitly for cost other than the direct costs of tags, and readers, thus by-passing important cost categories as training expenses and cost of process change. Similarly, there is no comprehensive evaluation of the benefits associated with the use of RFID in healthcare. The studies also largely fail to discuss benefits and costs which occur to the different stakeholder groups involved in the design and use of the RFID systems, and do report sub-aggregate impacts. Finally, they provide only limited contextual information, for example about the pre-existing process in the healthcare facilities and the ways they were affected, on the basis of which biases affecting the reported results cannot be ruled out.

In contrast to these results stands a group of four studies identified during the review which provide more detailed cost, outcome and implementation process information. They discuss two Emergency Department (ED) patient and staff tracing applications, a surgical unit patient tracing application, and a hospital-wide asset management solution. While none delivers a comprehensive account, combined they help expand our understanding of what impacts can be associated with RFID applications and under what conditions. Each of them is summarized below.

**Evidence from sources providing implementation data**

Laskowski-Johnes, 2006 delivers the most detailed account of the impacts and adoption process of a patient and staff tracing application in the ED environment of Christiana Care Health Systems, Wilmington, DE.

Christiana Care - a 907-bed suburban teaching hospital, housing multiple residency programs, a Level 1 adult and pediatric trauma center – treats roughly 100,000 ED patients annually. Its ED includes 76 total treatment areas (5 core areas and 6 fast-track beds) and has 43 attending and 53 resident physicians. Staff relied on a triage light-board which light-coded room availability and manual patient-room tracking which became unusable after construction in 2004.

To improve upon the system rather than replace it, Christiana Care teamed up with an auto ID solution provider to adapt one of their commercially-available infrared/RFID ED workflow tracking products to the hospital’s needs. Driven by ED clinical and administrative staff’s willingness to change how they work, and through a series of stakeholder staff and technology provider

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129 Also discussed in PCTS, 2008 and Versus, 2008.
workshops the functionality requirements for the system were defined and tested. What staff and management identified as key challenges to be resolved included:

- limited ability to locate all ED patients and identify their care status without burdening staff with manual updates;
- a need to reduce ED patient length-of-stay;
- a need to reduce the rate of patients leaving without treatment;
- slow communication of diagnostic study results availability; and
- limited ability to quickly identify which staff cared for patients (for staff infection exposure control).

As a result a hybrid RFID-infrared ED workflow management application was implemented in 2004. The system records patient movement and staff interaction displayed at a department map and interprets care milestones based on the interactions between patients, staff and mobile medical equipment, which are time-stamped and displayed to caregivers. It is interfaced with the Admission, Discharge and Transfer (ADT) system, laboratory and radiology departments, as well as with the bed management system, and enables care providers to access integrated patient PACS and ED patient record. Granular data is continuously collected for retrospective analysis of department through-put, along with real-time indicator monitoring on individual patient acuity and real-time location, elapsed wait times for various care intervals, staff-patient contacts occurrence and duration. The system also enhanced communications between the individual departments and improved the facility’s functional capacity and service efficiency.

In the November 2004 – June 2005 period after implementation130 Christiana estimated that patient location was identified 100% of time (previously tracking was very difficult because of the spread-out design of the ED and patient-room location was accurate 70-80% of time and required multiple phone calls and walking tours). Length of stay was reduced by 14 minutes for treated and released patients, and by 36 minutes for admitted patients (previously at 4 to 6 hours), mainly due to the availability of patient information and lab results. A 24% decrease in patients leaving without treatment was also recorded (previously 4%-5% of total ED census left). The number of hours the hospital is diverting ambulances fell from 60 to 11 hours a month. And a statistically significant change in overall ED patient satisfaction was detected. Christiana also improved its emergency preparedness, sorting patient by acuity and generating staff encounter summaries for interactions with infection agents. According to the case study, the process/workflow automation also enabled by the system resulted in significant staff time savings, which translated back to increased patient interaction time. These were not measured. Staff commitment to wear badges – supported by their early involvement in the application design process and by human resources policies – was identified as a key driver of the documented benefits.

The total implementation cost of the application was $600,000 (including all hardware and software components and process re-design), and maintenance cost is 18% of the initial cost. No formal ROI analysis was carried out. Instead an argument was made that the benefits of the system are believed to exceed substantially the application’s implementation and maintenance costs (1/3 of the implementation cost was actually provided by a state grant for emergency response preparedness).

Follow-up interviews with the pilot implementation leader, however, revealed that the RFID component of the system is in fact only infrequently used131. Thus, the achieved benefits and

130 Data continued to be collected and analyzed, however two key changes occurred in July 2005 (initiation of “team triage”) and October 2005 (the opening of 17 additional treatment rooms) since these significantly impacted ED performance and introduced a discontinuity in previously parameter metrics.

131 The RFID component takes over the infrared technology when line of sight – needed for the operation of infrared-based tags and readers – is lost.
costs of the implemented technology cannot in fact be unambiguously attributed to healthcare RFID.

A similar issue was discovered with the second case study of a real-world ED management solution implementation in Albert Einstein Medical Center is the second ED RFID example\textsuperscript{132}. The facility – a 509-bed academic tertiary care center located in downtown Philadelphia, Pennsylvania, which is also a level 1 trauma center with 48 critical care beds organized within three pods and a 6 bed fast track area and over 76,000 patient visits annually – adopted a hybrid infrared-RFID ED patient flow automation system.

With a similar design as the Christiana Care ED application, the problems this technological solution was brought to resolve included:

- maximizing available clinical space in the face of increasing ED volume;
- improving clinical efficiency, patient flow and safety;
- improving patient and staff satisfaction; and
- resolving communication problems among ED staff and ED and other departments.

Reported achieved results included:

- 24% increase in ED volume and hospital admissions;
- reduction in leave without treatment from over 5% to 1-2%, and reduction by 89% of average hours per month the ED spends on divert;
- increase in patient satisfaction by 15-20%.

The application is also used as teaching tools for residents and has increased the continuous quality improvement of the department.

A white paper by Intel (2005\textsuperscript{133}) presents a cost-benefit evaluation of a surgical unit patient-tracking and real-time clinical information system pilot at St. Vincent Hospital, Birmingham, AL, in 2005. Facing significant bed management challenges, St. Vincent routinely diverted incoming patients – a practice estimated to result in a $20 million loss in net revenue. To address this problem, the hospital identified three goals it sought to achieve:

- improve patient visibility;
- eliminate backups in admissions and discharges; and
- reduce the time spent waiting for care.

Getting better insight into where patients were at all times, and having real-time information on doctors’ orders and test results available to all staff in the unit were the first-priority aims hospital management decided to target.

Adopting a commercially available solutions to the needs and environment in the hospital and redesigning key inter-departmental work processes affecting Environmental Services, Bed Control Management, Laboratory, Nursing and Admissions, St. Vincent first chose to pilot the RFID application in its 35-bed surgical (cardiac-care) unit. The pilot lasted 7 months. It involved the installation of smart display boards that were integrated to the hospital information system and showed room and patient location and status based on RFID tags integrated into the

\textsuperscript{132} Albert Einstein Medical Center. AHRQ Innovation Profile. Provided by Dr. Albert Villarin, Chief Medical informatics Officer, Albert Einstein Healthcare Network.

\textsuperscript{133} Also discussed in Gambon, 2006.
patients’ charts. In addition to the patient-location information, the system integrates clinical data and relevant information, such as notification of lab results, prescription orders and other medical instructions. The system conveys this information on screens through a series of color-coded graphics and icons, allowing nurses to tell at a glance what care a patient requires. To protect privacy, no names are displayed on the screens – only room numbers identify the patients. The pilot did not utilize the staff and asset tracing capabilities of the application.

Pre-post implementation data comparisons showed that:

- the number of patients discharged by noon climbed by 21% (from 48% to 58%);
- patient diversions dropped by 25% in the critical-care unit and 60% among medical-surgical beds;
- inpatient admissions climbed by 4%;
- average time of ADT improved by 85% (from 39 min to 6 min on average; range dropped from 1min to 8 hr, down to 1 to 45 min).

The project cost was estimated to stand at $1.7 million and to be offset by a projected net revenue increase of $2.58 million during the pilot phase. The latter was calculated as arising primarily from one additional admission per week per nursing unit and conservative cost avoidance from improved patient safety in which the additional cost for staff and supplies because of the added admissions are factored.

Although providing more detailed cost and benefit data estimates than other sources, the paper does not clarify the assumptions behind these calculations. Hence its findings also need to be treated with care.

A case study by another technology provider – Agility Healthcare Solutions (2007) – delivers an account of the impacts and adoption process of a hospital-wide asset management application implemented at Bon Secours Richmond Health System, in Richmond (VA).

Bon Secours implemented the RFID application in response to a specific business challenge the group was facing – the inadequate availability of biomedical equipment, in a proper operational condition, to clinicians when needed. The system was developed jointly by the technology provider and the group, adapting a commercial RFID RTLS product to the needs of the hospital group, to provide zonal-based coverage of all four facilities enabled with room resolution for equipment storage and cleaning locations.

During the period 2004-2006, Bon Secours Health System tagged approximately 12,000 pieces of movable equipment at its four hospitals (two with less than 200 beds, and two in the 200 to 400 bed range). Tagged assets include IV poles, pumps, wheelchairs, stretchers and hospital beds. To support the system, the group simultaneously installed Wi-Fi throughout the hospitals, to also support laptop computers and PDAs.

The high-granularity asset utilization data made available by the application was used to accurately measure equipment usage and to determine appropriate equipment levels. A new process establishing min / max equipment stocking levels and automated notification for replenishment was developed. The system also reportedly led to optimizing the preventive maintenance procedure, and improved staff satisfaction. The system, thus, produced capital and operational cost reductions, and increases the utilization for each piece of equipment. Theft prevention and enhanced employee productivity also contributed to reducing the cost of care delivery. Combined these resulted in an average of $1 million in annual net savings and a 45% ($2,500) decrease in the per bed cost of biomedical equipment management over the 2004-2006 period.

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evaluation time-horizon. About 80% of these are associated with reductions in equipment. The cost and benefit estimates reported in the study could not be verified through follow-up interviews.

Pooled, the 27 matching-case cost and benefit data sources show that a number of healthcare institutions have succeeded in leveraging RFID applications to improve certain aspects of the quality of care they provide, and to reduce some of the costs they accrue in its delivery.

These results on RFID’s capacity in healthcare however suffer from four key limitations:

- they are overwhelmingly based on industry-sponsored studies (i.e. potentially biased);
- which are not comprehensive in the impacts they consider, as they explicitly assess only some aspects of return on investment (ROI);
- there is a lack consistent use of parameters, measures, and occasionally constructs across studies; and as a result,
- the empirical cost and impact data they deliver remains limited and non-comparable.

### The obstacles and facilitators for RFID’s dissemination in healthcare

The final aim of the structured review was to identify the factors which can impede or facilitate RFID’s further dissemination in healthcare. These are briefly discussed in turn below\(^{135}\).

As the next figure illustrates, the factors identified in the literature as hindering RFID’s further dissemination in healthcare can be grouped in four categories:

- technology maturity-related obstacles
- industry maturity-related obstacles
- obstacles having to do with RFID implementation, and
- technology acceptance-related obstacles

#### Figure 11: Key obstacles to wider RFID dissemination in healthcare (% sources mentioning)

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance of RFID</td>
<td>11%</td>
</tr>
<tr>
<td>Technology maturity</td>
<td>36%</td>
</tr>
<tr>
<td>Implementation management challenges</td>
<td>21%</td>
</tr>
<tr>
<td>Industry maturity</td>
<td>32%</td>
</tr>
</tbody>
</table>

*Note: Non-mutually-exclusive categories*

\(^{135}\) For a more in-depth discussion on the obstacles, enablers and uncertainties affecting RFID’s dissemination in healthcare refer to Vilamovska et al. (2008), pp.40-55.
Inhibiting factors that have to do with the maturity of healthcare RFID technology (listed in Figure 12) include unit cost of RFID applications and the hardware, middleware and software they involve; the limited interoperability between RFID applications offered by different vendors, and with other HIT and clinical systems already in place, RFID signal reliability and interference concerns, and the lack of amassed and shared experience on best practices with RFID, among others.

**Figure 12: Obstacles related to RFID technology maturity (% sources mentioning)**

Industry maturity-related obstacles (listed in Figure 13) include concerns about the lack of universal standards on RFID technology tailored to use in the healthcare industry (such as data privacy, data security and data integrity concerns\textsuperscript{136}), the lack of clear laws and recommendations

\textsuperscript{136} These concern the risk of inappropriate protection and subsequent unauthorized access to private information collected via RFID applications.
about the tracking of persons, as well as issues related to the structure of the healthcare RFID vendor market – most notably vendor stability, size and product range.

Figure 13: Obstacles related to RFID industry maturity (% sources mentioning)

The third most-frequently mentioned group of factors impeding RFID’s further dissemination in healthcare comprises challenges associated with RFID’s implementation process management (see below). These relate to the fact that given the wide variation in healthcare institutional environments, the numerous types of RFID (mentioned in Chapter 1 and Appendix B), and the overall limited experience with this technology (both by vendors and adopters), successfully identifying what type of RFID (or combination of solutions) is needed to meet the targeted

137 It must be noted that on May 13, 2009 the European Commission issued its official recommendation on the implementation of privacy and data protection principles in applications supported by radio frequency identification. It is non-binding in nature and include guidance regarding opt-in requirements for the retail sector. No such framework exists in the U.S.
organizational/departmental goals can be a challenge. Ensuring that the RFID application is designed to meet the needs of all stakeholders which will use it as well as achieving stakeholder buy-in and undertaking process evaluation and re-design, while dealing with infrastructure configuration and cost uncertainties are some of the potential perils emerging during RFID’s implementation process identified in the literature.

Table 47: Obstacles related to the management of RFID implementation (% sources mentioning)

<table>
<thead>
<tr>
<th>Obstacles</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institutional culture issues</td>
<td>13</td>
</tr>
<tr>
<td>Difficulty of ROI estimation without pilots</td>
<td>10</td>
</tr>
<tr>
<td>Difficulty choosing the right technology</td>
<td>9</td>
</tr>
<tr>
<td>Technology not yet fully mature</td>
<td>8</td>
</tr>
<tr>
<td>Success of existing technologies</td>
<td>6</td>
</tr>
<tr>
<td>Lack of funding for RFID implementation</td>
<td>5</td>
</tr>
<tr>
<td>Cost of infrastructure in place (direct and indirect)</td>
<td>5</td>
</tr>
<tr>
<td>Need for on-site engineering of specific applications</td>
<td>4</td>
</tr>
<tr>
<td>Patient acceptance and knowledge of benefits</td>
<td>4</td>
</tr>
<tr>
<td>Challenge of modifying existing business processes</td>
<td>4</td>
</tr>
<tr>
<td>Integration of common RFID platform with existing IT application portfolio</td>
<td>3</td>
</tr>
<tr>
<td>Building back-office infrastructure to support the system</td>
<td>3</td>
</tr>
<tr>
<td>Increased demands on nursing staff - to keep RFID system operational</td>
<td>3</td>
</tr>
<tr>
<td>Active RFID tag size</td>
<td>3</td>
</tr>
<tr>
<td>Additional layer of complexity to infrastructure/processes</td>
<td>2</td>
</tr>
<tr>
<td>Staff training</td>
<td>2</td>
</tr>
<tr>
<td>No single vendor offers integrated broad solutions</td>
<td>2</td>
</tr>
<tr>
<td>Old building infrastructure</td>
<td>2</td>
</tr>
<tr>
<td>Comfort level of hospital staff/preserving freedom of individuals</td>
<td>2</td>
</tr>
<tr>
<td>No best practice guidelines for RFID (vs. bar codes)</td>
<td>2</td>
</tr>
<tr>
<td>Lack of appropriate evaluation framework</td>
<td>1</td>
</tr>
<tr>
<td>lack of standardization</td>
<td>1</td>
</tr>
<tr>
<td>No single hospital can test integrated broad applications</td>
<td>1</td>
</tr>
<tr>
<td>Existence of older radio frequency networks</td>
<td>1</td>
</tr>
<tr>
<td>Only rudimentary applications are tested at pilots</td>
<td>1</td>
</tr>
<tr>
<td>Passive RFID fully reliant on electricity, bar code readers can use batteries</td>
<td>1</td>
</tr>
<tr>
<td>The relatively easy detachment of transmitters</td>
<td>1</td>
</tr>
<tr>
<td>Vendors don’t tailor systems to specific hospital needs</td>
<td>1</td>
</tr>
<tr>
<td>Space for human error in scanning, despite 100% detection accuracy</td>
<td>1</td>
</tr>
</tbody>
</table>

According to the reviewed sources, a final set of obstacles to RFID’s wider dissemination in healthcare have to do with its acceptance (see below). These include:

- concerns about the surveillance potential of RFID
- lack of understanding of the true privacy and security threats associated with RFID in healthcare, and in general
- ethical, cultural, and social/societal perceptions about RFID and its functions
- lack of potential patient acceptance due to the factors listed above
- concerns about the cost-effectiveness of the technology

![Figure 14: Obstacles related to RFID acceptance (% sources mentioning)](image)

While RFID applications in healthcare have largely been received with much anticipation and attention to privacy issues, the true threats the technology carries for personal data security and privacy have largely been misunderstood in the popular media (Boulard, 2005; O’Connor, 2005c). The distinction between these threats and those posed by RFID applications in other fields is also not widely understood. Based on these fears, a number of blanket anti-RFID initiatives have already emerged in the US – including a Christian-based consumer union referring to RFID as the “sign of the Beast” (Albrecht, 2007) – and secular lobbying initiatives aimed at preventing RFID deployment through fear of ubiquitous surveillance (Boulard, 2005).

Although such strong negative reactions to RFID healthcare applications are not frequent or overpowering, the lack of public understanding about the feasible risks and challenges facing the still-developing healthcare RFID industry could have very damaging effects on its potential to improve the safety and quality of healthcare provided. In fact, a rather dated 2004 study by CapGemini reported that only 18% of European respondents to its survey had heard of RFID. These issues can be particularly hard to overcome among older patients whose acceptance of RFID is a prerequisite for the success of any RFID-based in- and outpatient quality-of-care improvements. Drafting national and supranational legislation which addresses the privacy and legal issues discussed in the obstacles section above, supported by public information campaigns, is likely to help avert such outcomes\(^\text{140}\). Finally, according to Fisher and Monahan (2008) there is

\(^{140}\) See Kelly, 2008a and Kelly, 2008b.
also a need to examine more closely the social and organizational factors that contribute to the success or failure of RFID systems, and their consideration should be woven in the preparatory work for RFID deployment.

The literature also identifies a number of factors likely to facilitate RFID’s dissemination in healthcare. These can be grouped in five categories (see below) and include:

- the capacity of RFID technology to enable the delivery of better healthcare
- the clear business case for some RFID applications
- the use of sound approaches to implementing RFID in the hospital environment
- the superiority of RFID technology over comparable solutions, and
- government incentives/support

**Figure 15: Key facilitators for wider RFID dissemination in healthcare (% sources mentioning)**

The improved patient safety, improved resource utilization, better workflow management, and increased effectiveness of care associated with RFID’s ability to supplement manual processes currently unsupported by existing IT solutions (e.g., automated data capture and transfer, positive identification, tracking, and sensing); as well as its ability to enhance performance-driven management are some of the key capacity-related facilitators sources highlight (see Figure 16 for full list).
Facilitators related to the emerging strong business case for some RFID applications, and the falling cost of RFID, along with vendor initiative for creating interoperable, cost-effective RFID solutions suited to specific client needs, are a second group of factors deemed capable of advancing RFID’s dissemination in healthcare (see below).
A third group of dissemination-enabling factors revolve around the management approach applied to the implementation process for healthcare RFID (see below). The fact that implementation management if seen as both a potential enabler and an obstacle to RFID’s wider uptake suggest that as is the case with other technologies in the healthcare setting, how they are introduced in an organization may play a more important role for their success or failure, than their intrinsic capabilities. In the case of healthcare RFID, having an understanding of how RFID will affect existing processes in advance, bundling different RFID technologies to suit specific hospital needs, achieving a satisfactory return on investment on the RFID pilot, and the staged (pilot ROI) and smart implementation (choosing the “right” technology from among passive, active and semi-active RFID, possibly supplemented by bar codes or other older technologies) stand out as key enablers.
A fourth group of adoption facilitators identified in the literature gravitate around RFID’s broader functionality – e.g., distant reading, linkage into wider hospital HIT environment, and in particular the gains in costs and quality of care associated with interconnecting separate RFID applications and other systems – and superior user-friendliness as compared to alternative technologies (see below). For example, Radiance Inc. highlights the following RFID capabilities:\(^{141}\):

- Patient throughput automation
- Faster bed turnover
- Improved admission and discharge management
- Fewer patient care delays
- Better patient experience
- Improved patient safety
- Accurate, objective measurement to determine whether and how to adapt processes
- Accurate, objective measurement to determine progress
- Sustainable process improvement
- Increased accountability and satisfaction

\(^{141}\) See http://www.radianse.com/why-radianse-ROI.html#
• Improved readiness at each stage
• Less asset shrinkage
• Increased utilization
• Efficient rental equipment management
• Improved scheduling
• Enhanced competitive position
• Increased surgical capacity for additional procedures

Figure 19: Facilitators related to technological superiority of RFID (% sources mentioning)

Finally, the creation of government mandates favoring auto ID solutions – such as regulations on the e-pedigree of pharmaceuticals – also emerge as both enablers and obstacles for RFID dissemination – for example if regulations favor investment in barcodes adopters may delay RFID implementation, although the two technologies generally fulfill distinct need-gaps (save for passive RFID).

Supplementing and alternative technologies also reviewed in literature

The structured review on the use and impacts of RFID in healthcare suggests that RFID is not necessarily a stand-alone technology. It is frequently deployed in combination with other Auto ID solutions (e.g., 1D or 2D barcode – for easy management of database, or to reduce the overall cost of the applications), or alternative information transfer solutions (infrared, ultrasound). The table below lists the different technologies discussed in conjunction with RFID in the information sources.
Table 13: Technologies and technology classes considered alongside RFID in literature

<table>
<thead>
<tr>
<th>Technology</th>
<th>N</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID (stand-alone)</td>
<td>310</td>
<td>71%</td>
</tr>
<tr>
<td>RFID and HIT</td>
<td>38</td>
<td>9%</td>
</tr>
<tr>
<td>RFID and bar code</td>
<td>33</td>
<td>8%</td>
</tr>
<tr>
<td>RFID and alternative data transfer solutions (WiFi, ZigBee, infrared, ultrasound)</td>
<td>18</td>
<td>4%</td>
</tr>
<tr>
<td>RFID and Auto ID (in general)</td>
<td>11</td>
<td>3%</td>
</tr>
<tr>
<td>RFID and mobile multimedia (PDA, cells)</td>
<td>10</td>
<td>2%</td>
</tr>
<tr>
<td>RFID and location technology (GPS, GIS)</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>422</td>
<td>97%</td>
</tr>
</tbody>
</table>

The main reason for the integration of these potentially competing technologies is that none of them represent a ubiquitous solution – for example RFID is reported to encounter signal spill-over when used for activities requiring room-level signal reading (a problem not experienced by infrared or ultrasound-based solutions, which however do not support the data transfer range offered by RFID).

The occasionally emerging discussion in the management stand of the RFID literature on the general supremacy of RFID over barcode, or vice versa, also appears to be unfounded as the two differ significantly in their engineering, functionality and ultimately suitability to different tasks and environments. The closest possible comparison between the two should be between passive RFID solutions and barcodes, but even for this no generally dominant technology. Such may in fact not be needed, as the technologies appear mutually-reinforcing.

More concerning is the fact that studies which have a management focus often explicitly or implicitly employ wrong or incomplete definitions of what constitutes an RFID solution, and include misunderstandings of what RFID can really do. For example, RFID is frequently referred to as a wireless chip-and-reader technology when, as discussed in Chapter 1, at least in the healthcare context it is a system of interfaced hardware, software and middleware providing unique identification and geolocation, and in the case of active RFID – continuous geolocation, or tracing. The importance of the difference between the two definitions becomes apparent once comparisons between RFID and barcode technologies are made; in the case of the management-focused literature typically to argue for/against the general supremacy of RFID over barcodes. Since barcodes fundamentally involve a non-unique identified tag and a reader, the shorter “wireless chip-and-reader” RFID definition invites an apples-to-apples comparison between the RFID and barcode – a topic of blanket discussions in many a source belonging to this research domain. The full RFID definition, instead, suggests that the two technologies differ sufficiently to not be directly comparable in the general case and to potentially be suited to fulfilling distinct functional goals (even if specific function-based comparisons between passive

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142 Bureau et al. (2008) argue that these problems characterize the entire peer-reviewed literature on RFID in healthcare. The systematic review of the literature suggests that sources focused on the engineering or standardization of healthcare RFID are largely not affected by these problems. The management and ethics/privacy strands in the literature (term used broadly), however, are. And this confusion cannot be attributed to any one type of sources (e.g., industry white papers vs. conference presentations, or peer-reviewed articles), making it an even more significant problem.
RFID and barcodes may be appropriate. Hence, such comparisons largely do not contribute to understanding neither the range, not the value of RFID in healthcare.

\[143\] It is interesting to note that most incomplete or wrong definitions of RFID are brought in the attempt to introduce a broader audience to healthcare RFID (as RFID is frequently dubbed an innovation this group is expected to be the average reader), but remain unexpanded/corrected in the paragraphs that follow. It has been observed across all information type categories included in the review.
Appendix 4: Examples of existing classifications of healthcare RFID


  This document suggests the following classification of RFID:
  - RFID and the patient (inpatient, outpatient)
  - RFID and medication
  - RFID in diagnostics
  - RFID for devices and surgical procedures

- Houliston, Bryan. “Integrating RFID Technology into a Drug Administration System”

  Houliston identifies 3 types of RFID functionality:

  1. Identification applications involve a single action at a single location (e.g., identifying a staff member for access to a secure area)

  2. Location-based applications perform continuous actions at a single location (e.g., an RFID-enabled “smart” medicine cabinet can provide a real-time inventory of drugs it contains, recording removals and additions)

  3. Tracking applications use continuous actions at multiple locations (e.g., individual pieces of equipment may be tracked to prevent them being lost or stolen, or staff and patients may be tracked to analyze workflow


  The scope of applications for active RFID include asset tags, staff badges, patient bracelets, PDAs, laptops, tablets, WiFi VoIP handsets and WiFi telemetry. These allow for the following:

  - Inventory and asset management: best use of equipment, and inventory; theft reduction
  - Patient, personnel, visitor ID location: patient safety and location (ED boards); wandering; security
  - Bed management: maximize use and throughput
  - Improved workflows: automation of processes; billing and audits; process observation and re-engineering
Appendix 5: Key RFID expert and stakeholder interview respondents

1) Healthcare RFID industry representatives:
   - Vice President of Marketing, PCTS, USA
   - Mobility Solutions Marketing Manager, Marketing / CMO, Cisco Systems Inc., USA
   - Chief Medical Officer, RadarFind Corporation, USA
   - Senior Director, Worldwide Health, Microsoft Corporation, USA

2) Representatives of non-government organizations focused on health information technology (HIT) and/or health care quality improvement:
   - Director, Engineering and Compliance, American Society for Healthcare Engineering, USA
   - President and CEO of HIMSS Analytics and Executive Vice President of HIMSS, USA
   - Chair, MIT Enterprise Forum RFID SIG, Research Affiliate, MIT Auto-ID Labs, USA

3) Non-government privacy-defense group representative:
   - Director, Health Privacy Project, Center for Democracy and Technology, USA

4) Independent researchers working on healthcare outcomes and HIT:
   - Senior Program Officer, Innovations for the Underserved Program, California HealthCare Foundation, USA
   - Senior Program Officer, Better Chronic Disease Care Program, California HealthCare Foundation, USA
   - Health Researcher, The RAND Corporation, USA

5) Healthcare professionals (providers of care and managers) with HIT and RFID experience:
   - Vice President of Operations, Wayne Memorial Hospital, USA
   - Principal Clinical Scientist, St. James' Hospital, Leeds, UK
   - Chief Information Officer, Director of Medical Informatics, Chairman of Hospital Information Management and Quality Assurance Group and Lead Clinical Director – Electronic Medical Record Implementation, Department of Emergency Medicine, Albert Einstein Medical Center, PA, USA
   - Vice President of Emergency, Trauma and Aeromedical Services, Christiana Care Health System, Wilmington, Delaware, USA
Appendix 6: Protocol for semi-structured expert interviews

This appendix contains the interview protocol for the 15 semi-structured expert interviews I used to divide the documented range of RFID solutions into currently market-ready and medium-to-long term market-ready applications, to prioritize the factors which drive RFID’s impacts and dissemination in healthcare – including system-level obstacles and enablers influencing the technology, and to explore expert knowledge on the impacts and costs of healthcare RFID.

6.1. Analytic Goals and Approach for Interviews

To validate, expand, and prioritize the results from the literature, during its course an initial sample of key experts on RFID and auto ID technologies in healthcare was identified. This was done with the intention of using expert interviews to address the publication time-lag and potential bias affecting published materials, as well as to access expert knowledge and potentially different stakeholder perspectives (e.g., vendor, user, patient) on healthcare RFID. Identified experts included representatives of the following key stakeholder categories:

1) healthcare professionals (providers of care and managers) with experience in HIT and RFID;
2) non-government organizations focused on health information technology and healthcare quality improvement;
3) healthcare RFID industry representatives;
4) non-governmental privacy-defense groups;
5) independent researchers working on health outcomes and HIT/RFID.

From the initial sample of experts who were approached with an invitation for interviews, two declined, reducing the expert respondents sample to 15 participants (a list of their affiliations is given in Section 6.2).

The specific goals of the key expert and stakeholder interviews were to:

- validate the results of the literature review;
- divide the documented range of RFID solutions into currently, near-, medium- and long-term market-ready applications;
- prioritize the factors identified in the literature as likely to affect RFID’s impacts and diffusion in healthcare – including system-level obstacles and enablers influencing the technology;
• gather more information on completed and on-going experiments with healthcare RFID and their impacts.

All interviews were semi-structured144, based on a questionnaire with mostly open-ended questions, to allow the collection of a rich set of data. It consists of five sections (see Appendix 6 for its full version):

• **Section 1: Important areas for RFID (in healthcare) and reasons for ranking**, which asks respondents to identify, motivate and rank important application areas for RFID in healthcare, and explores questions such as “In what aspect of healthcare can the use of RFID be considered unlikely and/or undesirable?”;

• **Section 2: Further insights into quality and cost impacts of RFID**145, which asks the respondents to rank in importance a range of specific RFID applications with respect to their effect on improving the overall quality and reducing the overall cost of healthcare;

• **Section 3: Experience with RFID applications**, which probes if the expert has first-hand involvement in the piloting of a healthcare RFID application, what organization-level impacts resulted from it; and if (and why) it replaced other technologies;

• **Section 4: Economic analysis**, which explores questions such as “Which are the main drivers of demand for healthcare RFID?” and “What will be the key developments in the market for healthcare RFID over the next 5 years?”;

• **Section 5: Additional stakeholders**, which probes if any stakeholders have been omitted from the analysis.

Respondents were allowed to freely associate, but thematic prompts identified through the literature review were used when a question failed to stimulate a response. The interviews took place over the telephone, or in person, and lasted between 40 and 60 minutes. At the beginning of each interview, respondents were informed of their right to decline to continue the entire interview at any point, to decline to answer a specific question, and/or to decline that notes be taken. In the analytic stage data was de-identified. Both quantitative – frequency of mention of topics; and qualitative methods – view range and belief structures unfolding146 – were used for response analysis.

### 6.2. Interview Protocol

**Introduction**

Explain purpose of the study and obtain consent to record interview, or take notes.

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145 This section builds upon the results of a Delphi survey conducted with a different set of experts which was used to answer a set of similar research questions on the potential of RFID in healthcare but in the European setting only.

146 For more information on the use of these analytical approaches for interview data analysis, see Bernard (2006).
Section 1: Important areas for RFID / reasons why these areas are important

1. What are, in your opinion, the main application areas of RFID in healthcare? Which are the four RFID application types you would consider most capable of addressing outstanding issues in the quality and cost of care delivery in the U.S. today and over the next decade? On what evidence is this based on? How do these systems create value?

Probe:
- error prevention e.g., via SurgiChip
- workflow optimization at hospitals
- patient identification to avoid wrong drug/dosage/time/procedure
- inventory management; maintenance of medical equipment
- asset tracking; asset identification/blood bags identification at hospitals OR to ensure blood type matching

2. In what aspect of healthcare would you consider the use of RFID unlikely and/or undesirable?

Probe:
- telemetry
- patient identification in open-loop settings
- implanted RFID

3. What alternatives are there to RFID? How do these compare to RFID? Which ones are complementary and which ones competing?

Probe:
- barcodes
- other wireless AUTO ID technologies: ultrasound/ infrared
- alternative signal/information delivery solutions: Bluetooth

4. What are in your opinion the main enablers and barriers for the speed and breath of RFID dissemination in healthcare, now and in the near future?

Probe (enablers):
- improved patient care / costs
- user-friendliness of technology
- ability to support better healthcare delivery
- success of pilot ROI
- vendor initiative for creating interoperable cost-effective solutions

Probe (barriers):
- direct RFID costs
• privacy, security and legal issues
• technical issues – integrity and interferences
• operational/managerial challenges
• cultural/ethical concerns

5. In your opinion, do the obstacles and enablers facing RFID dissemination in the U.S. and the European health systems differ? If so, how and why?

6. In your opinion, can RFID help improve the quality, safety and efficiency of healthcare delivery? How – can you provide specific examples? How do the benefits these systems produce arise? Do you know what costs are they are associated with? Are these benefits scalable? What evidence is this based on?

7. To the extent that you are aware, are there any differences across the U.S. and the European health systems which can result in different sets of priority implementation areas, uncertainties or effects from RFID implementation?

8. What are, in your opinion, the main four application areas of RFID in healthcare in the future (10+ years)? What evidence is it based on? Why are these areas important? Is this contingent on anything (e.g., new technological developments in RFID chips and equipment)?

9. What are the underlying assumptions/uncertainties for success and failure of RFID in healthcare that need to be tested further?

Probe:
• falling costs
• improved technical performance (better protection against signal disturbance/interruption)
• acceptance of standards
• promulgation of mandates/regulation on RFID implementation
• public opinion on RFID

10. Given the application areas, obstacles and enablers for RFID we just discussed, do you see a role for government in this debate (national, transnational)? If so, which specific actions would you advise governments to take?

Probe:
  a. setting standards
  b. funding research and/or pilots
  c. privacy: stimulating discussions, soft/hard law
  d. stimulating debate (e.g., setting up multi-stakeholder discussion groups)
Section 2: Further insights into quality/cost impacts of RFID

We would like to discuss some of the findings of our recent Delphi study with you. In this study we asked participants to rate the importance of a range of RFID application areas. The following figures show the importance of different application areas for RFID. The horizontal axes show the importance of the various applications to contain cost, while the vertical axes show the importance of the applications to improve quality of care. Each dot represents a specific RFID application area. Its place on the graph is determined by the percentage of respondents that rated this application 7, 8 or 9 on a 1-9 scale (1 representing “very unimportant” and 9 representing “very important”).

Figure 1:

11. The first figure suggests that applications related to staff have equal importance with respect to improving quality compared to containing cost (i.e. most dots are close to the 45-degree line):

   a. Does that result surprise you? Why, why not?
   b. If you were to prioritize the listed RFID applications in terms of their capacity to positively affect the quality of care delivery, which are the top four you would pick?
   c. If you were to prioritize the listed RFID applications in terms of their capacity to positively affect the cost-efficiency of care delivery, which are the top four you would pick?
   d. Are there any application areas which you would expect to have appeared at a different spot in the figure?
   e. Are there any application areas not shown in this figure that should be included? Where would they appear according to your knowledge?
12. The second figure suggests that applications related to patients have higher importance with respect to improving quality compared to containing cost (i.e. almost all dots appear above to the 45-degree line):

a. Does that result surprise you? Why, why not?

b. If you were to prioritize the listed RFID applications in terms of their capacity to positively affect the quality of care delivery, which are the top four you would pick?
c. If you were to prioritize the listed RFID applications in terms of their capacity to positively affect the cost-efficiency of care delivery, which are the top four you would pick?

d. Are there any application areas which you would expect to have appeared at a different spot in the figure?

e. Are there any application areas not shown in this figure that should be included? Where would they appear according to your knowledge?

Figure 3:

Importance of RFID Application Areas: Cost vs Quality (Assets)
(% of respondents answering 7, 8 or 9)

A Asset identification blood bags identification hospitals OR to ensure blood type matching
B Asset tracking
C Asset tracking and tracing for access control and inventory shrinkage decrease
D Asset tracking and tracing for expiration date and restocking
E Asset tracking and tracing to avoid procedure delays
F Inventory management
G Inventory utilization
H Maintenance of medical equipment
I Materials tracking to avoid left ins
J Medicine tracking
K Real-time inventory count and location tracking
L Tissue Bank operations

13. The third figure suggests that applications related to assets have lower importance with respect to improving quality compared to containing cost (i.e. almost all dots appear below the 45-degree line):

a. Does that result surprise you? Why, why not?
b. If you were to prioritize the listed RFID applications in terms of their capacity to positively affect the quality of care delivery, which are the top four you would pick?

c. If you were to prioritize the listed RFID applications in terms of their capacity to positively affect the cost-efficiency of care delivery, which are the top four you would pick?

d. Are there any application areas which you would expect to have appeared at a different spot in the figure?

e. Are there any application areas not shown in this figure that should be included? Where would they appear according to your knowledge?

14. We looked at the ratings shown in Figure 1-3 across three different respondent categories: industry, academia, providers, but found for the majority of application areas very little differences.

   a. Can you think of reasons why these differences are small?
   b. Based on your experience, do you think actual (i.e. in a larger population) differences would be more substantial?

15: How useful are these results? What do you think are their implications?

   a. For the industry?
   b. For policy makers?

Section 3: Experience with RFID applications

16. Have you ever been directly involved in an RFID pilot/trial?

   Probe if answered « Yes » :
   • What are the main benefit categories that were observed/monitored during the trial/pilot? (e.g., direct/indirect benefits)
   • What are the main cost categories that were observed/monitored during the trial/pilot? (e.g., direct/indirect costs)

17. Can you indicate in what way RFID is embedded in your technical infrastructure?

18. What was the organizational impact of RFID deployment? How was this dealt with in your case?

   Probe:
   • workflow challenges
   • improved staff time utilization
   • increased/decreased stakeholder disagreement in the organization

   If no RFID trial, then ask:
19. Which technologies are you currently using that could replace or could be replaced by RFID? Why were they chosen instead of RFID?
   Probe:
   - Barcodes
   - Sensors communicating via wired networks/ Bluetooth/ wireless (WiFi, WLAN, GSM,GPRS.3G)
   - Chip cards/smart cards

20. Are you aware of any important RFID trials and pilots in healthcare that are exploring new applications/ might be of interest for our study?
   Probe if answered « Yes » :
   - Can you provide us with a contact in the organization(s) which were involved in this trial/pilot?
   - And will you allow us to use your name as a reference?

Section 4: Cost and Benefit analysis
21. Are you aware of any estimates on the size of the market for RFID in healthcare in the U.S.?

22. How much do you expect this market to grow annually over the next 10 years?

23. How much concentration is there in the market? On the supply side? On the demand side?

24. In your opinion, what are the main drivers of demand for RFID?

25. In your opinion, what are the main cost components to produce RFID technology (for suppliers)? How will these change over the next 10 years?

Section 5: Additional stakeholders
26. Would you like to suggest an expert on RFID in healthcare and/or stakeholder?
   Probe:
   - industry / consulting
   - healthcare providers (e.g., hospitals)
   - research / academia
   - RFID associations
   - RFID Standards committees/organizations
Appendix 7: Impact measures for portable asset, operating floor and medical floor management RFID applications

The three tables which follow contain examples of measures RFID adopters can use to evaluate the RFID application they implement. The tables cover three application types – RFID for managing portable assets, RFID for managing Operating Floor (and Operating Room) workflow and processes, and RFID for managing Medical Floor workflow and bedside medication administration process. They provide information on:

- what measures evaluators can use to assess specific benefits elicited by each system type;
- where evaluators can find baseline (pre-RFID implementation) data on each of these measures;
- how costly collecting such baseline data may be (in terms of staff time needed to procure and analyze the data);
- whether additional analytic steps will be needed to derive a monetary value for each of the measures, and if so – what steps and what additional information are needed for each measure; and
- whether the suggested RFID impact measure should be interpreted with caution, and if so – what biases may affect it.
<table>
<thead>
<tr>
<th>Suggested Benefits</th>
<th>Quality/ Cost domain</th>
<th>Exemplary low-level measures</th>
<th>Baseline data source</th>
<th>Baseline measurement cost</th>
<th>Post-RFID implementation measurement cost</th>
<th>Can be monetized?</th>
<th>Possibility for other confounders?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced asset loss/ theft</td>
<td>cost (capital and operative cost reduction)</td>
<td>reduction in number of IV pumps annually due for replacement due to inability to locate; penalty payments for lost outsourced assets</td>
<td>hospital budgets</td>
<td>medium</td>
<td>low</td>
<td>yes, directly</td>
<td>low</td>
</tr>
<tr>
<td>Faster asset location</td>
<td>cost (increase in staff productive time); quality (patient-centered care and care-coordination improvement)</td>
<td>time spent to locate a bladder scanner for patient preparation</td>
<td>staff interviews; time-motion studies</td>
<td>medium to high</td>
<td>low</td>
<td>yes, as wage-based value of staff time spent on location for asset location for immediate use, cleaning, servicing, annual preventive maintenance or recall</td>
<td>low</td>
</tr>
<tr>
<td>Understanding of asset utilization patterns and facility needs</td>
<td>cost (operative cost reduction); quality (continuing quality improvement)</td>
<td>number of IV pumps needed to meet facility needs pre/post system introduction</td>
<td>hospital budgets; end-user interviews</td>
<td>medium to high</td>
<td>low</td>
<td>yes, through capital outlay and operation costs reductions</td>
<td>low</td>
</tr>
<tr>
<td>Improved preventive maintenance of asset fleet</td>
<td>cost (increase in staff productive time); quality (patient safety improvement)</td>
<td>share of assets due for PM which were successfully identified</td>
<td>staff interviews; regulation compliance records</td>
<td>medium to high</td>
<td>low</td>
<td>not directly, through impact of regulatory compliance on asset PM and CM on hospital rating; and through impact of preventive maintenance prolonging assets' useful life</td>
<td>medium</td>
</tr>
<tr>
<td>Suggested Benefits</td>
<td>Quality/ Cost domain</td>
<td>Exemplary low-level measures</td>
<td>Baseline data source</td>
<td>Baseline measurement cost</td>
<td>Post-RFID implementation meas-t cost</td>
<td>Can be monetized?</td>
<td>Possibility for other confounders?</td>
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<tr>
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<td>-------------------------------------</td>
<td>-----------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td><strong>Improved infection control of asset fleet</strong></td>
<td>quality (patient safety improvement)</td>
<td>share of assets due for infection control which were successfully identified</td>
<td>staff interviews; direct observation</td>
<td>medium to high</td>
<td>low</td>
<td>not directly, through impact of regulatory compliance on asset PM and CM on hospital rating; and through impact of infectious control on risk for dissemination of hospital infections</td>
<td>medium</td>
</tr>
<tr>
<td><strong>Reduced patient waiting time</strong></td>
<td>quality (patient-centeredness; timeliness) and cost (improved patient placement)</td>
<td>patient waiting time at location for transport or discharge</td>
<td>time motion studies</td>
<td>medium to high</td>
<td>low</td>
<td>not directly, can be captured through impact on efficiency of other processes (scheduled procedure delay and associated revenue loss) or through impact on patient throughput and placement (revenue stream)</td>
<td>low; but other measuring problems include need of sufficiently large sample to find a statistically-significant difference; and baseline establishment</td>
</tr>
</tbody>
</table>
Table 2: Operating Floor process management RFID application benefits, quality/cost domain attribution and valuation considerations

<table>
<thead>
<tr>
<th>Suggested Benefits</th>
<th>Quality/ Cost domain</th>
<th>Exemplary low-level measures</th>
<th>Baseline data source</th>
<th>Baseline measurement cost</th>
<th>Post-RFID implementation meas-t cost</th>
<th>Can be monetized?</th>
<th>Possibility for other confounders?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing ease of care coordination across providers</td>
<td>cost (increase in staffs' productive time); quality (care coordination improvement)</td>
<td>average number of steps needed for patient's peri-operative preparation; number of phone calls necessary to move patient</td>
<td>time-motion studies; direct observation</td>
<td>high</td>
<td>low</td>
<td>yes, based on regular and overtime pay per employee category</td>
<td>low (reliability of measurement and lack of intermittent policy changes)</td>
</tr>
<tr>
<td>Reducing nurses' unproductive time</td>
<td>cost (increase in staff's productive time)</td>
<td>number of hours a SF nurse spends daily locating patients, re-entering data</td>
<td>time-motion studies; direct observation</td>
<td>high</td>
<td>low</td>
<td>yes, as above</td>
<td>low</td>
</tr>
<tr>
<td>Reducing clinical staff's unproductive time</td>
<td>cost (increase in staff's productive time)</td>
<td>number of hours a surgeon spends daily waiting for patient preparation</td>
<td>time-motion studies; direct observation</td>
<td>medium</td>
<td>low</td>
<td>yes, based on regular and overtime pay</td>
<td>low</td>
</tr>
<tr>
<td><strong>Suggested Benefits</strong></td>
<td><strong>Quality/ Cost domain</strong></td>
<td><strong>Exemplary low-level measures</strong></td>
<td><strong>Baseline data source</strong></td>
<td><strong>Baseline measurement cost</strong></td>
<td><strong>Post-RFID implementation meas+ cost</strong></td>
<td><strong>Can be monetized?</strong></td>
<td><strong>Possibility for other confounders?</strong></td>
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</tr>
<tr>
<td><strong>Easy identification of latent patient safety threats (e.g. fall, allergies)</strong></td>
<td>quality (patient safety improvement)</td>
<td>positive identification and alarm for all patients with identical names currently in treatment; detection of post-op left-ins</td>
<td>time-motion studies; direct observation</td>
<td>medium</td>
<td>low</td>
<td>partially - using estimates on economic burden of adverse event types</td>
<td>medium (control for concurrent interventions and natural high/low)</td>
</tr>
<tr>
<td><strong>Reduction in potential adverse drug events and medication errors</strong></td>
<td>quality (improved patient safety)</td>
<td>number of averted medication errors</td>
<td>chart reviews; prescription review; control group evaluation; automatically captured data</td>
<td>high to very high</td>
<td>low</td>
<td>yes, through estimates of av. cost of preventable adverse event</td>
<td>no, but need large amount of data to show statistical differences and chart reviews do not capture all errors (possible documentation effect)</td>
</tr>
<tr>
<td><strong>Risk reduction</strong></td>
<td>quality (patient safety improvement); cost (non-labor operational cost reduction)</td>
<td>CMS fines for re-admission</td>
<td>billing and admin data</td>
<td>medium</td>
<td>low</td>
<td>partially - using estimates on economic burden of adverse event types</td>
<td>low</td>
</tr>
<tr>
<td>Suggested Benefits</td>
<td>Quality/ Cost domain</td>
<td>Exemplary low-level measures</td>
<td>Baseline data source</td>
<td>Baseline measurement cost</td>
<td>Post-RFID implementation meas cost</td>
<td>Can be monetized?</td>
<td>Possibility for other confounders?</td>
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<tr>
<td>Accurate documentation of key clinical data elements</td>
<td>quality (continuous quality improvement, improved patient safety); cost</td>
<td>proportion of inadequately registered IV infusions</td>
<td>chart reviews; prescription review; direct observations; reimbursement and billing data</td>
<td>medium to high</td>
<td>medium</td>
<td>yes, via reimbursement</td>
<td>low</td>
</tr>
<tr>
<td>Increased compliance with evidence-based practices and protocol guidelines</td>
<td>quality (patient safety improvement)</td>
<td>improved time antibiotics administration to incision time; surgical tray decontamination cycle evidencing</td>
<td>time-motion studies; direct observation</td>
<td>high</td>
<td>low</td>
<td>partially - using estimates on economic burden of adverse event types</td>
<td>medium (control for concurrent interventions and natural high/low)</td>
</tr>
<tr>
<td>Improved medication and inventory cost capture</td>
<td>cost (reduction in non-labor operating costs)</td>
<td>pre/post system level of correct per-patient cost capture</td>
<td>human resources log</td>
<td>high</td>
<td>low</td>
<td>yes</td>
<td>low</td>
</tr>
<tr>
<td>Event and process audit trail creation</td>
<td>quality (continuous quality improvement); cost (non-labor operative cost reduction)</td>
<td>reduction in steps/processes to create an audit trail with system</td>
<td>administrative data</td>
<td>medium to high</td>
<td>low</td>
<td>partially, through impact on facility's accreditation and insurance premiums</td>
<td>low</td>
</tr>
<tr>
<td>Suggested Benefits</td>
<td>Quality/ Cost domain</td>
<td>Exemplary low-level measures</td>
<td>Baseline data source</td>
<td>Baseline measurement cost</td>
<td>Post-RFID implementation meas-t cost</td>
<td>Can be monetized?</td>
<td>Possibility for other confounders?</td>
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<tr>
<td>High-granularity process and event data enable continuous improvement of department performance</td>
<td>cost (increase in productive staff time)</td>
<td>number of nurses leaving within first annual quarter</td>
<td>human resources log</td>
<td>low</td>
<td>low</td>
<td>yes, based on av. length of training period per staff type, and staff's pay</td>
<td>low to medium (over time can be identified through multivariate statistical analysis)</td>
</tr>
<tr>
<td>Reduced staff turnaround</td>
<td>quality (continuous quality improvement)</td>
<td>internally-developed or external surveys</td>
<td>medium</td>
<td>medium</td>
<td>no</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>Improved staff work satisfaction</td>
<td>cost (increased patient placement); quality (care-coordination improvement)</td>
<td>case-adjusted patient throughput in ED department (admission and release)</td>
<td>billing and administrative data</td>
<td>medium</td>
<td>low</td>
<td>yes, based on av. revenue associated with admitted ED patients per patient type</td>
<td>medium (control for concurrent interventions and natural high/low)</td>
</tr>
<tr>
<td>Faster patient throughput</td>
<td></td>
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<table>
<thead>
<tr>
<th>Suggested Benefits</th>
<th>Quality/ Cost domain</th>
<th>Exemplary low-level measures</th>
<th>Baseline data source</th>
<th>Baseline measurement cost</th>
<th>Post-RFID implementation meas+t cost</th>
<th>Can be monetized?</th>
<th>Possibility for other confounders?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preventable adverse drug events</strong></td>
<td>quality (patient safety improvement)</td>
<td>number of averted adverse events</td>
<td>chart reviews; prescription review; control group evaluation; automatically captured data</td>
<td>high to very high</td>
<td>low</td>
<td>yes</td>
<td>no, but need large amount of data to show statistical differences and chart reviews do not capture all errors (possible documentation effect)</td>
</tr>
<tr>
<td><strong>Potential adverse drug events; medication errors</strong></td>
<td>quality (patient safety improvement)</td>
<td>number of averted medication errors</td>
<td>chart reviews; prescription review; control group evaluation; automatically captured data</td>
<td>high to very high</td>
<td>low</td>
<td>yes</td>
<td>as above</td>
</tr>
<tr>
<td><strong>Easy identification of latent patient safety threats (e.g. fall, allergies)</strong></td>
<td>quality (patient safety improvement)</td>
<td>ability to pinpoint all patients at risk of allergic reactions from nurse's desk</td>
<td>time-motion studies; direct observation</td>
<td>medium</td>
<td>low</td>
<td>partially - using estimates on economic burden of adverse event types</td>
<td>medium (control for concurrent interventions and natural high/low)</td>
</tr>
<tr>
<td>Suggested Benefits</td>
<td>Quality/ Cost domain</td>
<td>Exemplary low-level measures</td>
<td>Baseline data source</td>
<td>Baseline measurement cost</td>
<td>Post-RFID implementation meas-t cost</td>
<td>Can be monetized?</td>
<td>Possibility for other confounders?</td>
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<tr>
<td>Risk reduction</td>
<td>quality (patient safety improvement); cost (non-labor operational cost reduction)</td>
<td>CMS fines for re-admission</td>
<td>billing and admin data</td>
<td>medium</td>
<td>low</td>
<td>partially - using estimates on economic burden of adverse event types</td>
<td>low</td>
</tr>
<tr>
<td>Accurate documentation of key clinical data elements</td>
<td>quality (continuous quality improvement, improved patient safety); cost</td>
<td>proportion of inadequately registered IV infusions</td>
<td>chart reviews; prescription review; direct observations; reimbursement and billing data</td>
<td>medium to high</td>
<td>medium</td>
<td>yes, via reimbursement</td>
<td>low</td>
</tr>
<tr>
<td>Event and process audit trail creation</td>
<td>quality (continuous quality improvement); cost (non-labor operative cost reduction)</td>
<td>reduction in steps/processes to create an audit trail with system</td>
<td>administrative data</td>
<td>medium to high</td>
<td>low</td>
<td>partially, through impact on facility's accreditation and insurance premiums</td>
<td>low</td>
</tr>
<tr>
<td>Increase in staff productive time use</td>
<td>cost (increase in staff productive time)</td>
<td>time spent per patient; placing orders; administer medication</td>
<td>time motion studies; usage logs</td>
<td>high</td>
<td>low</td>
<td>yes, based on regular and overtime pay per employee category</td>
<td>low</td>
</tr>
<tr>
<td>Suggested Benefits</td>
<td>Quality/ Cost domain</td>
<td>Exemplary low-level measures</td>
<td>Baseline data source</td>
<td>Baseline measurement cost</td>
<td>Post-RFID implementation meas-t cost</td>
<td>Can be monetized?</td>
<td>Possibility for other confounders?</td>
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<tr>
<td>Reduced frequency of chart and result checks/pulls</td>
<td>cost (increase in staffs' productive time)</td>
<td>number of steps needed to view results</td>
<td>direct observation; staff search logs</td>
<td><strong>medium to high</strong></td>
<td>low</td>
<td>yes, based on regular and overtime pay per employee category</td>
<td>low</td>
</tr>
<tr>
<td>Increasing ease of care coordination across providers</td>
<td>cost (increase in staffs' productive time); quality (care coordination improvement)</td>
<td>average number of steps needed to place a new patient; number of phone calls necessary to move patient</td>
<td>time-motion studies; direct observation</td>
<td>high</td>
<td>low</td>
<td>yes, as above</td>
<td>low (reliability of measurement and lack of intermittent policy changes)</td>
</tr>
<tr>
<td>High-granularity process and event data enable continuous improvement of department performance</td>
<td>quality (continuous quality improvement); cost (all)</td>
<td>integration of system data in formal process improvement loop</td>
<td>administrative data; time-motion studies; surveys</td>
<td>high</td>
<td>low</td>
<td>not directly; indirectly - though pre/post net revenue comparison</td>
<td>low to medium (over time can be identified through multivariate statistical analysis)</td>
</tr>
<tr>
<td>Suggested Benefits</td>
<td>Quality/ Cost domain</td>
<td>Exemplary low-level measures</td>
<td>Baseline data source</td>
<td>Baseline measurement cost</td>
<td>Post-RFID implementation meas-t cost</td>
<td>Can be monetized?</td>
<td>Possibility for other confounders?</td>
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</tr>
<tr>
<td>Improved room turnaround rate</td>
<td>cost</td>
<td>time needed to identify room as dirty, clean and make available to new patient</td>
<td>billing and administrative data</td>
<td>medium to high</td>
<td>low</td>
<td>yes, based on av. revenue associated with admitted ED patients per patient type</td>
<td>low</td>
</tr>
<tr>
<td>Faster patient throughput</td>
<td>cost</td>
<td>case-adjusted patient throughput in ED department (admission and release)</td>
<td>billing and administrative data</td>
<td>medium</td>
<td>low</td>
<td>as above</td>
<td>medium (control for concurrent interventions and natural high/low)</td>
</tr>
<tr>
<td>Improved patient satisfaction</td>
<td>quality</td>
<td>patient satisfaction with episode of care</td>
<td>internally-developed or external surveys</td>
<td>medium</td>
<td>medium</td>
<td>no</td>
<td>high</td>
</tr>
</tbody>
</table>
Appendix 8: Adaptive structuration theory and healthcare RFID’s organizational value

This appendix takes a look at the broader organizational context in which healthcare RFID applications are expected to function, and the conditions likely to critically affect healthcare RFID’s value in different healthcare delivery environments—factors explored in the in-depth case studies presented in Chapter 4.

The structured literature review showed that a significant portion of the grey sources on healthcare RFID have the viewpoint of one of the two historical schools on the value of non-clinical information technology in healthcare—the technological determinism school (the other main school, adaptive structuration theory, is discussed next). If simplified, technological determinism holds that the impact of any technology will be the same in any context of use and regardless of the process of implementation. Frequently used to explain the adoption and impacts of communication technologies today, primarily under its influence during the 1970s and 1980s healthcare computerization was seen as a powerful instrument to increase the quality and decrease the costs of hospital-based health care. Notwithstanding, research on the computerization of healthcare, suggests that automating a status quo does not lead to a more efficient or safer system. As Diamond and Lemieux argue, “IT can improve the quality of care only when underlying system processes are transformed at the same time.” Moreover, identical technologies have been shown to have greatly different impacts subject to the way in which they are introduced and used in a healthcare delivery organization.

Hence, if the potential of healthcare RFID is to be assessed, some note needs to be taken of the key factors likely to define RFID’s impact bounds identified in the cost benefit evaluation frameworks presented in the previous section—i.e., the conditions which critically affect healthcare RFID’s value-added in different healthcare delivery environments. Adaptive structuration theory, the second main school of thought on the value and adoption of HIT, provides a useful starting point for the development of such a frame.

Adaptive structuration theory argues that the implementation of new technologies within healthcare organizations is only an “occasion for structuring” (Barley, 1986). First developed by Giddens to reconcile the agency/structure, subjective/objective, and micro/macro perspectives in sociology (1982, The Constitution of Society), structuration theory is today widely endorsed and used to analyze the effects of IT (DeSanctis and Poole, 1994; Orlikowski and Robey, 1991; Pozzebon and Pinsonneault, 2005). In its sociological incarnation, at a basic level, the theory

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147 The term “technological determinism” is said to have been coined by the American sociologist and economist Thorstein Veblen (1857-1929).


149 For example, see Burau et al. (2008) and Shekelle et al. (2006).
means that people make society, but they are at the same time constrained by it. Structure and action constrain each other in an evolving way\textsuperscript{150}. Adapted to the realm of HIT, adaptive structuration theory states that on the one hand, the same health technology could have different impacts depending on the context of use and the attitude adopters and users have towards the technology (Barley, 1986). On the other hand, “health technologies embody values and act normatively on health care practices” (Lehoux, 2006).

One model which relates adaptive structuration theory particularly well to the task of assessing healthcare RFID’s value-added, is a model DeLone and McLean (1992) create to define and evaluate information system success (value-added) in healthcare delivery organizations (shown below). According to the authors, an information system can be evaluated in terms of information quality, system quality, and service quality. These characteristics affect actual system use or intention to use and user satisfaction, from which benefits arise. The net benefits will (positively or negatively) influence user satisfaction as well as the further use of the information system.

![Figure 1: DeLone and McLean (1992) information system success model](image)

The model identifies information system (IS) value as based on six key dependent variables:

- \textit{System quality} – reflecting the engineering performance characteristics of the systems in question (e.g., data timeliness, completeness, accuracy);
- \textit{Information quality} – comprising the added process and event insights which are delivered by the system (\textit{the benefit frameworks developed in Section 3.1.});
- \textit{Information use} – rate of recipient consumption of the output of an information system;
- \textit{User satisfaction} – with the technology, that drive its repeated use;
- \textit{Individual impact} – the effect of information on the behavior of the recipient which also offers the potential to gauge the contribution of information systems to the success of the enterprise; and
- \textit{Organizational impact} – the effect of information on organizational performance.

Two critical conclusions for assessing healthcare RFID follow from DeLone and McLean’s model:

- while related, system quality, information quality and information use should not be confused;

\textsuperscript{150} Adaptive structuration theory proposes that action and structure cannot be analyzed separately, as structures are created, maintained and changed through actions, while actions are given meaningful form only through the background of the structure: the line of causality runs in both directions. Hence, social life is not the sum of all micro-level activity. Yet social activity cannot be completely explained from a macro perspective either. Furthermore, the repetition of the acts of individual agents reproduce the structure, but social structures are neither inviolable nor permanent.
- the individual and organizational impacts of an IS depend both on the system’s quality and the quality of the information it produces, but also on its use and user’s satisfaction with it.

Building on the cost-benefit impact frameworks created in Section 3.1., adaptive structuration theory, and the findings of the literature review and expert interviews, a theoretic frame of the enterprise-level factors affecting healthcare RFID’s value can be drawn (see below). It addresses the question of what factors can be expected to critically affect healthcare RFID’s value in different healthcare delivery environments and, thus, to define RFID’s impact bounds.

Figure 17: The value of healthcare RFID - a theoretic frame

In a nutshell, the theoretic frame states that factors which affect the decision to adopt an RFID application do not have a direct bearing on, but are related to, the value an adopting organization is likely to be able to derive from an advanced healthcare RFID application (as is the case with...
HIT in general). Hence, adoption factors will indirectly influence system value factors, which in turn will directly affect healthcare RFID system impacts (costs and benefits), creating constraints around the maximum benefits identified in the four benefit frameworks and the cost framework developed in Section 3.1. Therefore, if the potential of healthcare RFID is to be assessed, we need to test the validity of this relationship hypothesis by examining real-live implementations of healthcare RFID systems. As so established the theoretic frame and the cost and benefit frameworks it encompasses serve as the theoretical basis for the in-depth case studies of actual healthcare RFID implementations, presented and analyzed in Chapter 4. Each of the three factors spheres – adoption, value and impacts – is explained next.

System adoption factors include:

- the high-level HIT adoption incentives which exist in the healthcare system within which the health care delivery organization functions;
- the innovation culture and innovation management capacity which exist within the organization itself (assumed to encompass the ability to successfully identify areas for improvement and for defining relevant improvement measures; as well as providing strategic leadership for their implementation);
- the cost of RFID technology (the organization’s capacity to finance the acquisition of an RFID application being the key factor determining if an RFID system will be purchased);
- the potential adopter’s existing business processes (shortcomings which create the justification for the applications’ adoption).

The four factors are linked: while HIT healthcare system adoption incentives can affect both the cost of the application (e.g., lowering it through targeted grants or subsidies) and the state of organizational processes (e.g., via any care quality or cost-efficiency regulations and prerequisites for expense reimbursement); innovation culture and innovation management capacity which exist within the organization can have bearance only on the state of the facility’s processes.151

Preceded by the decision to implement an RFID application, three factors can be singled out as shaping an RFID systems’ value:

- the system’s design (governing system quality and information quality);
- the system’s use; and
- the system users’ satisfaction.

A system’s design incorporates the physical blueprint of a technological application (e.g., how far apart RFID readers will be situated, what signal strength will be used, whether it will involve active RFID tags and at what intervals these will emit signals - i.e. if the system will have room-level or zonal coverage, if it will supply real-time information or not). Hence, it is correlated with system cost. It also includes the aims set for the application to fulfill (e.g., help in the location of a mobile asset, notify nurses that a medication prescribed for “John Brown” is to be administered to a person with the same name but with a different treatment regiment) – i.e. the benefits the application is expected to deliver.

151 Available evidence of the fact that healthcare delivery organizations which are capable of successfully self-innovating and from successfully introducing and benefiting from new technologies typically also have better care outcome and process performance supports this assumption. This applies to all HIT, and is further valid for RFID as well.
The literature review and expert interviews suggest that the degree of matching between technological/engineering choices and an RFID application’s aims amasses to a solution's system quality (e.g., the accuracy of the data it provides). Yet, a system that has high system quality can simultaneously be characterized by low information quality (if the capacity of an application is under-utilized by the aims chosen for the system – e.g., process automation vs. process reorganization). Because of this, it is important to distinguish between the two, even if high-information quality can hardly exist in the absence of high system quality.

An application’s information quality is the application’s benefit spectrum range – its functional and operational purpose mix, its ability to integrate in and enhance existing systems and processes, and its end-user friendliness. These are the key factors which determine what value the application delivers to its users (positive, negative, or null) and if it will be used or not. If combined, information system’s quality and the quality of its information in practice both affect how extensively a solution is used and what satisfaction users derive from interacting with the system.

Since RFID application functionalities are, however, primarily user-defined and dependent, user feedback (along with vendor responsiveness and technical feasibility) is the key factor driving system functionality. In fact, system use and system satisfaction can form a self-enhancing loop where increased system use leads to increased system satisfaction or dissatisfaction which results respectively in further increasing or decreasing use of the system – i.e. in its practical adoption by staff or its die-out.

Information use is also directly linked to a solution’s value, as even high information and system value systems which are not used as intended or embraced by staff fall short of achieving any positive impacts. Finally, user satisfaction impacts system’s design in the process of the applications’ on-going development fine-tuning, for example by making requests for specific system functionalities or appearance. Hence, a loop of system design, use and satisfaction forms.

System impacts include the individual-level impacts which arise with the implementation of the RFID application (e.g., reduction in staff time spent on non-care-essential tasks if the implementation is successful), and the aggregate organizational-level impacts which follow from them (e.g., improved patient throughput under the same condition). Some individual-user level application impacts can be assumed to aggregate to the organizational level (e.g., reduction in staff's unproductive time), while others only exist at the latter level (e.g., improved process and event audit capacity, and improved management and forecasting capacity).

Considered as a theoretic evaluation model, the first two factor circles of the theoretic frame establish the independent variables of interest (the sources of the witnessed effects; and the last circle – the dependent variables of interest in an RFID application’s evaluation: the impact of the application on quality of care and the cost-efficiency of its delivery.

Finally, RFID applications can support a continuous process improvement loop at the organization level by delivering a substantial improvement in accurate event capture the applications create process visibility, which in turn creates the opportunity to identify process segments whose alteration can critically improve overall process outcomes. The availability of reliable empirical evidence furthermore provides a means to test how different process changes impact overall outcomes. Hence, system impacts can also influence the adopting organization’s innovation culture and management capacity and the overall state and structure of its processes (and with them the group of system adoption factors) if the low-level even data shaping the individual impacts of the technology is leverage to obtain higher-level information (e.g.,

\[152\] Information quality also relates to the concept of meaningful technological use.
department process and workflow-level data) and the latter is used in periodic quality process and outcome reviews and facility management.\textsuperscript{153, 154}

Two key conclusions follow from this theoretic frame:

- \textit{the impacts of RFID applications are highly-dependent on their system design} (system quality and information quality);

- \textit{the impact of RFID will not be the same in every hospital}, since effects will depend on the system information's use, the context of use and the process of implementation;

The first conclusion seconds the findings of the cost-benefit impact frameworks developed in Section 3.1. The second, on the other hand, motivates the case studies presented in Chapter 4. Not unique to healthcare RFID alone, these conclusions further ground our understanding of this technological cluster within those of HIT and other disruptive innovations.

\textsuperscript{153} For example, if individual portable asset status data is aggregated on a weekly basis it will be possible to determine if any assets are utilized and how asset distribution can be changed to improve availability; the regular abstraction of such reports can enable staff to engage in continuous performance review and strengthen the organizations' overall ability to self-innovate while improving existing processes for asset management.

\textsuperscript{154} That such a link can be established is suggested by the multiple references to the role of previous information system innovation experience made in the literature and the expert interviews, whereby bad experiences are frequently regarded as a key factor for resistance or limited success of subsequent implementations; and positive initial experiences are seen as subsequent technology adoption enablers.
Appendix 9: Methodology for multiple case study design

This section presents in more detail the methodology behind the multiple case study design.

1. Case Studies objectives and aims

The objective of the case studies analysis is to gather in-depth information on the different benefits, costs, barriers and enablers associated with the real-life implementation of RFID solutions for healthcare delivery; including their impacts for key stakeholders, and the institutional environment within which they are deployed. An additional objective of the studies is to learn how these vary across a range of RFID applications. Finally, the studies aim to build on and validate the RFID evaluation structures I developed.

To achieve these goals, within each case the research design will distinguish between the effects of RFID on different groups of actors, including but not limited to healthcare providers – doctors and nurses; hospital administrators; patients and their relatives, and the healthcare system – each forming an individual unit of analysis. Moreover, the case studies are designed to provide detailed cost and benefit data to be subsequently used in a cost benefit analysis (CBA) of the studied RFID applications. To this end, the case studies will collect information both on the direct and indirect costs and benefits of the studied RFID applications.

The above-listed general goals and specific aims of the case studies are operationalized via a multi-case embedded research design.

2. Design of the case studies, and operationalization in interviews

For purposes of this analysis a "case" is RFID technology as it has been introduced into a healthcare organization and is being used in the delivery of one or more inpatient services as a part of regular operations. So defined, "cases" include contexts of use in which RFID technology forms a functional part of one or more healthcare delivery processes. The work flows that integrate the technology into the setting bound each case. Hence only those aspects of organizational context that have to do with the technology will be studied.

The dependent variables of interest in the case study analyses are the individual implications of the RFID application for the quality of delivered care and its cost. These will include the costs and benefits parameters and measures identified in the evaluation structure for each of the four application types.

The independent variables of interest – the sources of the witnessed effects – include technology characteristics of the RFID application itself (e.g., reliability and performance; system quality and information quality); the technology implementation process (e.g., how the application was
integrated in the application setting); characteristics of the institutional context (e.g., hospital size, inpatient vs. outpatient setting, health system financing mechanisms); and the degree of diffusion of the technology (e.g., what proportion of intended users in the workflow actually use the application, use it as intended, and perceive it as useful).

Information on both the dependent and independent variables of interest is collected through direct on-site observation, interviews and collection and review of operational and administrative data on the processes affected by the RFID application. The main topics on which these data collection methods aim to provide information for each case study are:

A. Characteristics of the RFID implementation process and institutional context

One set of topics which the case studies will address have to do with the institutional context into which the application was introduced and its process of adoption. Specific items of interest include:

- how the application was conceived and implemented
- how were the individual stakeholders brought on board and motivated
- how the institutional characteristics affected the decision and outcome of adoption (e.g., do opportunities for return-to-scale, or institution size matter)
- how did the application impact the institutional environment - existing processes (what process changes did it impose, on which specific stakeholder groups).

B. Technical description of the RFID application

A second set of topics centers on the RFID application itself. Specific items of interest include:

- a technical description of the application – e.g., whether passive or active tags are used, why, for what functions (for the physical, virtual and business layers)
- an operational description of the application – how does the application work, who operates it, how and by whom is it maintained
- information on the overall functioning of the application – e.g., what is the information/real event matching rate of the application; what interferences with other systems/devices have been noted; how much data does this application generate, how is it used; if more than one application is used – were there compatibility issues between the separate applications.

C. RFID costs

The next set of topics focuses on the costs associated with the deployment, use and maintenance of the RFID application. Costs are defined as the resources consumed/utilized during the implementation and useful life of the application, and include:

- Direct costs: the value of all the goods, services and other resources that are utilized/consumed
  - initial costs (e.g., staff training, process re-design costs, existing HIT integration)
  - maintenance costs (e.g., system re-setting, replacement of readers, RFID-data management capacities)
  - other (e.g., privacy protection costs, costs associated with interferences caused by the RFID application)
• Induced costs (e.g., productivity gains or losses due to the consequences stemming from
  the alternative options under comparison).

While obtaining second-hand and interview data on these costs is relevant, of particular
importance would be the procurement of the detailed operational spreadsheets on the RFID
application/pilot.

D. RFID benefits

The benefits that originate from the RFID application form another set of topics to be probed in
each case study. Within it, of particular interest are:

• impact on patient safety (e.g., prevented nosocomial infections due to good sterilization
  practices, complications avoided due to prevented data errors, bad provider communication,
  old/miss assigned patient data; medication-dispensing errors; additional bed days avoided)
• impact on effectiveness of care (e.g., averted liability costs from malpractice)
• impact on efficiency of care (e.g., higher patient volume, decrease staff overtime,
  increase staff productivity)
• other types of gains associated with the adoption of the RFID application (e.g., increased
  time with patients, better cost capture due to process, billing and audit automation).

The cases will also investigate if the reported benefits outstrip the initial and on-going costs
associated with the deployment of this application? By how much annually?

E. RFID adoption process facilitators

A fifth set of topics has to do with the enabling factors which support the adoption of an RFID
solution as captured in each case study. Topics include:

• advantages of the technology vs. alternative solutions
• factors affecting the decision to invest in RFID (e.g., how proactive manufacturers are
  about developing a custom-tailored application; capacity to ensure the interoperability of the
  RFID application with the other clinical and management systems; availability of dedicated
  financial grants for the launch/expansion of RFID pilots)
• factors which influenced staff adoption and continued use, as well as the impact the
  application has had.

F. RFID adoption process obstacles

Reciprocally, another set of topics which the case studies will seek to address explore the
adoption obstacles associated with the studied RFID applications. Topics include:

• shortcomings of the technology (e.g., uncertain interoperability with other clinical systems
  and biomedical devices, significant initial disruption in work/business processes)
• impact of cost on dissemination (e.g., would a reduction in the cost of RFID technology
  affect the way you use RFID in your enterprise; why – scale, training cost; how large does it
  need to be and applied to what part of the technology – tags, readers, middleware, etc.)
• other issues that can negatively affect dissemination (e.g., staff or patient privacy
  concerns, lack of standards on interoperability across RFID systems and across RFID
systems and other clinical systems and biomedical devices, lack of easily-accessible best practices for RFID, lack of information on the business case for specific applications).

H. Perceptions hospital staff expected to use the RFID system hold on it
The final set of topics which the case studies will seek to address explore the attitudes organizational stakeholders have towards the RFID application. Topics include:

- how useful is the application perceived to be in improving the pre-existing workflows and processes, and why
- how comfortable are users with it, what is its adoption level among staff
- how safe/secure do they believe the application is, and the personal data it stores.
Appendix 10: Detailed case study presentations

This appendix presents the eight individual case studies discussed in Chapter 4. Presentations are structured as follows:

- An “application snapshot” introduces the reader to the studied RFID solution (its primary objective, hospital context, and technological profile).
- The implementation story of the case – why and how the healthcare delivery organizations adopted the application, and how the individual stakeholders were integrated in this process – is presented next.
- A review of the organizational and user-group system costs and care benefits (positive or negative outcomes) which resulted from the applications’ introduction and use in the facility follows.
- The critical factors for the application’s success or respectively failure learned from each case on the bounding factors for RFID’s value (i.e. the within-case conclusions) are discussed last.

1. Emergency department (ED) process and workflow management application

1.1. Case 1: Treviglio-Caravaggio Hospital, Italy

Application snapshot

Application: stand-alone orthopedic patient tracing in and between the ED and X-Ray departments.

Date of implementation/lifespan: 2005 - .

Adoption objective and Current use: prevents staff from being overwhelmed by requests from patients’ relatives for information updates on patients’ whereabouts.

Hospital context:

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155 Information about this application was collected over a single-day site visit at Treviglio-Caravaggio Hospital – November 6, 2008 - and subsequent follow-up interviews and data exchanges with hospital stakeholders and the technology’s developers at SICED and Softwork which took place between November, 2008 and February, 2009.
• mid-sized general regional hospital which replaced several small facilities;
• newly-built ED department (2004), with 55,000 visits in 2005 (of these roughly 4% orthopedic patients);
• ED patient volume increasing by 10-12% annually since 2004.

The technology (at time of assessment):
• zonal-level system, piggy-backs on existent hospital WLAN;
• includes 200 active tags, 8 readers, 6 collectors, 1 server with middleware, no designated software license (using existing license agreements);
• Tags: active long-range (6 meters) tags, 6yr. lifespan, activated upon completion of patient registration with the ED and triage, deactivated when dismissed or admitted to hospital; reusable: placed in plastic bubble-bags worn by patients around the neck (for tag protection and to prevent infection transmission);
• Readers: long-range, ultra high frequency (UHF), dispersed around in the ED triage area, stretcher rooms and X-ray department;
• Collectors: integrate data concurrently received from up to four antennas (triangulation to reduce error read rates), time-stamping provided by a system-internal clock, can store up to 2000 messages to prevent data loss, Ethernet connection to server;
• Server: standard HP server, backed up by two synchronized disks, back-end database developed using SQL, middleware functionalities rely on Compuware Unicode, supporting technical infrastructure is Windows 2000 web server;
• no strong authentication system as the system identifies patients only by an ID number and is not integrated with the hospital IT central infrastructure.

The implementation story

Ospedale Treviglio-Caravaggio (OTC) is a 440-bed hospital with a comprehensive set of ambulatory practices located in Treviglio, Italy. After the closing of nearby hospitals, it became a major healthcare centre in the Lombardy region in Northern Italy. Due to its new role, since 2003, the hospital underwent substantial expansion of its ambulatory units: in 2004 a new emergency department (ED) was launched, followed by a new Radiology Department in 2005. Since 2004 OTC’s ED patient volume continued to increase by 10-12% annually, and in 2005 its census reached 55,000 patients. Of these, monthly roughly 200 were orthopedic ED cases, each requiring an average of 4 separate treatments prior to dismissal or hospitalization.

This sustained rise in ED patient volume opened OTC to complex patient and work process management issues. In particular, hospital management detected two priority needs in the ED:

• to improve staffs’ ability to locate each orthopedic patient in their process of care, both for ED and radiology department workflow purposes, and to meet the high volume of information requests from relatives/friends about patients’ treatment progress;

156Covering the demographically and socio-economically highly diverse population living between Brescia, Bergamo and the southern part of Milan.
to better understand the time and steps required to complete the assigned treatment process for orthopedic ED patients from admittance to discharge.

Hospital senior management focused on ED orthopedic patients for two reasons: i) they represent the largest ED patient group; ii) they require repetitive interactions between the ED and the radiology department which creates undesirable communication volume and bottlenecks. In addition, ED waiting room and nursing staff were experiencing increasing frustration over the high volume of requests for information update from ED patients’ family members/ friends.

Following an internal technology assessment, OTC management decided to implement a patient-tracing solution using active RFID for continuously locating (tracing) emergency room patients with orthopedic problems as they were admitted to the hospital’s emergency wing (ED) and then moved between the ED and the X-ray department receiving medical services. The active RFID system displays the location of each orthopedic patient (identified by a numeric code) during their clinical journey on an interactive map available for viewing at the ED lounge, and at nurses’ stations.

After an open tender, the development and delivery of the system was awarded to a local system integrator with expertise in developing IT solutions for supply chain management and people/assess tracking (SICED Srl.). RFID hardware was provided by a different company (SOFTWOK).

The development of the system involved:

- system functionality and information requirement identification (2 weeks of observation and 2 weeks of analysis and consultations);
- system design (2 months);
- system building and testing (4 months);
- system piloting (2 month) and full-scale deployment (15-day staff training).

To identify what functionalities and information the system should embody to meet its goals, during a two-week period SICED experts observed the activities of ED staff and identified the overall system strategic and operational objectives. A counterpart OTC RFID project team was formed and heavily involved throughout the design and implementation of the system. It included two ED nurses and the head of the ED (directly involved during the design and testing phases); IT department staff (who monitored system compliance with overall IT strategy), and OTC’s senior managers (who steered the process and gave formal approvals). The two teams discussed the collected data and defined the system's goals, functions and specifications.

The design of the system was done in the two months which followed, including one month for RFID hardware selection. Zonal coverage was perceived as sufficient in light of room allocation within the hospital. An “open systems” approach was chosen to facilitate integration of the application with OTC’s overall IT infrastructure and its future scalability should this be needed. Configuration and settings were defined through standard web interface. These last two characteristics were extremely important since they allowed the readers to be integrated in the hospital local area network for the collection and transfer of data towards a central point of collection, rendering a costly and disruptive own-signal infrastructure creation unnecessary. The possibility of using bracelets with barcodes was also explored but was abandoned due to the complex scanning and data collecting process which a barcode would have required to produce meaningful information on patient’s location.

Building, testing and deployment of the application took another four months. A two-month system piloting and fine-tuning period followed, during which technical issues related to the precise localization of patients were resolved. Finally, following some initial test, readers and antennas were seen to be able to avoid interference with other hospital devices. Prior to the
application's full release, emergency room staff underwent full training on the system functionalities and operational procedure which lasted about 15 days.

Application costs

The table below depicts the relevant costs identified for this application using the cost evaluation framework presented in Chapter 3. Due to non-disclosure agreements signed by the various participants in this case study, the precise quantification of the costs was not possible. However, the conducted interviews have allowed the collection of specific qualitative cost data. It has been possible, therefore, to extrapolate an overall final figure that was validated during the follow-up interviews.

Implementation costs include system development costs (born by SCIED Srl.) and the cost of three representatives of emergency room staff for about 15 days over the entire development and delivery phases of the project. SICED Srl’s tender proposal for developing and implementing the application was ca. €100,000. These funds covered SICED staff time and the procurement of the necessary hardware such as: 200 active tags, €20 each; 8 readers I-Port 3, €1,500 each; an HP server for roughly €3,500. No designated software licenses were acquired. It has not been possible to quantify the cost associated to the direct involvement of hospital staff.

For maintenance, labor costs include a minimal cost of ED staff time for system use (such as nurse time spent on setting up and pulling down the data from patient RFID tags), along with system upkeep by the ED department. Patient tags have also been replaced, although their number has remained the same during the application’s life. Hardware replacement costs are unknown.

<table>
<thead>
<tr>
<th>Implementation costs</th>
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</thead>
<tbody>
<tr>
<td><strong>system development costs</strong></td>
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<tr>
<td><strong>software costs</strong></td>
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<tr>
<td><strong>cost of staff time for application design</strong></td>
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<tr>
<td><strong>staff training time cost</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Maintenance costs</th>
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</thead>
<tbody>
<tr>
<td><strong>replacement hardware cost</strong></td>
</tr>
<tr>
<td><strong>cost of IT staff time spent on system maintenance</strong></td>
</tr>
<tr>
<td><strong>cost of ED staff time for setting up and pulling down the data from patient RFID tags</strong></td>
</tr>
</tbody>
</table>
Application benefits

Unfortunately, no formal evaluation for the system has been carried out thus far and no detailed information on the benefits of this RFID system is available.

According to interviewees, the application provides noticeable operational benefits stemming from the real-time accurate data on ED orthopedic patient’s whereabouts it delivers. The following gains were consistently outlined:

Quality gains:

- Current, immediately accessible information on ED orthopedic patient whereabouts to staff and patient’s family at ED, resulting in better care coordination, reduction in staff’s non-care-related tasks, and improved patient (relative) satisfaction;

- Increase in ED nurse time spent with patients and reduction in nurse shortages in the ED setting;

- Improved patient safety in the ED and X-ray departments through unique patient identifiers (it should be noted that tags carry only a number and patient name, no patient health record or medical information);

- Better understanding of the workflows linking the Radiology and ED departments (these have not been amended as a result);

- Better understanding of how the Radiology department operates.

Cost gains:

Given the context and focus of this application, the primary effect of the technology results from the gains associated with increased patient throughput per shift and reduced average patient servicing time. These are, in turn, associated with productivity improvements for nursing staff and better patient visibility. Whether the increased rise in the annual number of ED visits led to a rise in ED full-time staff as well, and if the application had any bearing on this is unknown.

If a partial economic analysis of the cost of care gains associated with nursing staff time-savings due to the decreased volume of information requests is done (shown below), the introduction of the RFID system brought savings of about €37,183 just by cutting the time a nurse spends updating the relatives of ED orthopedic patients about their whereabouts.

While this monetary value may be hypothetical, as the time saved is unlikely to lead to a reduced headcount, it shows that the system is likely to recoup its initial cost through staff time savings in less than two years (and further supports the stance taken in Chapter 4 that an evaluation focused on the direct financial stream of impacts of an application is not well suited to assessing healthcare RFID technology).

Table 2: Partial economic evaluation of ED orthopedic patient tracing application at Treviglio Caravaggio Hospital

<table>
<thead>
<tr>
<th>Scenario 1: ED Nurse spends 12 minutes talking to relatives</th>
<th>Scenario 2: ED Nurse spends 2 minutes talking to relatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without RFID</td>
<td>With RFID</td>
</tr>
<tr>
<td><strong>FTE staff cost</strong></td>
<td><strong>FTE staff cost</strong></td>
</tr>
<tr>
<td>Salary</td>
<td>Salary</td>
</tr>
<tr>
<td>€ 1,400</td>
<td>€ 1,400</td>
</tr>
<tr>
<td>Italian Social Security</td>
<td>Italian Social Security</td>
</tr>
<tr>
<td>€ 1,000</td>
<td>€ 1,000</td>
</tr>
<tr>
<td>Indirect ED/Hospital Costs</td>
<td>Indirect ED/Hospital Costs</td>
</tr>
<tr>
<td>€ 500</td>
<td>€ 500</td>
</tr>
<tr>
<td></td>
<td>Total Monthly costs</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td></td>
<td>€ 2,900</td>
</tr>
<tr>
<td>Daily cost</td>
<td>€ 131.8</td>
</tr>
<tr>
<td>Hourly cost</td>
<td>€ 16.5</td>
</tr>
<tr>
<td>Minutes</td>
<td>€ 0.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost of staff time informing relatives</th>
<th>Cases</th>
<th>Daily</th>
<th>Daily cost per case (case takes 12 minutes)</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200</td>
<td>9</td>
<td>€ 29.96</td>
<td></td>
</tr>
<tr>
<td>Daily cost</td>
<td></td>
<td></td>
<td>Daily cost per case (case takes 2 minutes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>€ 4.99</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total cost</th>
<th>Y2006</th>
<th>€ 10,665.3</th>
<th>Y2006</th>
<th>€ 1,777.5</th>
<th>€ 8,887.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y2007</td>
<td>€ 10,985.2</td>
<td>€ 1,830.9</td>
<td>€ 9,154.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y2008</td>
<td>€ 11,314.8</td>
<td>€ 1,885.8</td>
<td>€ 9,429.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y2009</td>
<td>€ 11,654.2</td>
<td>€ 1,942.4</td>
<td>€ 9,711.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y2010</td>
<td>€ 12,003.9</td>
<td>€ 2,000.6</td>
<td>€ 10,003.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y2011</td>
<td>€ 12,364</td>
<td>€ 2,060.7</td>
<td>€ 10,303.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>€ 44,619.6</td>
<td>€ 5,494.2</td>
<td>€ 37,183</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Assumptions: 1) Length of ED nurse time spent with patient relatives under two scenarios is based on an assumption that if average time spent in X-ray by each patient without the system is 15 minutes, and can be reduced to 5 minutes with it, family-nurse interaction time for the entire episode of acute care can be reduced from 12 minutes to 2 minutes. 2) Total staff monthly costs include staff salary (monthly salary of a professional ED nurse is based on Italian government statistics; it includes the cost of overtime), social security (social security dues that the Hospital has to pay to the government on behalf of the professional ED nurse) and indirect mandatory costs of ED staff nurses needed to pursue his/her tasks (e.g., professional insurance, equipment). Staff daily cost assumes that a staff nurse works 22 days per month. 3) Interviews with hospital staff has indicated that the RFID system for orthopedics is used an average of 200 times per month. 4) Daily cost per case is based on the cost of staff per minute, minutes each case takes and number of cases per day. 5) The number of cases does not change between scenarios. 6) Annual total cost is based solely on the daily cost per case and does not include costs associated with the replacement of RFID hardware, software maintenance or staff time needed for patient tagging, information download and system maintenance. 3% annual inflation is assumed when estimating annual total costs.

Implementation success enablers/barriers

In the conducted interviews hospital staff stated that the system has successfully fulfilled its operational promises due to the following factors:

- The hospital had clearly identified the overall operational and strategic objectives and benefits expected from the systems;
- Prior to selecting RFID as the core application for this system, it undertook a technological assessment considering different options including bracelets with barcodes;
- When the RFID solution was accepted and the technological partner identified, it was decided to allocate two members of staff to the project team.

Essentially, a strong operational partnership was created between hospital staff and the technological partner.
While end-user staff initially expressed some reservation regarding the introduction of this application, their participation in the design and implementation in the system (during which ED staff members were able to check the validity of the assumptions required for the formalization of system functionalities), the implementation team’s practice of regularly updating ED staff on the development of the system, and ED staff’s targeted system use training eliminated initial concerns. The direct benefits of the system staff saw in their day-to-day activity further led to their embracing the solution.

IT engineering’s perspective on the application was also positive due to the easy integration of the system with the overall hospital IT infrastructure, due to the “open standard” and web interface it uses.

Finally, although no formal process evaluation has been undertaken, anecdotal evidence reported by staff indicates that patients have reacted positively to the RFID system. In particular, relatives could “follow” the treatment processes of their next of kin without having to constantly request information to emergency room staff. Nevertheless, as clearly indicated by respondents, this result was due primarily to the fact that emergency room staff explained to patients the functionalities and objective of the system.

Key lessons learned

The results of the Treviglio-Caravaggio case study suggest that Chapter 3 accurately describes in its ED applications cost and benefit evaluation construct the link between the benefits of healthcare RFID ED management systems, their application operational purposes and their system sophistication variability; and

Furthermore, the case confirms the applicability of the top-, mid- and low-level RFID cost and benefit parameters suggested in the ED evaluation structure, and the anticipated difficulties of obtaining baseline measurements and non-monetary measure valuation with respect to ED management RFID solutions.

The OTC case study, moreover, advances the following key insights:

- The use of an open standard approach for developing an RFID system can ease its maintenance and reduce its cost;
- System tailoring can be fast - the system was developed in seven months during which one full month was devoted to the study of emergency room processes and activities - but its full development and launch took substantially longer (nine months);
- Healthcare RFID’ adoption in and value to a care delivery organization depend on: i) the detailed assessment of processes prior to developing and implementing the system, ii) active stakeholder engagement and iii) clear identification of facility needs;
- Privacy concerns are not a key barrier to this RFID system adoption: patients embrace the system if properly introduced to it; end-user staff embrace the system if actively involved in the application’s design and implementation, and well trained to use it; system supporting staff appreciate applications which do not require constant oversight or maintenance;
- System implementation and outcome evaluations can be of secondary importance for hospital managers if user’s satisfaction with and perceptions of the application’s value-added are positive and staff satisfaction was a primary motivation for adoption;
- Healthcare RFID has a comparative advantage over other auto-id technologies (e.g. barcode) when process visualization and real-time data are needed to resolve an organizational challenge.
Finally, based on the observation that the benefits arising from this patient-tracing only RFID solution, in fact, stem from the elimination of tasks the frequency and duration\(^{157}\) of which are correlated with patient volume, the OTC case study suggests that mid-sized and large hospitals with busy ED departments are likely to benefit most from implementing similar RFID applications.

Application costs, on the other hand, are less likely to be as responsive to hospital size - since the bulk of the implementation costs are not size-variable hardware costs but system conception and design costs, and maintenance costs appear to be more closely related to the type of technology chosen rather than to number of maintained tags and readers.

2. Operating floor and operation room process and workflow management applications

2.1. Case 2: Birmingham Heartlands Hospital, UK\(^{158}\)

Application snapshot

*Application*: passive real-time pre-operative decision support system, fully integrated with core clinical systems used in five hospital ear, nose and throat (ENT) Department wards.

*Date of implementation/lifespan*: 2007 - .

*Adoption objective and Current use*: to automate the pre-operative process by having a digital operating list, enabled by automated patient recognition, preventing wrong site/side surgeries, increasing hospital efficiency, and decreasing exposure to litigation costs\(^{159}\).

*Hospital context:*

- large urban acute care hospital;
- part of one of UK’s best-performing hospital trusts;
- approx. 800,000 ENT surgical patient admissions annually.

*The technology (at time of assessment):*

- near-range, closed-information-loop data system (data is Trust-owned and in compliance with patient data governance guidelines);
- real-time application integrates with core systems through SOAP XML Web services and HL7 messaging, builds on and extends patients’ electronic health records;
- Tags: passive single-use read/write RFID (13.56 MHz) embedded in patient wristband;

\(^{157}\) The assumption here is that with rising patient volume, the time needed to identify each individual patient for example also increased due to the increased busyness of the environment.

\(^{158}\) Information about this application implementation was collected over a single-day site visit at Birmingham Heartlands Hospital (BHH) – on November 13, 2008 - and following interviews and data exchanges with BHH stakeholders and technology developers which took place between December 2008 and March 2009.

\(^{159}\) The application has also been deployed at a second site in the UK, and at an in-patient facility in Australia, however as the circumstances under which this occurred are unclear reported results of these implementations have not been considered in this analysis.
• Patient band and RFID Tag Printers: Zebra RFID/barcode printers, placed at primary points of patient admission;
• Webcams: provide patients' pre-operative record photos;
• Readers: fixed and mobile FEIG RFID/barcode scanners, PDAs and USB-controlled PCs spread to cover all milestones of patients' pre-, intra-, and post-operative care journey;
• Servers: three, to simplify integration with hospital information infrastructure - Microsoft Windows server/VMWare, Microsoft internet information server, and Microsoft SQL 2005 server;
• Software: includes safe patient tracking application, safe patient tracking integration engine, electronic OR theatre list, OR patient records, and role-based pre-operative safeguards check lists (detailed below).

The implementation story

Birmingham Heartlands Hospital (BHH) is part of the Heart of England National Health Service (NHS) Trust, one of highest-performing in the UK, which includes three other medical institutions. Two factors motivated the adoption of an RFID-based OR decision support and workflow solution at BHH:

• The persistence of adverse patient safety “never events” — such as wrong procedure being performed on the wrong patient — occurring due to operating list errors and unreliable paper-driven processes despite heightened attention paid to patient safety;
• The rising human and litigation costs of patient misidentification borne by the NHS.

The adopted solution, Safe Surgery System (SSS), was designed and implemented by one of BHH’s consultant surgeons. First conceived in 1994 in reaction to an actual last-minute-change adverse event, formal SSS product development began in 2004 when Safe Patient Systems Limited was established as a privately-funded company emerging out of the Research and Development Unit at Birmingham Heartlands Hospital. Its development and implementation involved:

• concept-to-pilot design (12 months for application design, plus 6 additional months spent securing stakeholder buy-in at the hospital-level);
• obtaining Trust-level go-ahead (2 years, due to “trust lethargy”, broken up ultimately by the 2007 Corporate Manslaughter and Corporate Homicide Act which made patient

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160 As of 2005 the Trust had over 1,200 beds, cared for 1.3 million people annually, and had a turnover in excess of £265m. It is a leader in tackling hospital-acquired infections; voted Acute Trust of the Year in the 2006 Health Service Journal Awards.

161 According to the NHS Litigation Authority, clinical negligence claims in 2006/7 were circa £600 million and its reserves for known and anticipated claims for 2007 is over £9 billion. Most notably, claims from surgical specialties account for almost 40% of the total number.

162 Within the NHS surgeons and anesthesiologists among other specialties have the status of “consultant” — they are semi-independent contractors, and as such command some powered within the institutions they work.

163 Previous attempts of SSS’ creator to develop the system in-house and in collaboration with universities did not come to fruition.
safety a collective responsibility of Trusts’ board directors with any serious incident caused by systems failure resulting in criminal prosecution);

- 12-month application piloting at BHH (in 2007 the application was rolled out in two BHH surgical wards - at ENT day surgery which had familiarity with the process of SSS since it had been developed in that ward and at thoracic surgery);

- application expansion to a total of five ENT surgical wards at BHH in 2009 (ENT; day surgery; thoracic surgery; children’s short-stay and ENT short-stay surgery).

Within Safe Surgery System (SSS) RFID-based patient and staff identification form a real-time workflow tracing and event management environment, whose primary aims are to improve staff and patient safety, to automate data capture and transfer, and to optimize OR theater patient throughput. SSS, furthermore, ensures that patients are positively identified during any step of their treatment (using RFID-embedded wristbands), and that all the pre-operative manual checks have been performed in conformance with patients’ health records. In essence, the application supplements but does not replace the manual pre-operative check process.

At BHH, SSS is installed at points of primary patients admission (ED, administration units), where on arrival the patient is photographed and given a printed wristband with an embedded RFID tag. The digital image of the patient is then saved in her/his record and used to further verify the patients’ identity. Patient details are sourced from the hospital’s Patient Administration System, confirmed by the patient. Once recorded in the system, the patient record is available to all staff on the ward, including anesthesia rooms, operating theatre and recovery rooms, displayed with the OR operating schedule.

The surgeon, anesthesiologist and pre-operative nurse have wireless Laptop/Tablet PCs or PDAs which allow them to view the operating list and patient records. When the clinician approaches the patient, the system confirms positive identification. The wireless device is then used to record the patient pre-operative checks which immediately update the operating list.

Via SSS clinicians, anesthesiologists and nursing staff are each responsible for the carry-out of various pre-operative checks. These include patient consent, site and side agreed and marked - used for decision support, such as DVT risk assessment and the appropriate prophylaxis recommendation. The system uses a series of “traffic lights” in the patient record which change from red to green as the checks are done. If the checks on a patient are outstanding or there is a risk of infection, the surgeon can change the order of the surgery list – SSS makes everyone instantly aware of the change. For data protection and clinical governance accountability, editing of patient data is restricted and any changes to the items/tasks in each check list are role-based.

As the patient is moved from ward to pre-op and to the OR, the patient’s wristband is scanned to display their surgical record on the local screen – preventing misidentification of the patient or the planned procedure(s). Only when all the pre-operative checks have been verified and patient identity confirmed can the surgery start.

OR process controls include visible and audible messages between clinicians and nursing staff, and can record and broadcast expected discharge times (aiding bed management). If a biopsy or test is undertaken in the OR, the correct patient label for the sample can be printed directly, preventing mislabeling. OR theater efficiency is measured automatically as each step in the process is logged with a time/date stamp.

All events recorded by SSS are stored in the main database and every 24 hours the list of discharges is sent to the database to close events and the history is sent to archive data automatically, minimizing system maintenance. During the application’s development and piloting, particular attention was paid to detecting interference between SSS and other equipment. Such

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164 Only a surgeon of the same specialty can access and change a surgery check but he cannot change the contents of the check list for nursing staff nor for the anesthesiologist. Scanning is not role-specified.
were not found. Signal read errors were documented and one of the further directions for SSS developments is to supplement PDAs and handheld scanners with computers on trolleys (as the former two were describes as “not so reliable”).

Application costs

Due to confidentiality reasons, details on both the implementation and maintenance costs of the system could not be disclosed\(^{165}\). A total implementation cost of £100,000 was identified as the cost borne by BHH’s Trust for a 12-month pilot in 2 wards, and was suggested to include the hardware, software, training and process redesign costs\(^{166}\). Although it corresponds with commercial hardware cost estimates collected to verify interview data\(^{167}\), its accuracy can’t be verified with respect to BHH staff time used during the design, piloting and scaling of the application.

A somewhat different estimate was given of the cumulative - implementation and maintenance - cost of the application to BHH, i.e. £4 per admitted patient for over a three-year horizon (the length of the vendor contract)\(^{168,169}\). This cost includes service project management, configuration, installation (of software), testing, user training, and system maintenance\(^{170}\). It was reportedly calculated over the annual number of surgical admissions to BHH, adjusted to contract length, and does not reflect average useful life of the application. If this calculation is correct, it would suggest that the true cost of the system is therefore 0.003% of the public reimbursement of average hospital costs for each admitted surgical patient in the UK\(^{171}\).

Application benefits

Although a formal outcome evaluation of SSS was conducted by the Trust, it has not been cleared for public release and only partial information from it is non-proprietary. The public part of the evaluation, the interviews and data reviews outline the following as key benefits of this RFID-based decision support system which, should be noted, does not replace the manual pre-operative check process:

\(^{165}\) An internal evaluation of the twelve month pilot phase of the Safe Surgery Systems was conducted for the Heartlands Trust (ENT Performance Comparison before and after go-live of Safe Surgery Systems in March 2007). When a request for a confidential copy of this evaluation report was made at the time of the site visit, it appeared that the ownership of the report belongs to the Trust and may not be available to others not directly involved with the pilot.

\(^{166}\) In contrast, the system’s reported concept to pilot development costs were £300,000 and were incurred in the period 2004-2006 and were borne by Safe Patient Systems Limited.

\(^{167}\) RFID/Barcode printer (Zebra R2844Z) - £400-700; Webcam (LogiTech) - £60-75; FEIG scanner TI-FEIG 13.56MHZ Hand Hels - £250-300, and cognitive systems (w/USB cable) - £200-250 ; Dymo LabelWriter 400 series (optional) - £92.00, as of 30 Dec. 2008.

\(^{168}\) This cost was reportedly calculated over the number of surgical patient admissions at Heartlands in 2008 (approx. 800,000) and was said to depend on contract length as well (i.e. it is not the).

\(^{169}\) Here it is also interesting to note that £1 is the cost of a thermal RFID wristband per patient – the single "consumables for this application.

\(^{170}\) System maintenance was clarified to include a technical refresh of the software every 3-4 weeks, performed remotely by SSS staff, and responses to any on-going technical issues as glides result in an automatic message sent to SSS staff to clear the problem. Maintenance involves either 24-hour technical support or regular business day support (taking on average approx. 1 hour per week of SSS staff time).

\(^{171}\) For each patient admission, every NHS hospital receives £1,250 which is the typical operation tariff (i.e. average cost of an admitted surgery patient).
Quality gains

A) Improved patient safety:

- cuts errors due to patient misidentification by allowing clinicians and nursing staff to match patients to the correct intervention and clinical record, via the stored digital photograph, particularly valuable in case of last-minute operating list changes (see below, left panel);
- ensures all pre-operative checks have been completed prior to surgery by all staff (below, right panel);
- captures any DVT/VTE prophylaxis risk and ensures it is addressed prior to surgery;
- infection risk for each case is identified and OR surgical list is adjusted accordingly;
- automatically records any patient safety incident at the point of care in the Trust risk management system;
- prints patient sample labels linked to patient identity eliminating risk of wrong patient/sample errors.

B) Enhanced clinical governance:

- automatic generation of workflow and process metrics for daily/weekly analysis which result in:
  - consolidated and improved performance reported by multiple criteria (including specialty, theatre, procedure and consultant – see below);
  - improved clinical progress audit capability (the system uses role-based permission for editing of patient data and pre-operative lists);
  - ability to capture patient safety incidents at the point of care.
ability to identify “weak links” in processes much more easily and to redesign them / address them in time;

• ability to comply with NPSA Safer Practice Notice 24, enforcing printed patient wristbands from July 2009.

Figure 2: BHH application – automatic generation of metrics functionality/benefit

Cost gains

A) Operating floor/ theater patient throughput improvement by:

• effective visualization of bottlenecks in care pathways leading to timely resolution;

• allowing changes in the surgery sequence (to get around potential delays, or to ad hoc patients) to be immediately recorded and be viewed by all relevant clinical and nursing staff simultaneously;

• every staff member is aware of the OR theatre list and each patient’s degree of operation readiness;

• centrally predicting bed availability by patient discharge times;

• printing specimen ID labels at the point of care, thereby avoiding unnecessary printing costs and litigating risk of errors due to misfiling of labels;

B) OR nurse time savings on:

• locating operation lists and checking patient status (previously a “very significant portion” of nurse’s time was used to make phone calls and/or physically track the status of pre-operative checks);

• easily locating and tracking patients through the system;
• automatically documenting and coding procedures to provide better data capture and, therefore, free up nursing staff from administrative duties;

C) Significant clinical error litigation risk reduction: respondents indicated that both the quality of care improvements and economic burden of patient safety errors reductions achievable through SSS, are likely to be substantial for individual hospitals and the UK healthcare system overall.\textsuperscript{172}

Evidence of impacts (as of March 2009):
• in the first 12 months, SSS prevented 4 potential patient safety incidents (i.e. near misses) in those theatres using the system;
• the average number of cases per OR session in ENT increased by nearly 12\% overall, and by 24\% for the top 5 performing ENT consultants after the roll-out of SSS;
• as a result, an extra patient per half-day list, or an extra 1-2 cases per list could be seen at BHH due to time management improvements (suggesting a return on investment within 12 months).\textsuperscript{173}

Implementation success enablers/barriers

Safe Surgery System (SSS) users and developers alike regarded the application as a success. The factors interviewees highlighted as responsible for this are:
• Focused and powerful implementation leader: SSS benefited greatly from having an influential internal champion - the application’s developer - was also a representative of one of its main end-using stakeholder groups which possesses substantial internal clout;
• SSS delivers real value-added: system capable of addressing the weak points in the existent manual and paper-based pre-operative process, “feeds into new standards” and gives previously unavailable workflow and event visibility.\textsuperscript{174,175}

\textsuperscript{172} For example, according to NHS-National Patient Safety Agency Reports, 44 wrong side surgery incidents occurred at 28 sites in 10 months and 22\% were due to mismatching, 236 reports of patient safety incidents and near misses related to missing wristbands or wristbands with incorrect information in a 20 month study, misidentification accounts for 19\% of all Root Cause Analysis (RCA) in hospitals, and 493 reports of misidentification from 45 Trusts in 4-month study, highlighted 32 incidents of missing wristbands, 4 out of 10 inaccuracies on wristbands and 26 incidents due to inaccuracies on wristband. A separate analysis showed that clinical negligence payouts by the NHS in England are expected to rise by 80\% in 2010 to £713mm. With a typical contribution to the Litigation Authority in the order of 1-2\% of the total income of the hospital, achieving the highest compliance and error-avoidance can deliver substantial savings by reducing the hospital’s insurance premium by as much as 30\%. At the national level this can bring a £213m reduction in clinical negligence payouts. In terms of hospital efficiency this system is likely to address the existing problem of under-utilization of operating theatre time (according to Annals of the Royal College of Surgeons 25\% of theatre time was underused).

\textsuperscript{173} Based on Heart of England NHS Trust business directorate assessment.

\textsuperscript{174} E.g., errors due to patient surgical list mismatching, patient misidentification.

\textsuperscript{175} Of particular importance to BHH management.

\textsuperscript{176} For example, the noticeable reduction in the number and frequency of phone calls required by nurses to track the status of operation lists and patient readiness the application brought.
• SSS benefits distributed across key stakeholders: surgeons, nurses, and management all benefit substantially from the system;

• Achieves positive ROI quickly despite being an add-on procedure - by increasing patient throughput, reducing litigation risks and by improving correct procedure coding;

• End-user friendly, requiring minimal day-to-day maintenance;

• Produces no interference between SSS and other equipment.

However, while post-implementation nursing staff response to SSS has been overwhelming positive, interviews with OR staff revealed that SSS piloting and scaling encountered initial end-user resistance to adoption from three groups:

• technologically un-savvy end-users;

• staff accustomed to paper-based work routines (older staff); and

• users who had unfavorable experiences with previous HIT implementations and had consultant status (i.e. ability to easily switch employers, as anesthesiologists).

This resistance was overcome by extended end-user training of “super-users” who later became the “help point” and trainers for other BHH users as well as newly-hired staff (BHH staff other than the creators was largely not included in the application’s development). According to nurse respondents and application developers, this implementation strategy was particularly helpful for overcoming staff’s limited involvement during system design, and addressing any outstanding concerns with respect to SSS privacy implications and risks.

In addition, respondents identified three key barriers to making SSS’s success sustainable:

• RFID tag cost: hospital-level management regarded the cost of the RFID system as a particularly strong adoption disincentive, specifically referring to the unit cost of RFID passive tags used in patient’s wristbands, as compared to barcode-bands (a £1 to 10 pence per patient difference);

• UK’s NHS institutional structure system: the decision-making process at the Trust level - “lethargic”, “locally autonomous feudal-like system” - requires that 6 different committees be passed for a decision about a new idea to be made, leading to slow application piloting and scaling;

• Full enterprise-level deployment taking longer than potentially optimal: at the time of interviewing BHH was still admitting patients by hand-writing patient wristbands, hence system for some surgical patient admissions nursing staff had to switch between using the new automated and the old paper-based system for others; this resulted in an unnecessary burden on staff and increased error risk.

Key lessons learned

The BHH case outlines four main insights on healthcare RFID success:

• The internal organization of a care-delivery organization - in particular lack of streamlined management and the (resulting) inability to bring all decisionmakers and users on-board

177 A fourth barrier was also mentioned by SSS developers, but it remains mainly to the “concept-to-pilot” development of the application, due to which it is not listed above: BHH’s IT department was under-resourced hence an IT specialist had to be hired for the product’s development.
in the application planning process - can strongly impact the fate of an RFID application deployment due to the large upfront costs associated with it and the relatively longer time needed for system development and implementation (i.e. being in a highly-performing environment does not automatically guarantee that structural barriers to the implementation will not occur);

- Prior negative experience with other HIT implementations can create end-user resistance to adoption which can be hard to overcome, just like baseline lack of technical capacity/literacy; and strategic end-user education is needed to overcome both;

- Staff concerns over wearing a location badge can best be addressed by communicating effectively that staff’s location will only be tracked in care giving areas and not staff lounges and other non-care giving areas (to overcome concerns of Big Brother), and highlighting its staff safety aspect (e.g. ability to quickly locate staff likely to have come into contact with a patient having a contagious condition.

- While the piloting of RFID systems is important for their fine-tuning and no-threat validation, their scaling should not be overly protracted, as such implementations are likely to alter critical workflows and processes and unless implemented universally across their targeted domain of use they can create a reality of duplicate workflows/processes, increasing stress on staff and inverse-to-desired outcomes;

- Unit RFID tag cost may be an obstacle to wide diffusion: BHH management attitude towards unit cost suggests that until there is mass production to bring down the price of RFID tags, cost-only based comparisons of RFID and barcode tag costs will not help RFID adoption.

In addition, the results of the BHH case suggest that the healthcare RFID OF evaluation construct outlined in Chapter 3 accurately describes the healthcare RFID OF management system benefits, their link to application operational purposes and variability subject to system sophistication (such as the relationship between the application’s capacity to associate patient admission and pre-operative records and deliver positive patient identification, which decrease the risk for wrong patient-wrong procedure errors and nursing staff’s administrative burden, and improving patient throughput).

Furthermore, based on the observation that the benefits arising from this OR RFID solution stem from the reorganization, elimination or automation of highly-complex tasks - OR patient preparation, OR staff coordination and process and event documentation - which are also compounded by patient volume, the BHH case study suggests that small, mid-sized and large facilities can all benefit from implementing similar RFID applications (reaping process optimization, cost reduction and safety improvement gains associated with their successful implementation).

Based on the BHH case study, however, it is not possible to ascertain how the implementation and maintenance costs of such applications would vary with hospital size and patient volume (as BHH is a private case due to the way the system was developed, and due to the lack of precise information on the solution’s implementation and maintenance costs). While the bulk of development costs can be expected to arise from the system functionality identification, process redesign and system design stages (as in the case of the OTC application), the implementation costs can be expected to be relatively patient volume/hospital size insensitive.
2.2. Case 3: Amsterdam Medical Centre (AMC), NL

Applications snapshot

Applications: three passive/active operating room (OR) RFID applications focused on reducing materials waste, improving patient safety, and providing better operating floor and OR workflow visibility: OR theater person identification, OR material and medication and OR blood product tracing.


Adoption objective: to explore questions such as “is this a technology that works”, “what can we learn from this technology”, and “what is the added value in terms of patient safety”.

Current use: all three pilots were dismantled.

Hospital context:

• large university hospital;
• older infrastructure (1980s);
• pilots covered Operating Room complex, Intensive Care Unit, and Blood Transfusion Laboratory.

The technology (at time of assessment):

• LAN-based and wLAN-based applications, integrated with each other but stand-alone with respect to other clinical applications run at AMC;
• Tags: passive and active RFID tags were attached to vascular grafts and baskets filled with suture materials, staff and patients (as wristbands and cards), blood products - bags with red blood cells and platelets, and blood plasma (temperature sensors);
• Readers and Antennas: 125kHz wake-up antennas and unit assembly devices (for active tags), 868MHz FEIG readers (passive tags), hand-held scanners;
• Software: all data were stored in an Oracle database and analyzed through the Movida application developed by Geodan which allows to link the RFID tag numbers to patient IDs or blood product IDs;
• Servers: HP Proliant sever 3.4 GHz 2MB running Microsoft Windows 2003, ORACLE database server, application server, and edge server.

The implementation story

The Academic Medical Center (AMC) is one of the largest hospitals in the Netherlands, housing the university hospital and the medical faculty of the University of Amsterdam, as well a number of medical institutes and biotech companies.

In 2005 the AMC participated in three simultaneous RFID pilots including: identification/localization of persons in OR; OR materials tracing; and blood products tracing. Although the three pilots involved three stand-alone applications, they relied on a common

178 Information about this application was collected over a single-day site visit at Amsterdam Medical Centre (AMC) – November 10, 2008 - and following conversations with AMC stakeholders which took place between November, 2008 and January, 2009.
infrastructure and focused on similar processes and patient populations. They included AMC’s recovery room, four operating rooms (ORs), three intensive care units (ICUs) and the blood transfusion laboratory of the AMC. Based on data from the previous year (March-April 2005), it was expected that during the pilot period (March-April 2006) 8-9 patients and 13-14 blood products per working day would have to be tagged.

The aim of the project, as formulated by the Dutch Ministry of Health, was to stimulate innovation in healthcare practice and delivery. And, in particular, to demonstrate the added value of healthcare RFID applications. AMC considered it an exploratory analysis. Executed by CapGemini\textsuperscript{179}, the pilots were a public-private venture. An interdepartmental subsidy financed 50\% of the pilots’ costs. The other half was covered by a series of industry partners approached by Cap Gemini for the purpose of the project, including Oracle, Geodan, Intel and the Amsterdam Medical Centre.

The medical-ethical commission of the AMC declared that the study was not subject to the medical ethical research protocol. Even though it was not formally required, the AMC asked all patients for their consent to participate in the study.

Implementation of the pilots followed the PRINCE2\textsuperscript{180} project management method, encompassing five distinct stages:

- project initiation, which included objectives formulation, contractual arrangements and the establishment of a project structure;
- development of pilots, during which decisions were taken regarding which patient populations, materials and processes to target, as well as what RFID hardware to purchase;
- building/testing of pilots, when the actual RFID technology was built and installed by CapGeminin in close cooperation with technicians from the AMC; a procedure handbook and instructional materials were also developed;
- roll-out - during this stage, the RFID systems were calibrated, participants in the pilots had to wear the RFID tags and received instructions about using the technology;
- reporting and evaluation - the results of the pilots were reported back to the Dutch Ministry of Health and disseminated to the general public through a white paper.

To ensure the reliability of the information produced by the system, various tests were carried out. First, under controlled circumstances, time stamps and locations of RFID tags reported by the system were compared to manual observations (the technical test). Second, an acceptance test was carried out in which a number of cases was followed in a real-world setting and data produced by the system compared to manual observations. These tests were repeated until the data produced by the system were consistent with the manual observations.

During the pilots it became clear that some of the initial goals were over-ambitious and not feasible in practice:

\textsuperscript{179} CapGemini is a consulting firm headquartered in Paris and operating in more than 36 countries with more than 86,000 staff.

\textsuperscript{180} “PRINCE2 is a process-based approach for project management, providing an easily tailored and scalable project management methodology for the management of all types of projects. The method is the de-facto standard for project management in the UK and is practiced worldwide.” Retrieved on-line 17 November 2008 http://www.prince2.com
• for reasons of patient safety, it was decided not to change any of the existing processes during the pilot;
• for privacy reasons, it was decided only to identify staff by function rather than by name;
• staff participation in the pilots was voluntary and on average less than 50% of the staff working at the site of the pilots wore their RFID badges;
• due to cost reasons, instead of being tracked hospital-wide, patients were tracked from the recovery room to the four ORs, and from the ORs back to the recovery room or IC unit (active tags produce a signal picked up by ‘wake-up’ antennas situated near certain doorways);
• due to software limitations, it was not possible to use the information on blood products’ temperature (measured through RFID tags); they were only tracked from the blood transfusion laboratory to two operating rooms (both cardio-thoracic surgery) and recovery room or ICU.

In addition, tracking materials, fully and in real-time, was not possible, because:
• interference between the RFID system and medical devices in the OR prohibited the placement of RFID antennas in the OR;
• the passive RFID signals (for materials) were interfering and (based on technical specifications) overruling the active signals (for persons and blood);
• installing antennas on (moving) waste bins was difficult (due to the number of waste bins, the need to include power batteries, and to use wireless communication - not available in the OR).

For these reasons, materials were scanned by hand when leaving and returning to the storage room and through RFID antennas in the waste disposal room. As the latter were moved out of the waste disposal room to the hallway (as the result of maintenance work), not all materials were fully tracked.

Application impacts

The costs and impacts of the three pilots conducted at AMV are unknown because:
• the pilots ran parallel to existing (highly critical) OR processes, rather than replacing those processes;
• no evidence that hospital staff had used RFID system to improve patient safety, effectiveness or efficiency;
• the pilots did not develop in full scale application after their completions.

Therefore, for this case both the identification and then measurement and valuation of costs and outcomes is highly problematic. The available cost and benefit data is presented below.
Costs
• specific estimates of the cost of the RFID pilots were not obtained;
• available information indicates that 400-500 staff were involved in the pilots, with amount of time per staff member varying dramatically – e.g., 20 OR staff might require an hour of training each, whereas the project leader spent about a full year of work; other staff involved included professors, surgical staff, and anesthesiologists, who all had to be kept informed on a regular basis.
Benefits

- Impacts on quality of care:
  - RFID data allowed to observe how often staff would walk in and out of the OR. No process changes were made;
  - It was not possible to obtain information on the temperature of the blood products that was easily interpretable and of immediate use; specifically, it was not possible to use the information on the temperature of the product (measured through RFID tags) as this would require the development of models to relate the room temperature to the registered temperature and the core temperature of the product;
  - In a survey among staff participating in the pilot, staff members indicated that the information coming out of the RFID system regarding the tracking of patients (and displayed on screens accessible to staff) was confusing and of limited use to improve patient safety. Staff members were not hindered by tags attached to patients and products, but they frequently forgot to wear a tag themselves.

- Impacts on cost of care:
  - The data produced by the RFID system revealed that 53% (82) of the patients participating in the pilot went through the process as anticipated a priori; 31% did so partially (i.e. their data could be used for only some calculations); and data on 16% of the patients could not be used because of large discrepancies between the anticipated process and the process according to the RFID system. No process changes occurred;
  - The data produced by the RFID system on the use of materials (grafts and sutures) was of limited use because at some point the RFID tags were out of stock and because of disruptions caused by moving the waste disposal room. As a result, the RFID system suggested that only 85 out of 122 unique materials were used, while in fact nearly all materials were used. Still, without the disruptions, it appears the system would have been able to produce valuable information on the use and flow of materials;
  - The data produced by the RFID system on blood products revealed that only 38% of the ordered blood products are transfused and that the rest is returned to the stock. It is not known how many of the returned products were re-used because only a limited number of blood products (i.e. only those used at the pilot sites) left the transfusion lab with an RFID tag.

In sum, after pilots completion, AMC stakeholders were not convinced that RFID technology would be the right solution for the hospital. The reasons for this were:

- the limited rewards in light of what was expected;
- the lack of wireless infrastructure;
- the solutions’ cost/benefit ratio was unclear - i.e. it is unclear whether the investments can be earned back over time;
- tags were too large;

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181 Other studies have suggested that minimizing the movement of staff could have a positive impact on patient safety (due to less contamination of the air in the OR by harmful bacteria), and hence the data produced by the RFID system could be useful in monitoring these movements (CapGemini n.d., p. 39-42).
the RFID technology simply did not deliver what the AMC expected / hoped for, namely THE solution to reduce administrative burden and flawless measurement of processes (for a number of applications, data loss was a serious issue in the AMC, which could not easily be explained and/or fixed).

However, AMC interviewees noted RFID seemed to work well as an audit instrument (“why are these doors in the OR opening and closing 20 times per hour”). They also reported having learned a great deal about the technology from the pilots.

Implementation success enablers/barriers

The AMC case highlights the following critical factors to making an RFID project a success:

- Role of the project leader in adoption of the technology: The skills of the project leader to implement the new RFID technology are a key enabler. He or she: i) needs to know the organization thoroughly; ii) needs to know the people in the organization very well; iii) needs to know and speak the language of the organization; iv) needs to communicate the purpose of the technology and (in this case) the pilot study very clearly; and v) needs to be very visible at the different departments involved. From the experiences in the AMC, the process of adoption is gradual. In the beginning few people are willing to participate, but this will increase steadily as the project leader communicates the goals of the technology clearly. An important factor is how people perceive the technology and the implications for their privacy;

- The ability to incentivize staff to embrace the application and overcome privacy fears: Securing staff buy-in is critical to implementation success. Out of privacy concerns, staff members expressed resistance to being tracked through RFID technology as they expected that at some point there could be consequences to their movements tracked by the system. This suspicion was present even though staff had been informed extensively at the beginning of the project about the specific purpose of the pilot study, which was purely to test whether the technology worked, whether there were any traps, and whether there might be a business case for the future of this technology in the AMC and elsewhere. In particular, while nursing staff did not perceive wearing an RFID tag as problematic, physicians at the OR made substantial objections to even wearing a fully anonymous tag, and escalated their concerns to the workers council. After the project team gave a presentation to the workers council, the latter did not see any problems. The AMC executive board also requested to be informed but did not object to staff wearing an RFID tag. Eventually, part of the OR staff refused to wear the tag, and another part agreed to participate in the pilot and wear a tag (50%). For the purpose of the pilot study this was not a problem. This may not be the case for other applications;

- Caring for patients who refuse to wear a tag: The problem of refusing to wear an RFID tag might actually be bigger in the case of patients. For example, patients might ask for a guarantee that their health insurance company will never be able to access the data. Eventually, only two patients refused to wear an RFID tag in the AMC pilot - one because of his disease and general condition (i.e. the patient just didn’t want to be bothered by the issue); and another for religious reasons and experiences during the Second World War. This means that in case a hospital will implement a RFID tracking system for all patients, there always has to be an option for a patient to receive treatment without wearing an RFID tag;

- Reliability: Data coming out of the RFID system needs to be reliable. In particular, the AMC was experiencing data loss (i.e. incomplete tracking) which limited the usefulness of the data for subsequent analysis and improvement of processes;
Interference with other bio-medical equipment: An unanticipated development during the pilots was the issue of interference. The AMC requested an in-writing guarantee that there would be no risk for patient safety due to interference holding partners liable for any damage as a result of interference. As a result, vendors invited the Dutch technology research and consulting organization TNO to measure possible interference. However this only occurred just a few weeks before the pilot RFID system was about to become operational. Once TNO started to measure interference, it became clear that it was a real issue – while normally-functioning RFID tags did not interfere with clinical applications, “accidentally” turn up the power of the transmitter, e.g., a cleaning person hitting a button on the RFID device switching the power from 0.5 to 2 Watt. After testing 2 different RFID systems against 41 different medical devices, the researchers found 34 incidents of interference in 123 tests, including mechanical ventilators, syringe pumps and external pacemakers. Results of the study were later published in JAMA. Due to the interference measure, one of the three pilots could not be conducted as originally planned. Hence, it was decided that if the AMC were to implement RFID technology in a much broader setting, the technology would have to be more reliable and staff adoption would need to be higher. The current thinking in the AMC is that technology based on a WiFi network is more promising, although testing for interference (similar to RFID) would be required first;

Over-ambitious initial goals may be infeasible in practice: The pilot originally intended to track only inventory within the OR, in particular expensive biomedical implants. At the time, the AMC noted that this was a fairly limited approach, not much focused on the patient. Therefore, they expanded the scope of the pilot to include patients and blood products as well. Interestingly, it was the original pilot (OR inventory tracking) that could not be conducted as originally envisioned due to the interference issues. In this pilot, process innovation was one of the four explicit policy objectives as set by the government. The other three were standardization, safety and acceptance problems. AMC respondents, however, highlighted that not only was process redesign not an objective they aimed at, but that they rejected any change in existing processes. In addition, the vast scope of the project was deemed overbearing, and one of the key factors for the ultimate dismantling of the applications.

Key lessons learned

The AMC case highlights the following three lessons:

- Ownership at hospital level is important: this government/industry-sponsored trial shows that even if the implementation process is well-structured and executed, it does not by itself guarantee the application’s success;
- Pilot initiators need to think hard if hospital is really prepared to change critical processes (e.g. at OR);
- Patient and staff privacy concerns can lead to application rejection.

In addition, AMC respondents drew the following RFID implementation conclusions from their experience:

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• the processes of which the RFID application becomes part need to be mapped out in
great detail before the application is conceived;
• be aware of the risks and carry out a risk-assessment;
• it is important to test for interference early on, yet an extensive testing trajectory is
necessary, due to the complexity of the technology;
• limit the scope of the project;
• provide feedback regarding the results early on;
• find a skilled project leader (acting like a 'spider in a web');
• brief departments and their staff regularly;
• obtain informed consent from patients (even if this is not strictly required by law);
• be sensitive to staff privacy;
• make a free OR available for testing the technology since the OR is in use most of the
time which makes testing/experimenting with RFID technology in an OR difficult;
• WiFi tags might be a good choice if a WiFi infrastructure is already available, otherwise it
will be too costly/risky;
• static IP-addresses are preferable to dynamic IP-addresses;
• because assets move relatively slowly, active-RFID tag battery life can be conserved
through less frequent location updates; but tracking patients and staff requires updates of
10 seconds or less to automate nurse call systems, document staff-patient interactions
and measure clinical response times.

3. In-hospital medication management workflow and process applications

3.1. Case 4: University Hospital Jena (DE)\textsuperscript{183}

Applications snapshot

\textit{Application}: unit-dose medication commissioning, medication preparation at patient bedside and
medication administration in intensive care unit (ICU).


\textit{Adoption objective}: using the platform’s auto-ID infrastructure to identify, track and match
medication accurately and in real-time from the hospital's pharmacy until they are administered to
ICU patients;

\textsuperscript{183} Information about this application was collected over a single-day site visit at University Hospital Jena –
December 9, 2008 – followed by additional interviews with hospital stakeholders which took place over the
two month following the site visit.
Current use: replaced by DataMatrix (2D barcode) due to high maintenance costs (decision accelerated by 2008 AMC JAMA article on potential of RFID interference\textsuperscript{184} despite unsuccessful replication tests at UHJ).

Hospital context:
- large university hospital, regional acute care center;
- ICU: 72 beds, 100 physicians, 300 employees;
- new facility (built in 2004), with state-of-the-art technological infrastructure;

The technology:
- high-frequency, real-time, passive- and active-tag based application integrated with hospital clinical and administrative systems;
- no person-identifiable information is stored on staff/patient tags;
- Tags: staff badge - Mifare (13.56 MHz, encrypted, not ISO conforming, used for access control); 13.56 MHz sticky tags (ISO 15693, re-write, passive tags, used for procedure control); patient wristband, medication, drug boxes and transport containers: 13.56 MHz read/write passive tag (ISO 15693), Dynamics System;
- Readers: stations at pharmacy and WPA-2 operable handhelds with integrated web browser for ICU and transportation system (Blackjets Datalogic);
- Wristband printers: Zebra R2844Z;
- Software: software device management layer by Nofilis, software business layer (database and netweaver application) and commissioning application by SAP, interfaces to legacy IT system developed in-house;
- Servers: 2 standard Intel servers.

The implementation story

The University Hospital of Jena (UHJ) has 26 clinics, an overall capacity of 1,375 beds and more than 250,000 patients per year. It is also the focal acute care center for the state of Thuringia.

One of UHJ’s research units is the Centre for Communication and Information Technologies (ZIK), a key research area of which is the development of auto-ID solutions for patient safety, in collaboration with a conglomerate of industry partners.

UHJ faced two operational problems:
- finding an efficient and reliable way to track individual antibiotic prescriptions from its pharmacy to individual patients;
- increasing the cost-effectiveness of the overall medication treatment process.

To address these, and to build further ZIK and UHJ’s expertise in auto-ID for patient safety, ZIK’s Deputy Director (a former Intensive Care Unit (ICU) patient data management system leader) and UHJ’s Head of Pharmacy decided to design and pilot an RFID-based medication process management application. UHJ’s ICU unit was chosen as a pilot site due to the critical consequences minor delays and deviations in medication preparation can trigger in this setting.

\textsuperscript{184} See AMC case study for more details on this article: The JAMA article highlighted that RFID can cause severe interference problems with other monitoring systems if signal accidentally altered. (see van Lishout E. J. et al. 2008. Electromagnetic interference from Radio Frequency Identification inducing potentially hazardous incidents in critical care medical equipment, JAMA 299(24): 2884-2890).
The specific goal of the pilot was to develop an auto-ID application which can reduce the risk of adverse drug reactions (ADR) - one of the most common problems of patient safety. The pilot was initiated as a joint project between ZIK, SAP and Intel.

At the time of the pilot, the ICU was already fully integrated in the unit-dose process and SAP’s Patient Data Management System. Hence RFID was considered to be an add-on and intended to fully automate and capture order-to-delivery of prescriptions for intensive care patients and to provide new visibility into medication preparation at the bedside (see figures below). RFID was selected as carrier technology due to its:

- ability to automatically track and check drugs given to the patient at the point of care – e.g., for timeliness, dosage and route – decreasing the rate of medication errors to less than 0.5% (as compared to a 5.1% standard hospital error rate, which a unit-dose-system can decrease to 2.4%);
- automatic data capture functionality, which through improvement in documentation and new process visibility can aid the redesign and improvement of key medication administration processes at UHJ;
- value-added in optimizing logistics processes and enabling demand-driven supply management (reducing the amount of capital locked up in the pharmacy’s inventory and improving its expiration date management).

Figure 3: Serialization of unit-dose process

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185 Applications that can reduce these incidents have the potential to produce substantial savings, as roughly 30% of all adverse drug reactions (ADRs) are considered avoidable. Given that the economic burden of ADRs in Germany is estimated to be €400m, with an average treatment cost of approximately €2,044, a 30% reduction in ADRs would result in a €120m reduction of their economic burden at the national level (down to €280m).

186 which provided the hospital’s ERP system

187 Taxis K, Dean B, Barber N., Pharm World Science 1999

188 Intensive care patients often have no more than 3 probes (IVs) through which medication can be fed; patient receives on average 8-10 different perfusions that need to be fed through these probes. It implies that preparations will need to be mixed and that pills need to be prepared to be fed through a stomach tube.
A joint 10-person ZIK-SAP project team was created, involving an Intel and a Nofolis representative, and ZIK’s deputy head, UHJ’s heads of pharmacy, of RandD, and an ICU nurse - responsible for user support and local implementation – along with a communication and messaging and a database and unit-dose engineer.

SAP provided the business layer of the application - auto-identification infrastructure layer: database and netweaver application - and the commissioning application. Intel Systems were the hardware integrators responsible for hardware choices, including printers and RFID handhelds. Both companies offered “attractive pricing”, and financing was covered by UHJ (mainly through the acquisition of SAP All).

The pilot scope was set at:

- 10 rooms of the intensive care unit (~30 patients at any given time);
- RFID tagging of 120 different antibiotics (unit dose);
- RFID tagging of all drug boxes;
- RFID tagging of transport containers for the automatic transport system;
- RFID tagging of roughly 30% of ICU patients;
- RFID tagging of ICU medical staff.

The application was implemented step-wise:

- Together with SAP and Intel, UHJ performed a detailed analysis of the core processes supporting medication preparation and administration, and integrated them into a single RFID-based process. In the new process, based on passive RFID tags, medication could be tracked in real-time from the hospital’s pharmacy to the ICU and individual patients. Then it can be matched digitally to the individual patient by checking the reference codes on an RFID bracelet worn by the patient. Using handheld scanners, the nursing staff can read these codes, link them to the patient data in the hospital’s IT system, and gain instant access to detailed information on the patient. In addition, the system was envisioned to record all medication in the patient’s file automatically, including details about type, quantity and time of medication. In order to ensure an end-to-end process from the pharmacy to the patient, all unit doses of patient medication, transport boxes of the pharmacy and steel containers of the automatic, internal transport system are to be equipped with RFID tags. This design was approved by UHJ’s Ethics Commission, UHJ’s
Data Protection office, the Governmental Data Protection Office Thuringia, and the Workers Council at UHJ to ensure that concerns are properly addressed;

- In 2006, SAP started with a six-month experiment to test hardware, software and reader and tags and to integrate into existing IT infrastructure. Various wristbands were acquired and tested. A SATO printer was tested but considered to be too big and too expensive. Default Mifare staff identification card were complemented with a sticky tag placed on the employees' name tags. A high-frequency passive re-writeable 13.56 MHz (ISO 15693) EPC-96 RFID tags were chosen in order to get a wide range of suppliers and to realize cost efficiencies;

- The system was supposed to be fully operational in 2007. However, approximately 2-3% of tags were defect or broke between first write and first read procedure. Ultimately, Intel left the project in mid 2007;

- In response, UHJ's head of RandD took up the role of pilot manager and redesigned the project - e.g., redesign of device management, new acquisition of reader and hardware, and design of a new administration and preparation application that provide support in medication preparation at bedside;

- The actual test phase started in the last quarter of 2007, and the system was fully implemented and operational in early 2008.

Data protection was considered by design and motivated the decision to limit information stored on the tag. For security and privacy purposes, the tag only contained a number without any context. Handhelds did not save or cache data locally and were WPA-2 encrypted so that in case of loss, no patient data can be accessed. During the pilot implementation, patients were invited to participate. 30-40% of patients gave informed consent and participated in the pilot. This relatively low participation rate complicated the test phase and required staff to verify whether a particular patient agreed to participate or not. However, in terms of sample size, the participation rate was sufficient to achieve critical mass. Since 2008 patient wristbands have become compulsory at UHJ, and are now part of the hospital's patient service contract. Every patient has to sign when admitted at UKJ. The RFID application was, however, discontinued (see next section).

Application costs

Although two separate evaluations of the pilot were done – an outcome and an implementation evaluation – no comprehensive estimates of the pilot's costs exist. This is primarily due to cross-financing arrangements with UHJ's industry partners (the pilot was partially financed by the acquisition of SAP AII and initially some 10,000 tags along with other hardware were provided by Intel free of charge189) and the series of changes in the technology providers, technologies and pilot team that took place during the pilot190.

What is known about the pilot costs is that the original implementation and maintenance budgets were both substantially overrun. For example, the chosen high-frequency ISO tags were found to be too expensive and to lead to high operating costs, in excess of €195 per week for the ICU (including €0.75 per wristband per patient and €7.5 - €10 for antibiotics per patient per day, or respectively patient wristbands costing €45 per week, antibiotics tagging costing €150 per week,

189 Intel provided 2 PCs and 2 reader stations at the pharmacy, as well as the first 10,000 high-frequency sticky tags for staff and medication identification, and the device management layer (Nofolis) of the application. 2 servers for hosting the SAP applications, and 2 patient wristband printers.

190 SAP could not provide insights into budget, budget breakdowns and cost elements. Interview partners were only able to share qualitative information.
and drug box tagging costing €50 per week). Non-monetized training and education costs are also available: a total of 4 training sessions for staff were organized (lasting half-day each) and a pilot team member provided continuous support to end-users throughout the pilot (1 hour per day). Information posters and leaflets at the intensive care unit informing about RFID, and the background and benefits of the project, were also produced. Although unspecified, it is also known that the application’s segment pertaining to the hospital pharmacy was estimated to have a negative cost-benefit ratio, suggesting that the technology did not deliver sufficient benefits to justify its high cost.

Ultimately, the high operating costs, the unsatisfactory tag quality (approximately 2-3% of tags became damaged between first write and first read procedure), the need for patient wristband removal (as tag and MRI suppliers did not provide clearance for the use of wristbands during an MRI scan), and the short life of reader batteries amounted to a perception of an unsatisfactory pilot return on investment. As a result, following the publication of the AMC JAMA article on the potential interference some types of passive RFID may have with key clinical systems if inadequately serviced, UHJ decided to abandon RFID as a carrier technology.

Application benefits

UHJ has not evaluated this project in terms of economic profitability or cost effectiveness. However, within the first six months of the project 6,720 antibiotics medication preparations were electronically captured:

- 109 out of 6,720 (1.6%) errors were reported during the commissioning phase;
- 228 out of 6,720 (3.4%) error messages were reported in the patient-drug matching process (in most cases such message related to emergency cases where nurses used medication that was assigned to another patient);
- 209 out of 6,720 (3.1%) deviations from the unit-dose process were reported.

No monetary value has been assigned to these error messages.

Overall, despite its outcome, the RFID pilot was evaluated positively by all stakeholders involved. The following were considered its major benefits:

- it provided insights into the medication preparation process;

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191 Patient wristband tags cost €0.75 each, and on average a total of 60 bands were used a week (equalling €45/week). Antibiotics tags cost €0.50 each, and each of the 30 tagged ICU patients received 15-20 medications per day. As the tags are re-writeable the ICU used 300 such tags a week (at a total cost of €150 a week). Drug box tags, also re-writeable cost €0.50 each, with 100 of them used a week (equalling €50 euro). As highlighted, one of the reasons for the high cost of the tags was the high frequency chosen. Another reason was the high damage rate of the tags between first read and first write (at 2-3%).

192 6,720 antibiotics medications contain between 50-100 different drugs; 15 of the most used drugs make up for 80% of all medications.

193 Accountability and transparency: every employee at the intensive care unit knows that errors can occur and that they are part of the ‘business’. Errors identified and accounted for by the system are not used against employees. The system is intended to support employees and to better document care provided to the patient. Accountability issue in Germany and EU is different from accountability and legal system in the US. The popularity of RFID in the US should also be interpreted and analyzed from this angle.
- the automatic documentation provided by the system increased the accuracy, credibility and effectiveness of documentation, and ultimately led to better-informed decision making and higher quality of care;
- the better visibility and new information provided by the system – such as bringing the documentation process closer to the patient, and making critical patient and medication data available in real-time - helped UHJ synchronize and improve its inventory management;
- the system raised staff awareness of the need for better process quality;
- it facilitated communication between colleagues across teams and units.

The following were seen as its additional benefits:
- the application delivered patient safety improvements, including reduced risk of adverse drug reactions (due to real-time mismatch capture); improved compliance with best practices in intensive unit medication administration; and capacity to respond quickly and efficiently to a medication recall;
- it allowed UHJ to gain valuable experience in auto-ID serialization of patient IDs and objects\(^{194}\);
- it showed that RFID and auto-id technology can be beneficial for medication tracking and that the same method could be used for tracing people, objects, locations and commissioning units;
- it improved staff and patient understanding of the use and merit of RFID technologies;
- it enhanced the modern and innovative image of the hospital.

Respondents also indicated that the RFID pilot was beneficial in providing the following insights to HUJ's ZIK center:
- cost forecasts for RFID tags as marketed by industry may not been realized: the 1 to 5 cent unit cost of tags is an unrealistic expectation;
- bulk reading may not produce expected benefits and accuracy levels: even with the best set-up and configuration at the pharmacy, only 98% of all readings have been successful, well below an acceptable level;
- auto ID systems can emit "irrelevant" error messages, a problem which needs to be addressed in their design: for example, a very frequent error message was due to ICU nurses dynamically using medications assigned to other patients in the case of emergency – and unchangeable work routine.

To minimize the application's unsatisfactory signal reliability, high unit cost and potential interference, the pilot team decided to replace all RFID components in the system with DataMatrix (2D barcode). This substitution was reportedly possible with limited system modifications as no other data but identifying unique number was stored on all RFID tags. The

\(^{194}\) Serialization of patient IDs and objects is considered an important issue in healthcare at UHJ and was the main ambition of the project; technological choice was judged to be of secondary importance.
new system is described as a success. However, it is not known how the substitution of RFID with DataMatrix affected the quality of care and clinical governance benefits of the original RFID-based application.

Implementation success enablers/barriers

The factors interviewees outlined as facilitators for the RFID pilot at UHJ were:

- Pilot leadership role for project acceptance: in particular the excellent reputation of ZIK’s executive director;
- Technology developer’s and adopting organizations’ understanding of the need for application tailoring and environment imperatives: Successful implementation of RFID technologies involves a thorough understanding of the special requirements of a hospital environment and a partners’ willingness to fully acknowledge its complexity. In particular, intensive care requires special attention to detail and cannot be treated as any other logistics environment. In this context, the already existing close collaboration between UHJ’s Centre for Communication and Information Technologies and SAP, their expertise and commitment to the project facilitated the application’s design and fielding. Simultaneously, creating a common understanding of the need to tailor the application was an issue with cooperation partners. This limited understanding of the technology’s healthcare setting at the beginning resulted in miscalculations of the project’s overall cost;
- Healthcare RFID hype: Healthcare RFID has been heavily promoted. Consequently, innovative companies and hospitals have been eager to position themselves in the debate, to get the attention and to be part of this hype. In the case of UHJ, so was the hospital. A barcode solution would not have delivered the same support.

Inversely, the factors respondents highlighted as responsible for the ultimate failure of the RFID pilot centered on the limitations of the chosen technology. These factors are:

- Low tag reliability: Quality of tags was mixed and below industry standard: approximately 2-3% of tags were defect or broke between first write and first read procedure (less than 1%). Overall, an error rate of 1-2% was judged prohibitively high. An error rate of 0.01% was defined as acceptable;
- Standard HF ISO tags were too expensive and resulted in high operating costs: Intel opted for an EPC code (EPC-96 code), which by being relatively long (96 bits long), lengthened the reading process. Ex-post assessments showed that from a technical point of view a closed-applications domain-specific coding would rendering to the more costly and restrictive EPC compliant coding scheme unnecessary;
- Patient wristband removal was necessary for certain routines and seen as problematic:
  - Patient wristband needed to be removed during Magnetic Resonance Imaging (MRI) process. Tag suppliers and MRI suppliers were not willing to give clearance and to allow use of wristband during MRI;
  - Patient wristband also needed to be removed to allow some medical routines in the operating room, e.g., IV. In the best case, wristband was attached again after the intervention.
- Staff badges needed to be removed when entering the OR;
- Signal interference between readers and other technical installations (e.g., elevators, air-conditioning, etc.);
Inadequate battery life of handheld readers: Initially UHJ planned to use handhelds in battery-mode. However, batteries were not able to serve 24 hour-terms and needed to be recharged more often, which negatively affected user acceptance. UHJ installed local recharging terminals which considerably improved user acceptance, but added new problems (e.g., signal dropouts);

RFID not operating on metal surfaces: RFID does not work on metal surfaces, including metal-coated bags; as a quick fix, UHJ decided to add an additional plastic bag to place the tag or to use plastic extenders;

RFID too big to fit some objects: ampoule too small to place tag (smallest available RFID tag is 30mm x 30mm – for DataMatrix 7mm x 7mm); as a quick fix, UHJ decided to add an additional plastic bag to place the tag;

System required a complex alignment of readers to achieve acceptable reading rates;

Staff charged with informing about the RFID project and asking for consent were not closely involved in the project and did not have a particular incentive or motivation to highlight the benefits and scope of this project, contributing to low participation rate;

Some employees refused to adopt RFID technology: UHJ accepted individual decisions and respected them in process design (providing passwords to those who did not want to be identified by RFID). This mistrust appeared diminished in the case of DataMatrix.

Key lessons learned

The results of the UHJ pilot, although unsuccessful, suggest that the MF RFID cost benefit evaluation construct outlined in Chapter 3 accurately describe the healthcare RFID medication management system benefits, their link to application operational purposes and variability subject to system sophistication, and key stakeholder beneficiaries. Nonetheless, the case study also indicates that in-house innovation capacity alone is not sufficient to ensure the successful adoption of an RFID system.

The UHJ case study moreover advances the following key insights:

- Some technical limitations – such as error rates of 2-3% – are prohibitively high and unacceptable for some RFID application types (e.g. medication management safety);
- The cost of healthcare RFID hardware can impede the technology’s diffusion (e.g. through prohibitively-high operating costs), and other types of auto-id technology may be viable cheaper substitutes of healthcare RFID for specific tasks;
- Implementing or piloting an RFID application integrating several partly-supplementary technologies may place pilot success at risk; ¹⁹⁵
- Introducing an RFID application which integrates with clinical technologies and care protocols can involve technological compatibility clearance hurdles which may not be resolvable at the organizational level (e.g. lack of OR or MRI clearance can limit RFID use);
- Signal penetration and reading accuracy challenges are valid concerns even for newly-built adopting facilities that have state-of-the-art technological infrastructure;
- Even if unsubstantiated, fears of electromagnetic interference of RFID with any clinical application can lead to the abandonment of an RFID system;

¹⁹⁵ due to enhanced coordination and priority-setting challenges
Patients, and more importantly staff, seem to know little about RFID and need to be informed about its use and implications to avoid system rejection; however, staff and patient training/information may still not lead to universal application adoption and use.

### 3.2. Case 5: University Hospital Geneva (HUG), CH

**Application snapshot**

**Application**: RFID-supported computerized chemotherapy for patient safety (pilot, replaced by DataMatrix).

**Date of implementation/lifespan**: 2005 – 2007.

**Adoption objective**: To centralize the preparation of all chemotherapies administered at UHG, to integrate them into the e-prescription process, and to improve chemotherapy patient’s safety, by matching care giver, patient and medication ensuring the “5 rights”: right patient, right medication, right time, right dose, right route.

**Current use**: replaced by a DataMatrix (2D barcode) system.

**Hospital context**:
- large university hospital;
- older infrastructure;
- pilot covered eight HUG departments administering chemotherapy.

**The technology**

- W-LAN based application, integrated with e-prescription, pharmacy and administrative systems;
- Tags: staff badge - 125 KHz read/write passive tag; 13.56 MHz sticky tags; patient wristband - 13.56 MHz read/write passive tag; medication - 13.56 MHz read/write passive tag;
- Readers and Antennas: standard identification - GS1-128 (formerly UCC/EAN); RFID-enabled PDA (HP iPaQ);
- Software: supplied by Nicecomputing; interfaces to legacy IT system developed in-house.

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196 Information about this application was collected over a one-day site visit at University Hospital Geneva – December 4, 2008, and follow-up conversations with hospital stakeholders which took place between September, 2008 and January, 2009.

197 Please note that it has been difficult to choose which suppliers or providers to be mentioned or not in this document. For example, tag for employee badge has been provided by EM, but the badge supplier has been Cardintell; the payment solution was developed by Omega Electronic for Selecta; the readers for RFID badges are supplied either by Omega Electronic or by Tyco; Tyco supplied also other equipment and software for access control.
The implementation story

In 1995, the four Geneva-based university hospitals merged to become the University Hospitals of Geneva (HUG), a hospitals consortium spread across five campuses with more than 30 ambulatory facilities, 2,000 beds, 5,000 care providers, over 47,000 admissions and 780,000 outpatients’ visits each year. HUG is also the major healthcare facility for Geneva and the bordering region of France.

In 2004, HUG decided to reengineer the chain of processes involved in chemotherapy and to fully capture them electronically from prescription to commissioning and chemotherapy preparation and administration. The Clinical Information Unit, within Service of Medical Informatics (SIM), was charged with the planning, development and piloting of the application; the Oncology Department and the in house pharmacy were the other two key stakeholders.

The intention was to use RFID in combination with existing barcodes to computerize the complete process of chemotherapy – i.e. from tagging raw products as they come to the hospital/pharmacy, quality control, up until treatment administration. This was meant to enable real-time checks and last minute updates on medical results that could stop/change chemotherapy administration and commissioning if last-minute vital information of the patient changed (see Text Box below).

**Figure 4: Old and new chemotherapy process at HUG**

<table>
<thead>
<tr>
<th>Old Process:</th>
<th>New Process:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- A specialist in oncology prescribes a chemotherapy: hand computation of doses, self control of maximal doses</td>
<td>- Electronic prescription</td>
</tr>
<tr>
<td>- Clinician confirms week per week the chemotherapy: protocol is faxed to the pharmacy</td>
<td>- Electronic transmission to the pharmacy</td>
</tr>
<tr>
<td>- Pharmacist produces the chemotherapeutic agents: recipe is completed by pharmacists (template); medication is prepared generally one by one</td>
<td>- No retranscription of important information</td>
</tr>
<tr>
<td>- Clinician or nurse administers the medication: information written on the label</td>
<td>- Automation of the production of the prescription</td>
</tr>
<tr>
<td>- Partial traceability through paper &amp; pharmacy’s internal management application</td>
<td>- Support during the fabrication</td>
</tr>
<tr>
<td></td>
<td>- Control before/during/after the administration</td>
</tr>
<tr>
<td></td>
<td>- Traceability from the prescription to the administration</td>
</tr>
<tr>
<td></td>
<td><strong>Last Mile:</strong></td>
</tr>
<tr>
<td></td>
<td>- Administration phase is critical</td>
</tr>
<tr>
<td></td>
<td>- Wrong administration may cause death</td>
</tr>
<tr>
<td></td>
<td>- Need for:</td>
</tr>
<tr>
<td></td>
<td>o Reliable identification of patient, preparation, intervener</td>
</tr>
<tr>
<td></td>
<td>o Check of adequacy</td>
</tr>
<tr>
<td></td>
<td>o Information when specific controls have to be performed</td>
</tr>
</tbody>
</table>

**Chemotherapies are produced specifically for one patient and can have dramatic effects if errors occur. Providing an effective therapy depends on various data points, including patient-specific data such as temperature, weight or laboratory findings, drug-specific knowledge such as side effects or administration directives among others. The RFID application aimed to improve patient safety by gaining better visibility in key processes and ensuring the “5 rights”: right patient, right medication, right time, right dose, and right route.**
The RFID chemotherapy system pilot was split into two phases:

- Phase 1 - centralization of the preparation of all administered chemotherapies and their integration in the e-prescription process (in an effort to minimize the potential for chemotherapy-related errors); and,

- Phase 2 – introduction of RFID in the medication administration and commissioning process at the patient’s bedside (“last mile”) – via PDA-based link of the ID of the preparation, the patient and the nurse or physician administering the medication.

All partners (patient, nurse, medication) received an individual code that was read by a PDA and validated online according to the information stored in the Hospital Information System (SIH). All codes used the GS1-128 (formerly EAN-128) encoding scheme.

Initially, because of the difficulties of using printable codes and nurses’ ID badges, the labels for chemotherapy preparations were printed at the pharmacy and joined to the raw material required for fabrication, while the patient labels were produced at the admission desks. The solution was intended to enable the use of a single reader at the bedside. This RFID reader (specifically designed for this pilot) was meant to be used with a PDA (iPaq) with WLAN connection to the CPR. Its successful implementation would have allowed to validate “5 rights” checks in real-time and at the bedside.

All devices and data were in compliance with the Laws of the State of Geneva and HUG’s internal rules. No delocalization (tracking) of nurses was used. In the interest of data protection, patient’s personal data belonged to the patient and patient consent was required. Usual role-based access policy to the RFID-enabled chemotherapy process was applied.

Phase 1 of the project was executed as planned. However, a number of problems occurred, due to which in Phase 2 RFID was replaced with a 2D barcode (DataMatrix) solution. These problems were:

- Low user acceptance: Nurses did not like the reader developed for this pilot. It was perceived as too heavy and too big, and required a special pen that often got lost.

- Technical problems:
  - **Reader:**
    - At the time of the pilot, no light handheld reader that could fulfill all requirements (i.e. operating on two types of frequencies, reading RFID and barcodes) was available. The decision to complement tags on staff badges and to develop a special reader delayed the project by 12-18 months. Patient bracelets already standardized and used at HUG either did not have the right size or led to erroneous printing routines (ID printed across 2 labels). Hence they had to be replaced with an RFID-tag embedded bracelet;
    - **PDA WiFi roaming:** PDAs regularly started roaming to find the best WiFi network available which made them initially unavailable for 1 to 3 minutes;
    - **PDA and RFID reader power management:** PDAs automatically changed into sleeping mode if not actively used; yet, when switched on again, their RFID reader re-initialized itself 50% of the time, requiring a time-intensive restart and rebooting of the system which would delay scanning process by 3-5 minutes;
  - **Printers:**

---

198 1D (linear barcodes) were too large, 2D (Datamatrix) were not commonly read by classical readers so required human-readable information), HUG decided to use labels with integrated RFID chips for electronic identification of medications as well as patients (using a wristband with an RFID sticker.)

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1/3 of the printed labels had errors (e.g., code was only half-printed) and could not be used;

- Printer software did not inform when labels were printed erroneously, which considerably diminished confidence in printing process.

Tags:
- Most of the used RFID tags broke easily;
- Tags had reading rates between 95%-98%, deemed prohibitively low;
- Programming RFID chips in labels was difficult; so was getting the right label format;
- The requirement for unique IDs on raw substances was technologically unavailable;

- WiFi: not reliable under Windows CE 4 (2003), and created PDA driver issues.

Application costs

No comprehensive overview of costs could be established. On the basis of interviews, the following estimates could be made:

- Implementation costs:
  o investment budget: € 50,000;
  o hardware costs: € 8,940;
  o training to nurses: 1 hour.
- Maintenance costs: annual operating costs: €24,000. 199

Application benefits

Benefits realized in phase 1 of the project (with RFID):

- The prescription process improved in terms of transparency and readability: In the pharmacy, RFID allowed better management of raw substances, better traceability to increased safety and standardization of the operators’ work;
- Clear benefits have been derived thanks to the standardization, completeness and readability of treatment directives;
- The importance of having accurate, timely and granular information was well recognized and the application process management and audit tools were deemed high.

199 As comparison: DataMatrix: €6,300
However, formalization and validation of all processes, including each protocol, required considerable time investments. Analyzing the complete process of chemotherapy, from the design of a protocol to prescription, production, administration and follow-up as a coherent and shared workflow has produced great benefits in terms of improving both the safety and efficiency of the process, but required substantial amount of staff time, mainly on the side of oncologists.

Implementation success enablers/barriers

HUG interviewees outlined the following key barriers to the success of the pilot:

- the complexity of the process re-organization segment of the pilot was initially underestimated;
- the organizational impact of the pilot was not clearly outlined at its beginning and could have been managed better;
- the centralization of the preparation of all chemotherapies administered at HUG and the e-prescription process required considerable unexpected staff time and resource investments to formalize knowledge and to describe and validate chemotherapy protocols at the pilot’s start;
- the time needed for routine electronic translation of chemotherapy protocol was the main bottleneck for the solution’s take-up by staff: the electronic prescription processes required staff to electronically define and maintain chemotherapy protocols for validation purposes.
- depending on the department, clinicians and nurses differed in their willingness to invest time to transcribe chemotherapy protocols and to maintain e-documentation.

According to respondents, key factors which led to the pilot’s benefits included:

- the system’s conceptual design which led to all patient-related data being in patients’ records, the avoidance of information repetition, or double capture of information; and the creation of a universal log-in for all chemotherapy-related routines;
- the modular architecture (step-by-step integration) approach chosen for the pilot’s hardware and software components.

Key lessons learned

The results of the HUG case study suggest that the MF evaluation structure proposed in Chapter 3 accurately describes in its medication administration process management CB framework the link between the benefits delivered by such systems, their application operational purposes and their system sophistication variability.

Moreover, the case confirms the applicability of the suggested top-, mid- and low-level RFID cost and benefit parameters, and the anticipated difficulties of obtaining baseline measurements and non-monetary measure valuation with respect to medication process management RFID solutions.

The HUG case also highlights the following key lessons on the bounding factors for RFID’s potential in healthcare:
• if an application is designed in isolation – i.e. not considering of the organizational requirements and impacts its introduction will bring – it will only have a limited added value for the organization and may fail either due to high cost and delays in implementation, or due to high end-user time requirements;

• to obtain maximum benefits from complex RFID applications, extensive preparatory work for the formalization and validation of processes is needed;

• insufficient staff and stakeholder co-opting and incentivization can threaten the scalability of an RFID application, unless staff responsibilities are altered to allow for participation;

• the maturity of healthcare RFID technology (e.g. technical limitations of commercially-available solutions, high unit costs) can pose challenges for in-house designed solutions.

The following benefit and cost scalability conclusions can also be drawn on the basis of this case:

• the benefits of RFID-supported medication regiment management solutions are scale-sensitive (proportional to number of patient census) but will be present for any facility; these are primarily associated with improving the quality of patient care (safety and centeredness), but can also lead to reduction in litigation and insurance costs due to their ability to prevent adverse events from occurring;

• the costs of such applications may be more sensitive to enterprise size, but mostly with respect to the number of staff and amount of staff time needed for the design of the application.

4. Real-time portable asset management applications

4.1. Case 6: Wayne Memorial Hospital, NC, USA

Application snapshot

Application: hospital-wide tracking and management of portable assets and equipment.

Date of implementation/lifespan: 2007 - .

Adoption objective: to address the low portable asset visibility WMH was experiencing.

Current use: enables staff to time-effectively locate and service tagged assets and equips WMH management with workflow and potable asset utilization visibility.

Hospital context:

• mid-sized acute care community hospital;

• majority of facilities built between 1970 and 1992;

Information about this application was collected over a two-day site visit at Wayne Memorial Hospital (WMH) - October 21-22, 2008 – followed by follow-up conversations and data exchanges with WMH stakeholders and technology developers at RadarFind Corporation which took place in the two month after the visit.
• early technology adopter;

The technology (at time of assessment):

• real-time location solution, reliant on existing power grid for collector to server signal transmission, provides zonal coverage with choke points at premises boundaries;

• involves 1000 tags, 700 readers, 11 collectors, 1 server with software, no middleware;

• Tags: active (lithium-ion battery, 30 second beaconing, est. 6 year life); identify asset location (some also status: in use, dirty, ready for use); 920 to 928 MHz ISM band (does interfere with the 802.11 (WiFi) 2.4 GHz band); tamper-resistant, dimensions: 2.5"L x 1.25"W x (0.8" to 1.15")D, slide-in locking base, alcohol-resistant adhesive, plastic and steel mounting straps;

• Readers: plug into 120V AC electrical outlets (no Ethernet wiring or IP address required), do not compromise use of the hospital grade outlet, dimensions: 5" W x 12..3" L x 2.25" D, frequency-hopping spread spectrum (resistant to interference, difficult to intercept, and can share frequency with other devices in the band); certification classes: FCC part 15; UL 60950; UL 514-C, and UL 94V-0;

• Collectors: control multiple remote radios for better data transmission, WiFi-based and power-grid based (placed in the IT closets); 100BASE-T Ethernet connection to server, support for IEEE 802.3af (Power over Ethernet); require 1 IP address; dimensions: 6.5" W x 9" W x 2" D;

• Server: Linux engine, fully pre-configured, remotely monitored (requires remote access), 1RU standard server rack mounting;

• Software: browser based (no plug-ins required), supports multiple end-user data views, including touch-screen applications, instead of signal triangulation uses synchronous multiple-input and multiple-output (MIMO) technology, password-secured access to different software levels.

The implementation story

Wayne Memorial Hospital (WMH) is a 316-bed facility based in Goldsboro, N.C. WMH is a full-service hospital and provides all levels of care. It has roughly 1,400 employees, and 125 active members of the medical staff. WMH has an average daily census of 190 patients, and annually registers 15,000 admissions and 48,000 ED visits.

WMH was approached by RadarFind Corporation in 2004 as a beta tester for the firm's RTLS asset tracking solution, based on WMH's:

• size and clinical profile;

• proximity to the provider’s location;

• early technology adopter profile (implementing a barcode-based bedside medication administration system in 2004); and

• simpler management structure, involving fewer levels and a capacity to quickly make decisions.

The key motivational factor for WMH to participate in this trial was the technology’s potential to address the low asset visibility the hospital was experiencing: assets could not be (easily or occasionally at all) located for preventive maintenance, staff reported asset shortages, and asset accumulation in hospital hallways created potential threats for patient safety.
WMH and RadarFind Corporation spent nearly two years developing the first version of the RFID application, with WMH providing application software design input. During this process RadarFind Corporation engaged in extensive interviews with the key stakeholder groups expected to use the system at WMH, in order to gain understanding of how to apply the technology behind "RadarFind" to a hospital non-clinical environment (in particular behind the scene operation of a hospital).

The key implementation issues WMH and RadarFind Corp. confronted were:

- who and how to access the application;
- categories of equipment for searching, e.g., whether you want to group all available equipment in some way, or it would be better to just have a long list of assets;
- nomenclature: a need to define a common equipment and hospital area vocabulary\(^{201}\);
- maps/floor plans vs. lists;
- which items to tag; status vs. non-status tags;
- reports – utilization data;
- placement of readers – exits, loading docks, dumpsters;
- equipment inventory – finding assets to be tagged.

Hence, significant effort went into identifying the data utilization capacity the application needs to fulfill – a key WMH input component. Once the technology vendor understood why certain functionality was desired, it was easily inputted in the software. There was also a need for users to understand the technological limitations.

Considering staff technical and general literacy and comfort level, maps were chosen (see below). Grouping assets per category, to enable easy viewing, was decided to be more useful. Ultimately a unified lexicon of the different assets which were to be tagged was developed. For cost considerations, and to make use of already installed systems, assets also carried a 2D barcode through which their serial number and manufacturer were identified. To support the utilization value of the system, asset tags were equipped with a manually-operated asset status switch identifying each asset as “in use”, “dirty”, or “ready for use”. Tagged assets included infusion pumps, diagnostics machines, blood warmers, computers on wheels, and wheelchairs.

\(^{201}\) Care-providers develop their own specialized languages and lexicons to help them store and communicate general medical knowledge, patient-related information, and even asset or hospital location information efficiently. Such terminologies are characterized by a significant amount of implicit knowledge. The use of a standardized language, instead, decreases patient’s risk for injury by eliminating inconsistency of language or meaning.
In Nov. 2006 version 1 was launched in several units. In early 2007 the it went live hospital-wide. The scaling was managed by an application "developers" team which was formed during the initial development of "RadarFind".

To ensure the safety of the system, interference tests were carried out. None was positive.

One problem encountered during the scaling was occasional signal interferences due to the architectural design of WMH (where a floor protrudes) - readers picking up tag signals originating at a different floor (either below or above the reader). Once, the readers were adequately re-positioned no such errors repeated. Processes were not disrupted.

A more substantial challenge that needed to be overcome was staff use and interaction with the application. Targeted system users were initially reluctant to make effective use of the application: asset tags status was frequently found not to correspond actual asset status, and work-around were starting to develop. To discourage both, and secure that maximum values derived from the solution, weekly management meetings started to include a session in which unit manager reported on these discrepancies and on their staff’s feedback on the application. Set in a positive context, this quickly resulted in a constructive competition. By mid 2007 no asset tag status and actual status discrepancies could be found.

In early 2008 the application encountered a problem with tag battery life. Active tags beaconed every 4 seconds exhausting their batteries. The batteries were replaced with comparable ones engineered to beacon every 30 seconds (expected to allow a five- to six-year battery life). This led to one of the units loosing confidence in the system and abandoning use of it (Central Sterile).

There have been two hospital-wide training sessions since the hospital-wide launch of the application, the last occurring in the autumn of 2008 aimed at re-booting staff use of the
application. The latter included a $50 gas card treasure hunt component, and was evaluated as successful. In addition, smaller prizes and tokens were given away at additional booster sessions.

At present, the application is used by clinical engineers, environmental service staff, nurses (including nurse supervisors and clinical administrators), central sterile staff and the WMH VP of Operations. An expansion of the system to include staff and patient tracing for workflow and process optimization is under development.

Application costs

The annual implementation and maintenance costs associated with “RadarFind” are shown in the table below. Total fixed costs of implementation of hardware, software and training are $273,600. Variable implementation costs amount to $25,925. Operational fixed costs of software and backups are estimated at $25,000; and annual variable operational costs – including labor are $20,860.

<table>
<thead>
<tr>
<th>Table 4: Wayne Memorial Hospital: application costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
</tr>
<tr>
<td>Implementation fixed costs</td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Total implementation fixed cost</strong></td>
</tr>
<tr>
<td>Implementation variable costs</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Total implementation variable cost</strong></td>
</tr>
<tr>
<td><strong>TOTAL IMPLEMENTATION COST</strong></td>
</tr>
<tr>
<td>Ongoing fixed costs</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Total ongoing fixed costs</strong></td>
</tr>
<tr>
<td>Ongoing variable costs</td>
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<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Total ongoing variable costs</strong></td>
</tr>
<tr>
<td><strong>TOTAL ONGOING ANNUAL COSTS</strong></td>
</tr>
</tbody>
</table>

Note: Ongoing variable costs include Clinical Engineering staff time spent maintaining and further developing the application, and repairs of system hardware.
Application benefits

Collected case study data indicates that the benefits of this RFID-based RTLS asset management solution lie primarily in reducing the cost of healthcare delivery – most sizably in terms of forgone capital outlays and labor costs. Nonetheless, it also has ramifications for the quality of healthcare delivery. These are explored in detail below.

Cost of care gains

Table 5 below gives a summary of the capital expense and operational cost savings WMH realized in fiscal year 2007 using "RadarFind". Annual operating savings arise from cost avoidance for external partly service contracts and maintenance on the 53 pumps which were not purchased. The calculation does not include any time spent by CED on the maintenance of the IV pumps. This is partially to compensate the fact that saved time is spent on "RadarFind" maintenance and running.

<table>
<thead>
<tr>
<th>Table 5: Wayne Memorial Hospital: capital expense savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in infusion pump purchases: 303,147</td>
</tr>
<tr>
<td>Capital purchase savings</td>
</tr>
<tr>
<td>Annual operating cost savings</td>
</tr>
<tr>
<td>Reduction of bladder scanners: 24,000</td>
</tr>
<tr>
<td><strong>Total realized capital expense reduction 327,147</strong></td>
</tr>
</tbody>
</table>

Table 6 in turn, summarizes the efficiency gains achieved through WMH's Environmental Services department through this application.

<table>
<thead>
<tr>
<th>Table 6: Wayne Memorial Hospital: Environmental Services wheelchair process improvements (based on Jan-June 2007 data)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wheelchair transports</strong></td>
</tr>
<tr>
<td>Time needed to respond to a nurse call for patient transport within WMH</td>
</tr>
<tr>
<td>PRE-pilot measure: 40 min on av. per patient</td>
</tr>
<tr>
<td>POST-pilot measure: 15 min max per patient</td>
</tr>
<tr>
<td>Change: 63% (25 min) time saved per patient transport</td>
</tr>
<tr>
<td>Wheelchair location time (WLT)</td>
</tr>
<tr>
<td>PRE-pilot measure: 25 min on av. per chair</td>
</tr>
<tr>
<td>POST-pilot measure: 10 min max per chair</td>
</tr>
<tr>
<td>Change: 60% (15 min) time saved per wheelchair location</td>
</tr>
<tr>
<td>Annual cost of WLT * $110,705</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Wheelchair inventory</strong></td>
</tr>
<tr>
<td>Wheelchair round-up</td>
</tr>
<tr>
<td>PRE-pilot measure: 16 hr/mo</td>
</tr>
<tr>
<td>POST-pilot measure: 1.25 hr/mo</td>
</tr>
<tr>
<td>Change: 92% (14.75 hr) time saved per month</td>
</tr>
<tr>
<td>Equipment inventory and cataloging for servicing</td>
</tr>
<tr>
<td>PRE-pilot measure: 12 hr/mo</td>
</tr>
<tr>
<td>POST-pilot measure: 5 min/week</td>
</tr>
<tr>
<td>Change: 97% (11.7 hr) time saved per month</td>
</tr>
<tr>
<td>Annual wheelchair inventory labor charges</td>
</tr>
<tr>
<td>PRE-pilot measure: FY’06</td>
</tr>
<tr>
<td>POST-pilot measure: 2,630 FY’07</td>
</tr>
<tr>
<td>Change: 56% ($3,328) annual budget saving</td>
</tr>
<tr>
<td><strong>Wheelchair purchase budget</strong></td>
</tr>
</tbody>
</table>

267
<table>
<thead>
<tr>
<th>Annual capital expense budget</th>
<th>26,000 FY'06</th>
<th>13,000 FY'07</th>
</tr>
</thead>
</table>

Additional cost of care benefits realized with the application include:

- 50% reduction in labor costs spent on locating beds (associated with staff time utilization improvement, and more time available for PM on other equipment);
- avoidance 6 to 8 hours of one Clinical Engineering staff time monthly spent on location assets for routine inventory;
- avoidance of 3 to 6 hours of one Medical Floor Nursing staff monthly time spent on location assets to maintain par levels;
- asset loss avoidance ($3,000 for IV pumps, $500 for wheelchairs).

Quality gains:

- a reliable and highly-beneficial management decision support tool (via the different analytical capabilities embedded in the application);
- better compliance with preventive maintenance (PM) standards and regulations (improved compliance with Joint Commission PM from 96% to 100% of all equipment undergoing PM) – leading to improved patient safety and sustained high hospital accreditation;
- reduction in risk of patient safety adverse events associated with 20 to 30 min delay of patient care (due to inability to locate a needed asset);
- easy management of recalls;
- improved infection control capabilities (through the ability to more effectively locate and monitor equipment that has come in contact with patients carrying antibiotic-resistant organisms);
- improved patient experience and avoidance of procedure delays;
- improved nurse satisfaction with the reduction in non-care-specific tasks required of them;
- elimination of asset hording, preventing potential safety threat conditions arising from the clutter WMH was experiencing;
- more timely care delivery due to savings in time for patient transport;
- better disaster preparedness (due to ability to quickly locate assets in case of emergency).

Implementation success enablers/barriers

WMH end-users and developers regarded the application as a success. The factors interviewees highlighted as responsible for this are:

- Sustaining the innovation at a baseline level requires a commitment to training new staff on how to use the system as part of their on-boarding process;
The value of the system is truly achieved/sustained by analyzing the granular time-stamped data on a daily basis and bringing together clinical and auxiliary staff managers to discuss it;

Identifying the internal stakeholder responsible for maintaining the system, an “owner”, is of critical importance for steering the implementation and sustained value-added of the application;

Addressing the special needs of staff with low overall or low technical literacy: one of the key users of the system – the Central Sterile Department (CSD) – whose use of the application suffered strongly from the RFID tag battery life issues which occurred in January – June 2008; as a result of their disillusionment with the system and the technological challenge it posed, as of October 2008 CSD had not resumed its use of the system.

Simultaneously respondents identified the following as likely to negatively affect the value-added of advanced real-time portable asset applications:

- not embracing the process redesign opportunity the adoption of such systems brings – i.e. not undergoing a detailed cross-department review of the workflows which will be affected by the application, and not inviting all stakeholders to brainstorm how these may be improved;

- not developing a unified vocabulary – on hospital zones, assets, uses – to be embedded in the application and to replace department-level labels used until then.

Key lessons learned

The results of the WMH case study suggest that the portable asset RFID evaluation structure proposed in Chapter 3 accurately describes the link between the benefits of healthcare RFID portable asset management systems, their application operational purposes and their system sophistication variability.

In addition, the WMH case study outlines the following key factors as responsible for deriving value-added from an RFID application:

- having a strong implementation team integrating hospital leadership and all hospital stakeholders in all stages of the pilot: implementation involves leadership of department chairman and department directors, the participation and support of the IT dependent, as well as of auxiliary departments in order to develop new communication methods;

- tailoring an RFID application to a client’s specific needs – through repeated vendor and user interaction – to create a high information- and system-value application;

- working with a proactive technology provider that stages well the application’s roll-out;

- having an organizational application "owner" willing to oversee the development and serve as a local issue resolution center for the application;

- ensuring remaining staff’s sustained engagement and buy-in through periodic re-training sessions;

- understanding that task automation without consideration of the human element it still involves is insufficient to secure that an application would be beneficial (as was the initial case with the asset status function of the application);
- responding to after-full-scale deployment end-user feedback to ensure the longevity and continued meaningful use of the application (as opposed to work-around creation and phasing-out).

The WMH case study also suggests that while this application can deliver time savings for nursing staff as well as for non-clinical staff, nursing staff time freed for patient care is proportionally much slower than the time gains reaped by engineering and environmental service staff. Thus, the main impact of this application is on reducing the cost of care; quality of care gains are secondary.

Furthermore, respondents’ feedback on Table 31: Benefits of RFID mobile asset management applications that are dependent on system sophistication (presented in Section 3.1.) in combination with benefit data identified in the WMH case study, allow the following benefit attribution table to be constructed by expanding Table 31 with information on the size of the benefits each key stakeholder group derived from specific engineering functions the RFID system performs\(^{202}\).

\(^{202}\) The limited quantitative data available in the other cases did not permit the construction of such tables to for the other systems which were evaluated in the case studies.

<table>
<thead>
<tr>
<th>Application Operational Purposes, Benefits and (Hypothesized) Beneficiaries</th>
<th>&quot;Basic&quot; system</th>
<th>&quot;Adv.&quot; system</th>
<th>&quot;Comp.&quot; system</th>
<th>Stand-alone functionality contribution to maximum benefit obtainable from a comprehensive system (per beneficiary)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identify asset location on chokepoints</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidental asset loss avoidance/theft</td>
<td>Biomedical Engineering (Biomed)</td>
<td></td>
<td></td>
<td>to Biomed: 15% of max benefit</td>
</tr>
<tr>
<td><strong>Identify asset location continuously (zonal)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faster asset location for servicing, annual preventive maintenance or recall (utility loss due to lack of info on status)</td>
<td>Biomed</td>
<td></td>
<td></td>
<td>to Biomed: 15% of max benefit</td>
</tr>
<tr>
<td>Faster asset location for immediate use (utility loss due to lack of info on status; can lead to repeated hoarding)</td>
<td>Nursing; Environmental Services (ES)</td>
<td></td>
<td></td>
<td>to Nursing: 30% of max benefit; to ES: 10% of max benefit</td>
</tr>
<tr>
<td>Drop in time needed to respond to a nurse call for patient transport within hospital</td>
<td>ES</td>
<td></td>
<td></td>
<td>to ES: 5% of max benefit</td>
</tr>
</tbody>
</table>

Table 48: Asset management solutions: findings on operational purpose benefit attribution per beneficiary and system sophistication
### Application Operational Purposes, Benefits and (Hypothesized) Beneficiaries

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Stand-alone functionality contribution to (per beneficiary)</th>
<th>&quot;Basic&quot; system</th>
<th>&quot;Adv.&quot; system</th>
<th>&quot;Comp.&quot; system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to identify assets used on infectious patients, reducing the spread of contagious and hospital-acquired infections and improving safety of patient care</td>
<td>All departments; Patients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detect asset status</td>
<td>Management</td>
<td>Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital outlay and operation costs reductions through better understanding of asset utilization patterns and facility needs</td>
<td>Biomed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substantial staff time reduction in search rounds across facility for asset servicing, annual preventive maintenance or recall</td>
<td>Biomed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to repeatedly carry out preventive maintenance of full asset fleet, hence improving regulatory compliance</td>
<td>Biomed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assets ready for use are easy to locate when needed (reducing nurses' unproductive time)</td>
<td>Nursing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substantial staff time reduction in time spent looking for assets in routinely or in round-up</td>
<td>ES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to repeatedly carry out preventive maintenance and infection control of full asset fleet, thus prolonging assets' useful life</td>
<td>ES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce patient waiting time at point of care</td>
<td>Patients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce the number and duration of routine search rounds across facility to collect used assets for sterilization</td>
<td>Central Sterile (CS)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **All departments; Patients**
- **Management**
- **Biomed**
- **Nursing**
- **ES**
- **Patients**
- **Central Sterile (CS)**
4.2. Case 7: Royal Alexandra Hospital, UK

Application snapshot

*Application:* hospital-wide location and tracking of portable assets and equipment

*Date of implementation/lifespan:* 2007-

*Adoption objective and Current use:* need to reduce clinical and technical staff time spent on locating portable devices.

*Hospital context:*

- large district general hospital;
- built in 1986.

*The technology (at time of assessment):*

- 802.11 WiFi and wLAN-based application, not integrated with clinical systems, comprising approximately 1,000 tags and 40 readers;
- Tags: Aeroscout T2/T3 tags (active RFID tags placed on portable assets);
- Readers: Power over Ethernet (PoE)-based active readers, using signal triangulation; as well as passive choke-point readers (1242 and 1130 CISCO wireless access points); one 2700 Wireless Location Appliance (250 Client Licence)
- Antennas: 1/4 wave whip antennas supplied by CISCO;
- Software and Server: all data stored in a single MS Internet Information Server; 2 more servers run the software (Wireless Control Software and Airetrak ResourceView system); SQL-based software, which integrates with the Cisco’s 3350 Mobility Service Engine (MSE).

The implementation story

The Royal Alexandra Hospital (RAH) is a large district general hospital (over 650 beds), part of NHS Greater Glasgow and Clyde, situated in Paisley. It serves a population of about 200,000 people from across Renfrewshire with a mix of urban and rural populations.

RAH had an identified need to restructure its portable medical device management approach. Two key concerns motivated it:

- technical staff spent up to one man-year each year looking for misplaced portable medical devices that needed to undergo planned preventative maintenance (every 3, 6 or 9 months for different assets);
- compliance with scheduled inspection targets was not always up to par;
- clinical staff experienced delays in care delivery due to difficulty in locating portable devices for immediate use;

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203 Information about this application implementation was collected through a series of interviews and data exchanges with the former Royal Alexandra Hospital RFID pilot leader which took place between October, 2008 and February, 2009.

204 See http://www.nes.scot.nhs.uk/sfas/Prog_by_Region/West/hospitals/royal_alexandra/.
as a result, critical portable medical equipment was frequently hoarded by nurses (i.e. had low utilization).

In response to these challenges, in 2007 the Head of Clinical Engineering was placed in charge of a pilot aimed at creating an RFID-based portable asset tracking system which would help clinical engineers to locate portable devices on RAH’s medical floor. The project was financed by RAH’s Health Board and IT budget.

The goals set for the pilot were:
- to tag IV pumps safely and reliably;
- to successfully locate them once re-introduced in the hospital environment; and,
- to make the process of asset maintenance more efficient and effective (i.e. workflow optimization).

The pilot took place on RAH’s Medical Floor. A small implementation team was created, comprising:
- 5 RAH representatives: Head of Clinical engineering, 2 clinical engineers, 2 nurses; and
- 5 RFID technology provider representatives: a project manager, a system architect and 3 engineers.

During its first pilot stage, the team tested two different types of RFID applications under different usage and environment scenarios. The pilot evaluation was based on three measures of interest:
- equipment utilization;
- availability of medical devices at the point of need; and,
- reduced burden on technical staff locating medical equipment for routine scheduled maintenance.

RFID model A was not considered to be successful mainly due to the varying signal levels from the tags when attached to different medical devices. The manufacturer of the equipment for RFID model A was also not able to supply different tags for asset/equipment tracking using the type of readers installed. Ultimately, the pilot team decided that it is not economically worthwhile to pursue solutions to the problems and difficulties encountered with the tags and readers within RFID model A, and these were replaced by using equipment from a second manufacturer. For RFID model B, the tags used were specifically designed to work with equipment that had an outer metal casing. This proved to be more successful. Thus, the fine-tuning of the system, and the decision to abandon one of the technologies, as well as ensuring staff buy-in were described as “protracted and heavily time-consuming.” Nonetheless, RFID model B was later deployed also in 7 acute inpatient wards, and the ED.

As developed, the application focuses exclusively on assets the location of which system users see – via a web-based portal - as a real-time map of the hospital. The software functionalities of the application include detailed reporting and historical information, focused on auditing the use and distribution of devices, and an easy-to-use administration tool allowing users to define zones and to assign RFID tags to assets. At the time of the case study, the application was used only by clinical technicians, with nurse access in the pilot stage. Also, it only covered critical portable assets (such as IV pumps), since they were the scarcest and most needed asset at RAH (totaling
roughly a 1000 for the entire facility, and being subjected to hoarding by nurses). There was a
general plan to expand the application’s coverage over all movable assets.

Application costs

The total implementation cost of this application, based on RFID model B, was £210,350. Its
annual maintenance cost is £35,600. The table below provides the cost-breakdown.

<table>
<thead>
<tr>
<th>Total Implementation Cost</th>
<th>£210,350</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software costs</td>
<td>£44,500</td>
</tr>
<tr>
<td>Hardware costs</td>
<td>£81,900</td>
</tr>
<tr>
<td>RFID provider team staff time cost</td>
<td>£34,950</td>
</tr>
<tr>
<td>RAH team staff time cost (system integration)</td>
<td>£49,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual Maintenance Cost</th>
<th>£35,600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software maintenance contract</td>
<td>£8,900</td>
</tr>
<tr>
<td>Hardware costs</td>
<td>£10,700</td>
</tr>
<tr>
<td>Internal support and development costs</td>
<td>£16,000</td>
</tr>
</tbody>
</table>

Application benefits

The main benefits which were documented after the pilot’s completion included:

- improved equipment utilization (e.g., for infusion devices it was 25% at baseline);
- availability of medical devices at the point of need (minimize care delay);
- reduced time burden on technical staff locating medical equipment for routine scheduled
  maintenance (down from 15 min. per portable medical device, which relates to 250 lost
  man-hours at a cost of £10,000 annually, and does not include the time involved in trying
  to locate medical devices that have become ‘lost’ in the equipment management system,
  of which, in a typical district general hospital, there may be up to 25 min. at any one
  time);
- improved compliance with scheduled inspection targets (up from 20-30% at baseline);
- reduced consequent health and safety risks of failure to meet scheduled inspection plans;
- improved equipment tracking, training and use across departments, and effective medical
device recall.

According to the pilot leader, these can be summarized in order of importance/size as:

- labor costs (reduced asset location and paperwork on un-located assets time), and
- foregone capital costs (on unnecessary assets or assets replacing un-locatable
  equipment).

Overall, however, the application was judged to be too early in its hospital-wide deployment to
have been evaluated comprehensively, hence “figures need to be treated with caution.”
Implementation success enablers/barriers

As key factors which led to the success of the pilot, and its scaling, interviewees highlighted:

- the cost of the technology, in particular tags (with tags currently costing about £40); and
- its potential to deliver positive ROI for performance measures of interest to the NHS – e.g., diagnostic testing patient waiting time decrease.

The factors identified threats to the success of the pilot were:

- previous unfavorable experience with IT among the end-users of the technology which made them skeptical to the potential benefits and additional burden it may cause;
- reliability difficulties during the piloting and testing of the two RFID hardware alternatives: probably due to the casing of medical device one of the technologies experienced high tag signal interference;
- the wide variability across different active RFID systems—in their data capturing and transmission mechanism, capabilities, requirements and performance – and hence lack of cross-operability; and,
- the different lifespan and need for re-setting of different models of RFID hardware during the pilot.

Key lessons learned

The results of the RAH case study suggest that the portable asset evaluation structure presented in Chapter 3 accurately describes the link between the benefits of healthcare RFID portable asset management systems, their application operational purposes and their system sophistication variability.

Furthermore, the case confirms the applicability of the suggested top-, mid- and low-level RFID cost and benefit parameters with respect to portable asset management RFID solutions.

In addition, RAH interviewees drew the following conclusions from their experience:

- well designed and implemented RFID asset management applications can deliver substantial staff time saving, as well as equipment capital and maintenance cost saving;
- while the key benefits of portable asset management solutions lie in cost-containment, if quality-improving and assuring processes with respect to assets are not already in place in healthcare facilities, these systems can also lead to substantial quality of care gains;
- although passive RFID tags are smaller and cheaper, active RFID systems are actually cheaper (e.g. as their readers are cheaper) and easier to install (especially as stand-alone systems);
- to determine whether and how to adapt processes requires an automated way to measure where and when equipment is across a healthcare facility; such information is a critical precondition for improving workflow and reducing care delivery cost;
- developing a successful hospital-wide RFID asset tracking system requires significant initial work - to develop, test and install a system that is reliable and meets both clinical and operational requirements;
• there are both operational and clinical considerations when investing or expanding a system to accommodate real-time location; by considering both short- and long-term needs, an organization can ensure today’s investment won’t limit future potential.

5. Hospital garment tracking application

5.1. Case 8: University Hospital Geneva (CH)205

Application snapshot

Application: RFID-enabled staff and patient garment tracking.

Date of implementation/lifespan: 1995 - .

Adoption objective and Current use: RFID-enabled system manages the daily collection, ironing and redistribution of garments across 4 sites and 7 distributors.

Hospital context:

• large university hospital;
• Department of Logistics has ownership over the application’s planning, development and piloting;

The technology (at time of assessment)206:

• WiFi-based application, not integrated with clinical systems.
• Tags: staff badge - EM 4150, 125 kHz, read/write tag; RFID tag garment tag - 13.56 MHz read-only passive tag
• Software: supplied with equipment; interfaces to legacy IT system developed in house; supports automatic distribution facilities (24/7 service).

The implementation story

As outlined in Case 5 above, in 1995 the four Geneva-based university hospitals merged to become the University Hospitals of Geneva (HUG). The merger confronted HUG with a specific

205 Information about this application was collected over a one-day site visit at University Hospital Geneva – December 4, 2008, and follow-up conversations with hospital stakeholders which took place between September, 2008 and January, 2009.

206 Please note that it has been difficult to choose which suppliers or providers to be mentioned or not in this document. For example, tag for employee badge has been provided by EM, but the badge supplier has been Cardintell; the payment solution was developed by Omega Electronic for Selecta; the readers for RFID badges are supplied either by Omega Electronic or by Tyco; Tyco supplied also other equipment and software for access control.
logistical problem: the management of working garments within and across the newly-merged hospitals.

At that time a new building was also built, and included plans for cloak rooms and working garment distribution service with a capacity to serve 3,000 employees. Yet HUG was interested in finding a more cost effective (less labor intensive) distribution system for working garment that would allow to automate and streamline the distribution service.

To address this challenge HUG adopted and gradually elaborated an RFID-based garment tracking application. RFID was chosen as the most suitable technology to track and trace working clothes across HUG's different facilities because it:

- operates fast;
- does not require line of sight; and,
- allows the simultaneous detection and processing of a large number of items.

The Department of Logistics (DOL) – responsible for managing HUG's laundry service, provision of clothing and household linen, catering, cleaning, transportation, distribution and warehouse, reception and information services – took charge of the development of the RFID application and its piloting.

The application’s aims were to fully automate working garment distribution centers and to provide an effective personalized 24/7 service to employees. The application was launched in 1996. Following the success of the pilot, the laundry service set off on a multi-annual plan to:

- extend the concept of automatic distributors to each node of the distribution process;
- replace the old ironing installation (including store and conveyors) at the laundry by a modern one.

This second goal has given the opportunity to automate the production and to connect both processes. During its lifetime it gradually expanded from DOL to all sites at HUG.

In 2007, DOL replaced part of the equipment and fitted patient garment with an RFID tag that is attached to the garment throughout the whole process. This fully automated the distribution process, increased efficiency and allowed garments to be distributed across all sites and not as done previously to constrain it to specific locations/site.

Today this RFID solution is used to manage the daily collection, ironing and redistribution of garments across 4 sites and 7 distributors (12 lines of distribution for 6,600 users), allocating 28,000 garments per week. Data stored on individual tags does not contain person-identifiable information; it only stores the item ID. Laundry service data is only visible and accessible for relevant DOL personnel.

Application costs

No baseline or application evolution outcome data is available for this solution. This is due on the one hand to the merger which created HUG207. On the other, in 1995 when the application was commissioned, HUG had no public tendering obligations. After 1996 HUG introduced tendering obligations for investments exceeding €240,000. The cost of the distribution system was under this level; only the replacement of the old ironing installation requested a tendering procedure.

On the basis of in-depth interviews, the following cost estimations could be made:

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207 Finance came from different budgets and it is impossible to reconstruct ex-post, hence does not allow to identify overruns/underruns.
• Overall budget: approximately €2.1 million in 10 years (distributors 60%, laundry 40%)
• Maintenance costs (distributors only) approximately 10,000 EUR annually
• Management costs: not accounted for

Application benefits

The return on investment (ROI) period for this application was suggested to stand at 1.5 to 3 years, and to be primarily attributable to savings in full-time employees (FTEs).

The largest source of savings was the replacement of all garment distribution kiosks or semi-automated systems at HUG by automated systems. The specific monetary or FTE equivalent of this saving category is unknown.

The application’s benefits can be summarized as follows:

• Cost gains:
  • reduced garment stock, resulting in up to a 30% reduction in garment capital outlays;
  • improved purchase management capacity;
  • ability to invest in two-piece clothing, increasing staff and patient satisfaction.

• Quality gains:
  • improved quality of services;
  • ability to monitor how many times an item has been washed or worn, hence verifies whether garments would fulfill quality claims made by suppliers;
  • improved availability of service (24/7).

Also, RFID provided new data and allowed to learn about the life-cycle and quality of clothing; and to review purchasing decisions. HUG never analyzed behavioral data in detail, but observed that the simplicity of the system made it easier for people to change working garments. The improved efficiency of the system also provided the financial rationale for purchasing 2-piece patient garments.

Implementation success enablers/barriers

The key enabling factor for the success of this application, according to respondents, were the satisfactory bulk reading rates the technology supported: 99-99.5%. Its user-friendliness, efficiency and accessibility were the three other factors seen as pivotal for its success.

Inversely, respondents identified the following issues as critical challenges for deriving value from the application:

• Error management: The garment is rejected if its tag has not been read. Rejected garment can be easily identified and tags replaced. However, the real difficulty lies in finding out which tag was lost. Only with time, ‘silent’ tags can be identified;
• Tags cost on average 1EUR: In order to account for lost items and to have a better knowledge of the circuit ‘washing/distribution/storing/using/back to laundry’, their relatively high cost made it prohibitively expensive to tag low-cost items, even though they were very often “lost” (e.g., washcloth);
• Difficult to receive suitable prototypes for testing.

Key lessons learned

Interviewees suggested that if healthcare delivery organizations aim to ensure that similar, logistics-focused, RFID system deliver value-added they should “use what is readily available: make use of existing infrastructure (barcode on supplies) and combine it with RFID.”

The main risk factor, they identified, is the lack of shared knowledge between hardware and software developer. Thus, technical problems at the “boundary” between two parts of the process have proven difficult to be solved.