



RFID Uses, Benefits, and Costs: Literature Review and Key Informant Interviews

This research was supported by IntelliGuard and The Axia Institute – Michigan State University

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The healthcare industry is critical to the wellbeing of any nation, as it has the potential to affect not only the health and safety of its citizens, but also the costs associated with a nation's overall healthcare offerings. This is particularly important in the U.S., which "spends more per capita on healthcare than any other developed nation."¹ As such, healthcare providers, particularly hospital systems, are seeking processes and technologies that will enhance patient care while also reducing costs. One technology that has continued to show benefits and potential cost reduction opportunities in healthcare is Radio Frequency Identification (RFID). RFID allows digital data to be incorporated into tags or smart labels and enables the data to be transmitted to a reader through radio waves without line-of-sight, as required by traditional barcode technology. Data can contain unique identification information, and tags can be active (e.g., having their own power source to communicate with readers) or passive (e.g., activate when within the range of a reader's antenna).

This research report was developed to understand the current state of RFID usage in hospital systems and its associated costs and benefits. The first portion of this report summarizes a structured literature review (SLR) undertaken to understand what has been published in academic literature regarding RFID applications. The SLR highlights what has and has not been examined with respect to RFID in the literature. The second portion of the report provides an overview of in-depth, qualitative interviews with key informants across hospital supply chains using RFID to understand the specific applications as well as associated costs and benefits. Key trends, considerations, and opportunities are discussed and a potential framework for assessing the return on investment (ROI) of an RFID application is provided.

RFID Structured Literature Review

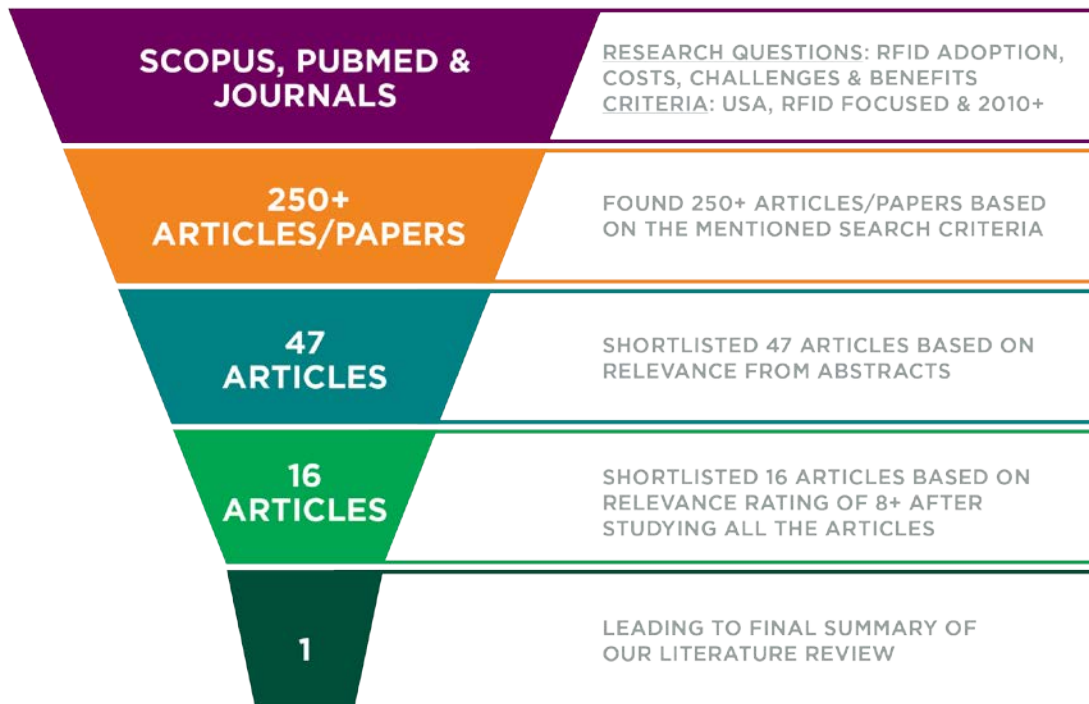
This research began with an SLR, which is increasingly important in healthcare research to provide updates and guidelines to healthcare providers as well as to identify/justify areas of research for academicians and grant agencies.ⁱⁱ SLRs provide a “means for identifying, evaluating, and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest” and are used in healthcare settings to summarize treatment/technology benefits and limitations, identify research gaps and provide frameworks for engaging in new research activities.ⁱⁱⁱ

SLRs begin by creating a review protocol, including identifying literature search strategies and understanding the specific research questions to be addressed. For this research, we predominantly utilized Scopus and PubMed to conduct the literature search and considered the following research questions:

- How has RFID been adopted in hospital systems?
- What are the benefits (direct and indirect) associated with RFID (compared to barcodes/no technology)?
- What are the barriers/challenges associated with the adoption of RFID?
- What are the costs associated with RFID?

Figure 1 provides an overview of the protocol followed, which resulted in the capture of over 250 articles based on our initial search criteria, as is consistent with recommended SLR processes. Each article’s abstract was reviewed to determine its potential fit with the research questions and broad research interest. From this review, we shortlisted 54 articles that were further assessed. This resulted in 47 articles that were deemed important to the study. Detailed summaries of these articles were conducted, and each article was ranked for relevance. The 16 articles ranked highest (8 or higher on a 10-point scale) were further evaluated and represent the majority of the literature review results described in this report. The Appendix lists the full references for the 16 articles.

Figure 1: Graphic View of the RFID Structured Literature Review



RFID Applications and Benefits

The literature predominantly focused on asset tracking or inventory management (e.g., medications and/or supplies) applications with fewer articles examining patient/personnel tracking applications. With respect to RFID benefits associated with these applications, we identified seven main benefit areas described in the literature: asset management, authenticity management, cost reduction, information management, inventory management, patient management, and process management. Table 1 summarizes these seven benefit areas.

Table 1: RFID Benefits

Asset management	<ol style="list-style-type: none"> 1. Asset tracking: Searching, tracking, and identifying machinery/equipment for better visibility. 2. Asset utilization: Tracking and understanding the utilization rate of assets for improving efficiency/assessing conditions through improved scheduling and planning processes. Decrease in asset over-purchases.
Authenticity management	<ol style="list-style-type: none"> 1. Counterfeit: Ensuring authenticity through tracking prescriptions, drugs, blood, etc., through the value chain. 2. Recall: Better management of medication recalls.
Cost reduction	<ol style="list-style-type: none"> 1. Assets: Lowering costs by minimizing shrinkage and improving utilization. 2. Inventory: Reducing costs through better inventory management associated with storage, labor, tracking of inventory, etc. 3. Workforce: Reducing staff, workforce, and administration tasks. 4. Other: Creating a lean system.
Information management	<ol style="list-style-type: none"> 1. Interoperability: Ensuring the ease of interoperability among the data sharing points by reducing manual interventions and data collection points. 2. Usage: Enhancing data utilization among several systems with ease for integrated support and planning, enhancing interdepartmental communication.
Inventory management	<ol style="list-style-type: none"> 1. Tracking: Improving materials tracking, reducing theft and shrinkage, enhancing misplacement detection without requiring line of sight. 2. Data: Improving inventory management, timely replenishment, and greater control over inventory.
Patient management	<ol style="list-style-type: none"> 1. Safety: Providing continuous patient monitoring, reducing misidentification errors, and improving monitoring of vital signs such as temperature. 2. Satisfaction: Reducing clinical trials, eliminating excess paperwork, and decreasing wait times. 3. Patient tracking: Tracking and identifying the patients to improve/synchronize the flow of medical procedures, avoiding mishandling or misidentification.
Process management	<ol style="list-style-type: none"> 1. Efficiency: Improving process efficiency and productivity through highly coordinated scheduling and planning. 2. Risk: Increasing the ability to detect errors.

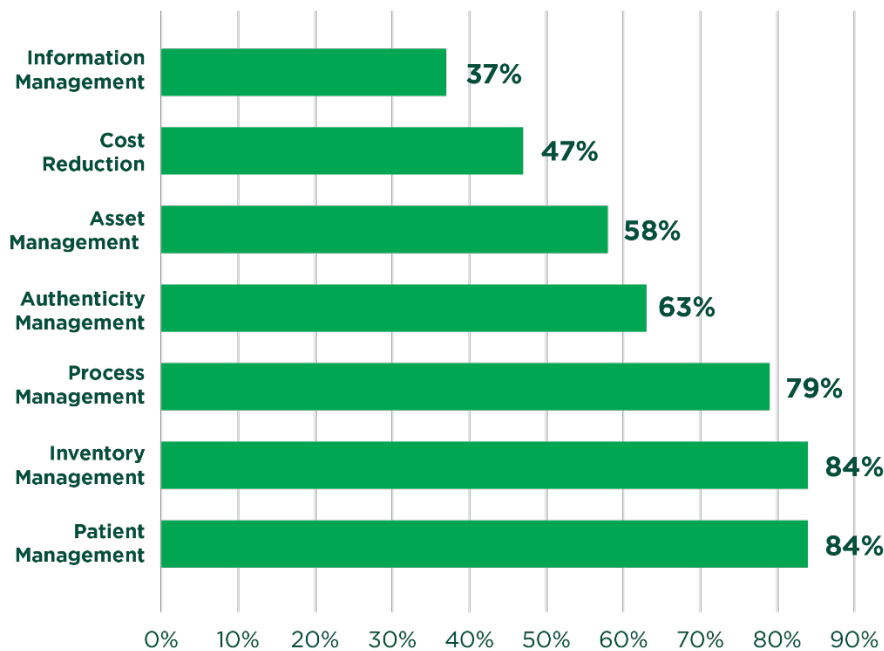
With respect to asset management, the literature focused predominantly on how RFID could improve visibility on where machinery and/or equipment, including beds, were located within a hospital to improve asset tracking. This improved visibility enables such assets to be utilized at significantly higher rates, meaning hospitals can decrease unnecessary purchases of assets to create unneeded redundancy when tracking processes are not in place. Asset tracking also improves efficiency as staff are no longer required to search for assets, which results in better patient care and reduction of non-value-added activities.

With respect to personnel/patient management, the literature focused predominantly on patient management improvements enabled with RFID technology. For example, patient tracking via RFID (embedded bracelets/ID tags) enables monitoring patients by location as well as information about patient vitals (e.g., temperature). Tracking patients (and personnel) can improve the flow of medical procedures which improves patient satisfaction and overall efficiency. Patient management results in improved information, which can result in increased patient safety (e.g., patient data on allergies could reduce the likelihood of a patient receiving the wrong medication) and billing accuracy. RFID applications can also be used for personnel tracking which can improve overall efficiency through better scheduling and productivity.

With respect to RFID applications for medications and other supplies, these applications provide better inventory management and control within a hospital setting by reducing unnecessary inventory previously needed to buffer ineffective inventory management and ordering procedures. This, in turn, means that inventory use is more effective, which enables hospitals to reduce obsolete inventory, as they can flag inventory approaching end of shelf life to be moved to higher use areas. Further, when RFID applications are broadened beyond the hospital to incorporate more supply chain participants, it can reduce the likelihood of counterfeit introduction by ensuring authenticity and results in better responses to recalls should they occur. Further, this promotes opportunities for vendor-managed inventory (VMI) and other replenishment approaches, which could reduce non-valued added activities (e.g., ordering) within the hospital.

Figure 2 illustrates the RFID benefits in terms of the percentage of times mentioned in the key 16 articles evaluated. As indicated, patient, inventory, and process management are the benefits most often discussed.

Figure 2: Most Frequently Mentioned RFID Benefits



RFID Barriers and Challenges

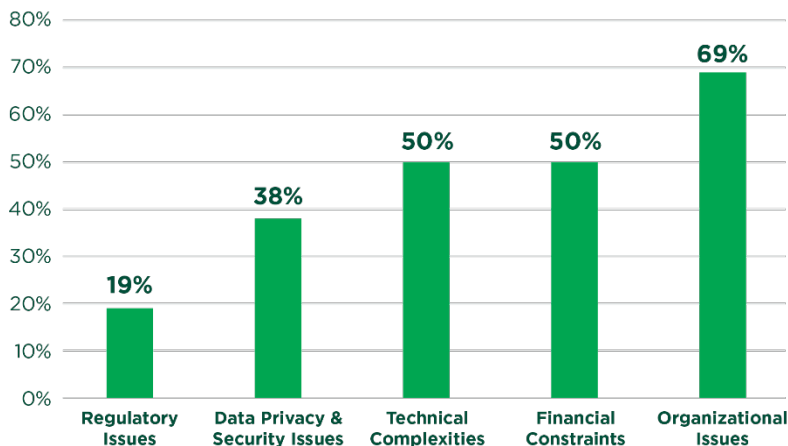
With respect to the barriers or challenges associated with RFID implementation, the literature review identified five key issues, including data privacy and security issues, financial constraints, organizational issues, regulatory issues, and technical complexities. Table 2 summarizes each of these barriers, and Figure 3 illustrates the percentage of times each was mentioned in the key 16 articles evaluated. Organizational issues, the most discussed barriers, were predominantly described as resulting from interoperability across systems. This could be across various RFID applications (e.g., older versus newer technology) and/or between RFID applications and equipment or hospital systems (e.g., billing). With respect to the former, the literature discussed how the lack of standards across RFID applications and providers makes investing in RFID applications less certain, particularly for broad adoption across the supply chain.

With respect to financial constraints and technical complexities, the literature discussed the lack of clarity with respect to the ROI of RFID applications, particularly the payback period for more advanced implementations. Further, the literature described the challenge of large-scale implementation, which is a considerable investment that is often unlikely to be considered without greater proof of concept from a financial and investment perspective. From a technical perspective, the literature cites concerns of interference between RFID radio waves and radio waves used by other hospital equipment. Finally, while one of the benefits is greater visibility of RFID tagged items, be it assets, people or other products, this results in a significant amount of data. Hospitals are challenged with managing this data, let alone using the data for greater decision-making, and this calls for improvements in integration and information operability.

Table 2: RFID Barriers and Challenges

Data privacy and security issues	<ol style="list-style-type: none"> 1. Ethical issues: Usage of the patients’ data is a grey area; privacy concerns for patients. 2. Security: Data transmission should be unbreachable; firewalls and third-party software security are a concern.
Financial constraints	<ol style="list-style-type: none"> 1. Investment criteria: Unclear ROI, longer payback periods are a concern. 2. Costs: High costs for RFID infrastructure and installation is a concern; assumed large-scale implementation is required, which is costly.
Organizational issues	<ol style="list-style-type: none"> 1. Interoperability: RFID configuration with different systems will be challenging as other systems would also have to support RFID tech. 2. Standards: Lack of standardized applications and procedures. 3. Value chain: Lack of adoption across the value chain.
Regulatory issues	<ol style="list-style-type: none"> 1. Regulatory bodies: In pharmaceuticals, technologies may need regulatory approvals; in other applications unclear if regulatory approval is required. 2. Legal issues: A mishap will result in severe legal problems; technology should be impeccable.
Technical complexities	<ol style="list-style-type: none"> 1. Interference: EM interference of radio waves with other waves used by other equipment 2. IT challenges: Integration into the ERP or common platform can be challenging; shortage of comprehensive information to evaluate; significant amounts of data to manage.

Figure 3: Most Mentioned RFID Barriers and Challenges



When RFID applications involve patient/employee tracking and/or patient data collection, privacy concerns and security issues become key challenges. With the increase in cybersecurity threats, the literature discusses the need for enhanced security around RFID applications and ethical issues that may arise with respect to patient/employee privacy. Finally, should security and/or privacy issues result in significant problems, it is likely that regulation and legal backlash may ensue for hospitals unable to mitigate security issues.

RFID Costs and Quantitative Results

The literature did not provide substantial cost data on RFID implementations and some of the cost data that was provided in older publications is likely not an accurate reflection of today’s cost considerations. This points to an area our SLR uncovers that is of future research interest given the gaps in the academic literature. However, our research uncovers seven main cost categories that RFID applications may impact. These include the following^{iv}:

- Development costs (e.g., RFID supplier selection, pilot programs)
- Initiation costs (e.g., building awareness within a hospital setting for RFID adoption, identification of costs/benefits)
- Switching costs (e.g., RFID application compatibility with existing systems, software/data, aging equipment, RFID interference issues)
- Capital costs (e.g., technology and financial risk, lack of standard RFID applications to serve as a foundation)

- Direct implementation costs (e.g., infrastructure, supplies, training, total cost of ownership) and ongoing maintenance (e.g., upgrades, replacement tags)
- Indirect implementation costs (e.g., business process reengineering, planning/management, and communication/ongoing training)
- Security/Ethical costs (e.g., protecting patient and staff privacy, ensuring data security)

It was noted that one of the key challenges associated with initiation and capital costs involves how to gain acceptance of RFID applications when such requests compete for capital with other strategic initiatives. This is further complicated by previously mentioned challenges associated with a lack of clear costs/benefits and ROI. Further, capital requests that do not have visible benefits to stakeholders/patients and/or are cost avoidance opportunities may be more difficult to sell internally.

Finally, the literature review uncovered two RFID applications aligned closely with IntelliGuard's RFID cabinet solution, which provided more specific cost information. However, these examples were pilot programs. The first article, published in 2012, discussed a pilot program undertaken at Centre Hospitalier de l'Université de Montréal (CHUM) to improve traceability and reduce paper-based replenishment of supplies.^v The RFID implementation involved tracking high value and consignment inventory in one operating room for implantable products (e.g., pacemakers, stints). The hospital affixed the RFID tags (note: this is not a cart/cabinet system) and, as part of the project, redesigned the replenishment process. The benefits included reducing inventory shrink, reducing inventory overall, gaining productivity in logistics, increasing service levels, better financial controls/case costing, and reducing non-value-added activities.

The second example involved University Hospital Cruces in Spain and was a 6-month pilot focused on improving traceability of product to increase stock availability and reduce staff time needed to manage the inventories. This paper was published in 2019 and reported results obtained from using StockKey smart cabinets in cardiothoracic surgery.^{vi} RFID labeling was performed in the hospital's warehouse, and product was stored in the StockKey cabinet. During the pilot, the surgical rooms experienced no stockouts, mismatched stock or incorrect assignments of stock to patients in surgery. Further, staff time for logistics was reduced by 50%.

There was one other RFID application described in the literature that the research team felt was a potential opportunity for IntelliGuard. This application used RFID in radiology, and the article was published in 2011.^{vii} Similarities to surgical applications involve the fact that many radiology procedures require some type of contrast media (60% reported in this article), and each vial of contrast media can treat up to 7 patients if used within one day of opening. In this example, the radiology practice moved from a manual process which was highly inefficient and resulted in exam mismatches, stock/billing issues, and shrinkage from expired products. The RFID system reduced inventory management costs by 76% over barcoded product and provided an internal rate of return of 54% with the assumption of a 10-year life expectancy on the RFID technology.

RFID Qualitative Interviews of Key Informants

As part of this research, we interviewed 16 individuals across 16 firms between October 2021 and April 2022. Typically, each interview lasted one hour, and the interviews were recorded and transcribed for analysis. Interview respondents included individuals working for branded and generic pharmaceutical manufacturers, distributors, technology providers (RFID and software), healthcare providers, and industry experts who provided deeper insight into the industry and technological applications. Table 3 summarizes interview respondent and firm participants' profiles (note: interviewees were promised confidentiality, so individual and company names are withheld).

Healthcare Providers' Perspectives

Healthcare providers are the point of direct contact with the patient and, as such, share a great interest in providing the best care for their patients. The healthcare providers we interviewed included anesthesiologists and pharmacists. The anesthesiologists were supportive of RFID-tagged products in the operating room (OR), from surgical trays to medications, and the pharmacists consider tracking drugs to the floor or room level as an important opportunity. Other applications discussed by healthcare providers included tracking assets, such as wheelchairs and beds, as well as high-value equipment, such as IV pumps and surgical instruments.

Table 3: Interview Participants' Profile

Interviewees' Sector	Number of Interviewees/ Number of Firms	Interviewees' Area of Focus
Healthcare Providers	7/7	Director of Pharmacy/ Director, Medication Systems, and Informatics/ Chief of Anesthesiology/ Chief of Supply Chain Officer
Distributors	2/2	Principal R&D Engineer/CEO
Drug Manufacturers	2/2	Sr. Director of Packaging and Technical Design/ Innovation and Development
Tag Suppliers	2/2	Co-founder/RFID Business Development Manager
Experts	3/3	Director of Industry Engagement/Sales Representative/CEO

There were four main benefit categories discussed by healthcare providers: (1) inventory management and traceability; (2) cost savings and labor efficiency; (3) patient care and safety; and (4) reduced theft/abuse. RFID enables inventory to be tracked without line of sight required by barcodes or more manual means of inventory management, enabling doctors and pharmacists to track inventory in real-time. This can aid in improved forecasting of demand for medication and supplies as well as flag medications near expiration dates for more immediate use (even moving such medication to other areas in the hospital with higher use) to reduce obsolescence. One interviewee mentioned that there are challenges with barcodes whereby they received an implantable pacemaker that had three different barcodes attached - all from the same manufacturer - which created challenges in terms of updating inventory in the system and illustrated a lack of standardization in barcode systems. As one participant described, "If you don't have good data about your usage rates, then you can't forecast your ...usage, making it difficult to develop a budget and difficult to stay ahead of shortages." When medications do expire, RFID can enable better and more consistent disposition of such inventory, flag removing it from stock so it cannot be used accidentally, and also assist in updating inventory stock availability. Inventory traceability is critical not only to reduce out of stocks, but also in the case of a potential recall where inventory must be found and removed from hospital inventory. With the case of asset tracking, hospitals can reduce the inventory of expensive and/or critical items by having greater visibility into their location to "right size" the assets needed and reduce the ability for a unit or floor to hoard assets.

Related to inventory management and tracking, RFID applications can provide *cost savings and labor efficiency*. For example, RFID reduces the need for physical inventory counts and improves inventory accuracy by not only highlighting where inventory is located, but also providing accurate levels of inventory availability. One interviewee mentioned that the use of RFID increased their inventory accuracy by 15% while also enabling tracking and using product before it expires. One participant specifically discussed how the IntelliGuard cart improved not only inventory management, but also labor efficiency. He discussed how prior to the IntelliGuard solution, anesthetics were often out of stock in OR rooms and/or required restocking efforts throughout the day, which could delay surgeries. After the IntelliGuard application, in-stock performance improved, and restocking was only needed once per day. Another physician discussed how the IntelliGuard application made finding medications during surgeries easier and faster and eliminated the need to scan medications and patient IDs, enabling greater attention to the patient and a reduction in non-valued added activities. This resulted in greater labor efficiency for physicians and anesthesiologists, and also increased billing accuracy through the reduction of no-charge capture situations or other non-billable materials. As this interviewee indicated, "*There's so many lost charges out there where the patients aren't billed for the meds, and then, the healthcare facility absorbs the cost, and it's not insignificant.*"

Interview participants discussed different ways in which RFID applications enhanced *patient care and safety*. First, with better inventory management and in-stock availability, medical personnel are less likely to face moral compromise situations where a safe but less-than-ideal medication must be used because the preferred medication is out of stock/expired. Additionally, when applications like IntelliGuard, include patient information, the automated system can notify an anesthesiologist of drug allergies or other issues before potentially harmful medication is used accidentally. Finally, reducing non-valued added activities, such as medication/supply tracking, enables medical personnel to focus more attention on patient care and safety.

Finally, the interviewees discussed the benefit of *reduced drug theft and abuse*. With the traceability provided by RFID, unauthorized access to medications and supplies can be reduced since *“drawers are locked for [controlled substances], and, you have to check them out by the name of the patient,”* which reduces/prevents drug theft. Further, it becomes easier to track and dispose of partially used medications (as well as expired medication, as already mentioned). For example, if a full vial of a medication is not needed in a surgery (and cannot be returned to inventory), it must be properly disposed of, including tracking the disposition and updating the inventory. RFID applications make this process easier, which results in behavior modification as one participant pointed out, *“People will act differently if they know they will be held accountable for their medication inventory.”* One interviewee mentioned moving of expensive medical devices, such as implantable products, from one hospital to another by physicians whereby the supply chain department has to absorb the associated cost. He pointed out that *“RFID tracking should reduce this type of behavior.”* To illustrate how proper disposition was not always managed prior to RFID implementations, one participant described how a hospital had experienced a sewage backup, and during the repair process, dozens of partially used/empty vials of fentanyl were discovered in the sewers. As indicated by one participant, *“Amazon can ship stuff all over, and you can know exactly where the truck is, but [we] have no idea where thousands of medication vials are.”* This becomes even more critical (and disappointing) when managing narcotics.

With respect to the challenges of RFID implementation, the healthcare providers predominantly discussed issues surrounding the cost and investment required. The most often discussed hurdle was related to the initial capital investment. Every hospital system has a process for assessing significant capital investments, which often involves considering trade-offs across various units and strategic investments. As one participant described it, *“there is a dedicated pot of money that everyone is competing for.”* Another interviewee mentioned that *“In their organization, the leadership appetite is missing [for RFID solutions] and there is no single owner to initiate a process.”* It is up to each department to determine issues resulting in the development of a problem statement to drive solution exploration which makes cross-departmental initiatives difficult to develop. RFID application requests often arise from pharmacists/physicians across multiple departments highlighting potential benefits and efficiency gains, often triggered by tradeshow demonstrations. It may be easier for units/initiatives promoting strategic investments (e.g., building a neonatal unit or cancer center) to argue for the capital need than a problem-avoidance/cost reduction opportunity such as RFID. The latter may be harder to build momentum, so *“the RFID value proposition becomes really important,”* and it often requires cross-department support (e.g., pharmacy, anesthesiology, IT, and management).

Once the initial implementation is approved, there are additional costs incurred with respect to infrastructure/systems development and training and business process redevelopment. One participant mentioned that the cost of RFID system implementation for the entire enterprise (approximately 950 beds) was \$15 million. He pointed out that the budget for the first year (\$2 million) was mostly associated with systems integration and infrastructure. Another participant estimated that for a 250-300 bed hospital, RFID-based trays and kits might cost about \$25k-30k for implementation and about \$15k for ongoing costs. There are also annual maintenance costs for not only systems updates, but also for new tags. As one participant noted, *“The IntelliGuard software cabinets need to be updated every year to be able to integrate and communicate with the hospital software system, which takes time and money. In addition, the hospital software system should be customized and connected with the IntelliGuard software system.”* Additionally, the need for a hospital to apply RFID labels and encode data for medications is time-consuming and can add labor costs, given source tagging at the manufacturer is not yet common (albeit some distributors will provide tagging services). There are also potential issues with incompatibility whereby manufacturers/distributors tags may not be compatible within a specific hospital system, per one participant who indicated, *“Each system has specific antenna readers and data capturing capability. It is necessary to have a unique standard for tags from different manufacturers that can be read by all RFID-based storage systems.”*

Distributors' Perspectives

Distributors sit at the heart of the pharmaceutical supply chain, connecting healthcare providers and pharmacies with the drug and supply manufacturers. To be competitive in a constantly evolving healthcare ecosystem, distributors must continuously innovate to maximize value for patients and their supply chain partners. One potential value that distributors can provide is better forecasting and order replenishment support when a hospital's RFID tag data is stored in “the cloud” and distributors have visibility to usage data in real-time.

One of the distributors that was interviewed discussed the use of RFID for tagging medication devices which has been in operation for *“the past 15 years”*. While this participant did not work on RFID applications for medications, he commented on the benefit of RFID tags over barcodes for products that need temperature tracking or to reduce expired medications, particularly if they are high cost.

When RFID tags are used, it is estimated, in general, that hospital labor can be reduced by 5 times, and human errors can be reduced up to 8 times. These benefits come from hospitals having better inventory visibility and accuracy, which, in turn, improves order management and results in fewer orders needing to be placed (and labor required to manage). This also reduces inventory obsolescence and labor required to manually count inventory and track/dispose of outdated product. Manual processes are more prone to error (e.g., miscounts, outdated product remaining in inventory), which can lead to mistakes and medication mismanagement, which can threaten patient safety.

Distributors described various challenges associated with RFID applications in healthcare. First, an RFID application requires changes to workflows and processes between the distributor and hospital as well as within a hospital system. This can include connecting RFID-based cabinets to the distributor and hospital network, which can be challenging and result in interoperability issues. Further, this is an area of concern with respect to cybersecurity and protecting data integrity.

Participants also discussed the lack of standardization as a potential challenge. RFID applications are often highly customized to the particular hospital (e.g., asset versus medication tracking; scale; infrastructure and IT systems). This lack of standardization could result in compliance issues, and often *“It is not clear who [in the supply chain] is going to absorb the cost.”* While this participant was specifically talking about the cost of tagging product, it is clear other costs associated with implementation (e.g., business process redesign, training) may face similar challenges.

Drug Manufacturers’ Perspectives

The idea of tagging medications at manufacturing facilities is gaining attention and traction. Interviewees indicated that their companies are investigating the internal and external benefits of applying tags to their products as a means for offering greater value. One interviewee indicated there are potential lessons learned from retail applications where manufacturers and retailers collaborated. As described, *“In retail, you lose track of 40% of inventory [with barcodes], but with RFID implementation, you see 99% precision.”* One of the participants indicated that RFID tagging during manufacturing likely benefits the value chain more (e.g., supply chain track and trace) than it benefits the manufacturer, at least initially, but could potentially result in competitive advantages in the long run.

For one company, applying RFID tags in its manufacturing facility resulted in offering greater value. In this situation, the CEO recognized the effort required to manually tag product at the client’s site. It was estimated that manual tagging costs around \$1/box. Manual tagging (e.g., at a hospital pharmacy) is subject to more human error (e.g., exchanging tags, tag not being applied correctly, tag covering important label information). Through cross-functional efforts with sales and manufacturing and a 4-month period of analysis and approvals, the manufacturer was able to tag medications within their own manufacturing facility. The cost incurred by the manufacturer included upgrading packaging lines (i.e., \$500K/line) and purchasing the tags (i.e., \$.015-.020/tag). As RFID applications increase and technology continues to improve, the costs associated with RFID should decrease.

RFID applications are not without challenges. RFID can be sensitive to certain types of materials (e.g., liquids), and there needs to be enough space available on the product for the tag. Additionally, not all tags are rewritable (and those that are generally cost more), which negatively impacts sustainability. RFID tags made from bio-friendly materials that can be more readily recycled can improve sustainability. Finally, there are costs associated with interoperability with existing systems and equipment changes as well as customization to specific customer applications.

Tag Suppliers’ Perspectives

Tag suppliers described how their RFID businesses actually started in non-healthcare industries, but as medical applications became more prevalent, these suppliers invested in healthcare due to a belief that medication management is one of the most value-adding opportunities for RFID. For example, one participant indicated, *“Barcodes provide 80-90% of inventory accuracy in retail settings, but in a hospital, it is much more critical [to have] inventory accuracy but [it] is currently only roughly 60%, [meaning] only a 6 in 10 chance the medication is available. That’s totally unacceptable from an inventory control standpoint.”* This participant indicated that hospitals could see 90% or more inventory accuracy with RFID. Another participant indicated that Amazon is seeing *“inventory accuracy of more than 99%”* using RFID where *“accuracy was less than 70%”* with barcodes. Despite the recognition that inventory accuracy levels are low in hospital settings, it is hard to get engagement around improving inventory management using RFID because, *“it is difficult to determine the cost of*

inaccurate inventory control” especially when trying to tie the cost of it to patient safety. The easiest cost to identify is the cost of the tag itself as *“Active tags cost around 50 cents each, whereas passive tags cost around 5-10 cents each to manufacture.”*

Tag suppliers described many of the same benefits as the previous participants, stressing the importance of real-time information visibility of medications within hospital settings, including location, batch/lot number, quantity, expiration date, and recall status, as well as asset tracking. There is tremendous opportunity for improvement as *“medication management in 90% of hospitals is currently being done largely by barcodes.”* One participant mentioned that an often-unrecognized benefit of asset tracking is associated with maintenance and repair. Using RFID not only allows the asset to be found more readily, but data regarding expiration, maintenance and repair work can also be collected, analyzed, and communicated with the right personnel.

RFID also reduces labor and errors. Under traditional systems, for example, expiration data printed on a drug’s package must be manually entered into an inventory system in a pharmacy if it is to be tracked. This is time-consuming and error-prone. Additionally, the ability to monitor and verify temperature is a critical benefit of RFID.

We asked tag suppliers to comment on tagging location, specifically concerning the difference between source-tagging at a manufacturer’s site versus tagging at distributors or hospital pharmacies. When a distributor adds an RFID tag, they need to open pallets and cartons to access individual medication packages (e.g., box or vial) and may also need to put tagged product in new boxes. Whereas manufacturers can add the RFID tag on the individual package at the end of a production line without disrupting carton packing and palletization.

Tag suppliers indicated that medications are one of the most challenging RFID applications because of the fluid aspects of some medications. Additionally, packaging properties (e.g., materials, size) can be a challenge, which can require RFID tag design consideration. So, items like saline bags, vials with metal caps, and small syringes are not always *“RFID friendly.”* In addition, RFID applications require infrastructure upgrades that vary based on what customers expect to get from RFID applications. One of the biggest infrastructure considerations includes *“cabling, hardware, readers, software. It can cost \$5k-10k for some companies or up to \$100k for bigger companies. However, this is a one-time cost.”* This highlights an additional challenge with respect to broader RFID usage. There is a lack of RFID experts in the healthcare industry to assist in broader implementation and applications as well as general misperceptions of RFID. For example, there is a lack of understanding regarding passive and active RFID tags leading *“people [to] think they can be traced everywhere!”*

Experts’ Perspectives

We interviewed individuals working for firms outside the pharmaceutical industry that were best-in-class service providers or firms engaged in unique and/or technologically advanced operations. One participant indicated that *“the RFID adoption rate is 15% across the USA healthcare systems,”* so there are significant opportunities for RFID in healthcare. This participant felt that one of the reasons for this low adoption is that *“manufacturers are not yet motivated to implement RFID tags”* in their products. One participant was hopeful that RFID adoption is more likely since *“technology has advanced, allowing for more complex implementations of RFID.”* However, this participant also indicated that RFID adoption is *“more challenging to make sure the engineering works.”*

Experts discussed the biggest differences between RFID adoption in retail settings in comparison with the healthcare industry. As described by one participant, *“The healthcare industry is more complex. The interactions between people and things are more intense, critical, and expensive, and the outcomes are more significant.”* Compared to the apparel industry, for example, healthcare RFID applications typically require greater information to be entered on a tag, requiring tags with larger storage capacity and, *“When the data capacity requirement goes beyond 128 kb, the price of the tag increases.”* This increased cost for tags can be a deterrent for RFID applications.

Participants’ assessments of benefits and challenges were consistent with participants from the other categories. Benefits result from improved inventory management, reduced labor/operational costs and human errors, improved patient care and safety, and process efficiency. Similarly, challenges to RFID implementation focused around the cost required (and who pays for these costs) as well as the lack of standardization of RFID applications due to the varied and customized ways in which healthcare systems implement RFID (e.g., applications, processes, customization required). The cost-benefit tradeoff challenges were perhaps best described by one of these experts who stated, *“So, there’s a cost of RFID certainly, but there’s also a cost of “not-RFID;”* the latter which can include the cost of a patient not getting the drug they need quickly or the liability associated with an error that results in under or overdosing and harms the patient.

Liability and other risk factors are often not considered when weighing the cost of RFID implementations.

Finally, one expert recommended that any RFID project should proceed with the following steps:

1. Identify which items need to be tagged and how they will be tagged. It is necessary to work with RFID experts to identify the type of the tag (active, passive, UHF, NFC, etc.) and the place for labeling the tag.
2. Select the RFID reader.
3. Perform a site and process analysis to understand the environment and the workflow.
4. Map out the current business process and determine how change the current workflow.
5. Define the location for the readers and complete installation.
6. Provide training to intended users and troubleshoot issues.

Summary and Conclusions

Based on the SLR, the largest focus on RFID in the academic healthcare literature is on asset tracking and/or inventory management applications; however, a few articles discuss personnel and/or patient tracking. As such, the literature is lacking with respect to articles focused on smart cabinet applications and tracking of pharmaceutical products, particularly used in surgical settings. It is clear that IntelliGuard has a unique RFID application that has not generally been explored in the scholarly literature in comparison to asset tracking and general inventory applications. However, the literature is clear on the various benefits associated with RFID and the value it can provide in the healthcare industry, particularly with respect to patient safety.

The literature is highly fragmented, with most articles featuring generic, high-level discussions of RFID (in particular, general benefits that RFID may provide) while only a few articles describe very specific applications (e.g., pilot cases, such as CHUM and University Hospital Cruces, discussed in the SLR section). As such, it is difficult to identify and verify data in terms of both quantifiable benefits and detailed cost information. This makes estimating a generic return on investment (ROI) for the use of RFID in healthcare extremely difficult. The complexity is pronounced since (i) the context of the RFID implementation (e.g., completely new RFID implementation versus pilot), (ii) the application (e.g., asset tracking versus surgical carts), and (iii) the scale (e.g., pilot on one surgical room versus implementation at a small versus large hospital) will significantly impact ROI considerations, costs and benefits. When specific applications, like the previously mentioned cases, the focus of the RFID pilot has predominantly been on non-financial outcomes, such as patient care and/or reduction of inventory out of stocks, and, thus, ROI has not been considered. The use cases written by IntelliGuard staff would need greater detail to fully quantifying the costs and benefits associated with case applications.

Similarly, the interviews have not identified the breadth of quantitative data that would be required to conduct a thorough assessment of ROI, with the exception of some costs (i.e., costs of tags, costs of manual tagging, implementation of a smart cabinet solution). Adding to this challenge is that the costs associated with RFID implementations include hard costs/benefits (e.g., purchasing tags and readers, reduction of manual labor and inventory), soft costs/benefits (e.g., reduction of non-value-added activities, which frees up labor to focus on patient care), as well as cost avoidance/risk reduction opportunities (e.g., improved responses to recalls, reduction of liability claims arising from improved patient safety). Cost avoidance/risk reduction benefits are perhaps the most challenging to calculate/estimate quantitatively. Further, the literature has not focused on various qualitative benefits (e.g., soft or cost avoidance/risk reduction benefits) such as increased charge capture/more accurate billing, less inventory waste and proper inventory decommission, moral compromise for doctors using acceptable but not preferred medications, and talent shortages in healthcare which makes the reduction of non-valued added activities of even greater importance.

Another aspect that makes analyzing quantitative costs and benefits more challenging is that the data needed is typically not captured/collected in a way that enables a thorough assessment of ROI. One takeaway from the interviews is that visibility to cross-functional cost/benefit data may be lacking (note: this visibility is further challenged when considering cross-supply chain implementations such as manufacturer tagging for distributor/hospital support). For example, the costs associated with labor to attach RFID tags may be charged to pharmacy, while the cost of the tags or the cost of the IT system interface required to implement the RFID solution may be charged to other functional areas within the hospital. To calculate the ROI of a specific RFID application, cross-functional cost and benefit data would be necessary, and an activity-based costing approach may be required.

In summary, the research team concludes that going forward, there are various ways to approach future research. One approach would be to conduct a highly specific cost/benefit assessment likely following an activity-based costing approach for a very specific application (e.g., the IntelliGuard cart for an average-sized hospital). This would require the participant to share significant amounts of data and information. Another approach would be to develop a framework based on the seven aforementioned cost categories, such as a cost/benefit checklist that could be deployed for various RFID applications by estimating and plugging in the necessary data. This pilot study left the team with the impression that estimating a general ROI for the use of RFID in the health sector requires a larger team of investigators who can dedicate full time to this effort, who are sponsored by a group of industry partners, such as the Axia Healthcare Consortium.

Acknowledgments

This research was funded by IntelliGuard and The Axia Institute at Michigan State University (MSU). The authors would like to acknowledge Dr. Swaminathan Subramanian from the Axia Institute for his support in conducting interviews. The authors also would like to thank Elise Claudepierre from IntelliGuard for facilitating communications with the interviewees. While we cannot mention them by name for privacy reasons, we greatly appreciate all the interviewees for their participation.

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About Axia Institute

Located in Midland, The Axia Institute® is a premier research and education center dedicated to developing effective and sustainable solutions to improve public and private value chains. Established by Michigan State University in 2013, The Axia Institute® partners with industry to solve grand challenges and conduct cross-disciplinary research in areas of value chain optimization, data analytics, engineering, smart packaging, anti-counterfeiting, and water and food safety. The Institute was founded by leaders in value chain creation and development at MSU, including the Eli Broad College of Business, the College of Agriculture and Natural Resources, College of Engineering, College of Social Science, and School of Packaging. Founding donors include The Dow Chemical Company, Dow Corning Corporation, Herbert H. & Grace A. Dow Foundation, Rollin M. Gerstacker Foundation, The Dow Chemical Company Foundation, and the Charles J. Strosacker Foundation. For more information, please visit www.axia.msu.edu.

About IntelliGuard® Intelligent Inventory Solutions

Founded in 2006, IntelliGuard is headquartered in Carlsbad, California. IntelliGuard offers Intelligent Inventory Management Software Solutions powered by RFID for use in the US, Canada, and EU. IntelliGuard® offers modular and scalable medication management systems that support a broad category of critical inventory and supplies serving 4 markets: Life Sciences consignment market, Specialty medication market, Hospital pharmacy, and Related markets. For more information, please visit www.ig.solutions.com.

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