

**Feasibility and Proof of Concept of Utilizing Radio Frequency Identification Tagging
Technology to Manage Evidentiary Materials in Forensic Laboratories**

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ABSTRACT

Radio Frequency Identification (RFID) is a technology that is gaining great popularity in many industries including retail, shipping, and pharmaceuticals. The technology promises to provide detailed, real-time, automated tracking of inventory or merchandise with minimal human interaction. Such a technology has the potential to be useful in forensic laboratory environments where control of evidence is essential. Forensics laboratories spend a tremendous amount of time and resource on evidence inventory management; thus, it is important to identify technologies and processes that can be used to increase the efficiency of data management, to more accurately track evidence through the laboratory process, and provide mechanisms to protect and improve the integrity of evidence and data about evidence. The question is, is RFID, in its current stage of development, up to the task of realizing the goal of bringing more efficient and accurate evidence management to forensics laboratories? This research seeks to address this question. We evaluate the current state of RFID technology, functional and technical requirements of forensic laboratories, RFID vendors, and offer insights garnered by this study. In summary, our conclusion is that while RFID offers the promise of improved data and evidence management, the technology is not yet mature enough for widespread implementation in forensics laboratories.

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INTRODUCTION AND PROBLEM DESCRIPTION

The sheer number of evidentiary items in any particular case is growing, and the items themselves have an increasing number of complex interrelationships that must be captured, maintained, tracked, and accounted for. Additionally, the number of processes requiring many procedural steps is increasing, and the integrity of those processes must not only be maintained but verifiable. The management of this evidentiary chain of custody process is essentially an inventory management problem analogous to inventory management problems faced by private sector organizations (e.g., Wal-Mart). Whereas forensic labs (and laboratories in general) spend the bulk of their resources developing effective forensic analysis capabilities, private sector firms view the management of inventory as a source of potential strategic competitive advantage, and devote considerable resources to the development of sophisticated inventory management tracking techniques. This not only saves the organization money but also provides real time information about inventory and organizational processes.

The goal of this project is to examine whether it is feasible to bring these state-of-the-art inventory management tracking techniques into the forensic lab environment so that criminalists can more efficiently manage laboratory evidentiary materials. At the center of the most recent developments in inventory management is the use of radio frequency identification (RFID) tagging to track and maintain accurate data concerning inventory items. While many labs currently use bar codes to tag items, RFID adds additional capabilities to tag and track items, and thus adds significant power to the inventory management system and, potentially, to the chain of custody. Specifically, we proposed the development of an implementation plan to bring RFID technology into the forensic lab environment, as well as a pilot test of RFID technology in a

specific forensic laboratory. The implementation plan, coupled with the working system, will demonstrate how the practical utilization of this technology will not only improve evidence tracking and verification, but also enhance the ability of labs to assure procedural continuity in accordance with accepted scientific practice.

PROJECT OBJECTIVES

The goal of this project was to develop an implementation plan and working proof-of-concept prototype for a forensic science laboratory, RFID-based, evidentiary management system. The proof-of-concept prototyping process is an important activity in the process of developing a new information system or technology. Most IT prototype systems undergo a development process similar to the systems development lifecycle (SDLC), which includes the following phases:

- Project Identification, Initiation and Planning
- Systems Analysis
- Systems Design
- Systems Implementation
- Systems Maintenance

For this project, we utilize this model not only to develop the proof-of-concept system but as a basis for developing scalable and generalizable implementation plans that are adaptable to the entire forensics laboratory environment. To provide focus and consistency, the working proof-of-concept system is designed for one specific application area – the field collection process.

Our goals in designing this RFID system and implementation plan are to examine the role and potential benefits of RFID in the following functions and processes that operate in laboratory and related crime scene investigation environments:

- Ensure the integrity of scientific processes by verifying the chain of custody and verifying evidentiary provenance
- Verify only authorized personnel have access to testing and evidentiary materials
- Monitor the processing of materials and processes
- Enhance the cost efficiency of the forensic procedures by providing real time evidentiary material location, with limited manual verification
- Provide the basis for the development of secondary systems (such as paperless operations) that use RFID to key evidence to specific laboratory procedures.

The RFID tagging system coupled with intelligent supporting computer applications will provide benefits for managing forensics laboratory evidence. In a recent article in *American Laboratory*, Venkatesan and Grauer (2004) made this point succinctly when they noted, “the use of RFID technology provides laboratories with immediate advantages over traditional identification methods such as bar codes, including enhanced security and the ability to read data without requiring line of sight” (p. 12).

There are several specific benefits to RFID. First, RFID will provide laboratories with the ability to ensure that appropriate laboratory workers in appropriate locations in the laboratory handle evidence. In other words, the right people in the right places! While existing barcode systems provide information about an item when it is deliberately scanned, an RFID system captures an item’s information (including location) even when someone has neglected to scan it. RFID can be used to track an item when it leaves an area, and RFID can actually record the

location of an item as it moves within the laboratory.¹ Second, if laboratory personnel were to use RFID identification badges while handling tagged evidentiary items, the system can provide verifiable data about who accessed the material at any time, which would assist in assuring compliance with lab policies, procedures, and chain of custody. Third, the system provides laboratory managers and supervisors with more information about sequence and completion of laboratory processes. This enhanced managerial information translates into more efficient and effective use of personnel time to accomplish laboratory analysis tasks.

PROCEDURES FOR PROTOTYPE DEVELOPMENT

Field Data Collection

The investigators obtained information for this study from several sources during this project as well as during a previous MFRC funded project that focused on an examination of the features and capabilities of LIMS. During the last two years we have had the opportunity to make observations of laboratory operations, to have discussions with numerous laboratory stakeholders, and to engage in structured discussions with a variety of employees in these facilities. . In total, the researchers visited nine (9) Midwestern crime laboratories during the summer of 2005 to discuss LIMS and RFID issues (see Ames Laboratory Report No. IS-5175 for further information). The researchers also visited two (2) crime laboratories (Johnson County, Missouri, and the Massachusetts State Police Forensics Laboratory) during the summer of 2006

¹ RFID and barcode systems contrast dramatically in the way that they can be read: a bar code requires a deliberate exposure of an items barcode tag to a reading device, whereas the RFID tag can be read by antennae that are within the range of the tag. In practice, this enables the design of tracking systems that require no deliberate action on the part of lab personnel to effect item tracking. Depending on the goals of an individual lab, the RFID system can be configured to track items that are leaving or entering areas (such as through a door or a check-out window) or can be configured to include room-monitoring equipment that can assay the tagged materials that are within a given workspace. Thus, RFID provides two key benefits that barcodes do not offer: first, RFID can reduce errors associated with failures to actively track evidentiary movement; and second, RFID can provide the basis of real time monitoring of evidentiary material location within the lab.

to specifically discuss RFID. At each location, several of the researchers met with the management team and with numerous scientific, technical, and administrative employees in semi-formal information gathering sessions. In addition, during the summer of 2005 we visited Porter Lee, Inc., the manufacturer of the Beast, to discuss LIMS and data management issues. Similarly, we also conducted a conference call with representatives of Forensics Technologies, Inc. (FTI), the makers of the BARD LIMS, to discuss LIMS and RFID.

This field-based portion of our research provided us with several very important forms of information about RFID applications in laboratories. First, it informed us about the data management issues that laboratories face in relation to field data collection, data in-take, data management, and data analysis. Second, it allowed us to examine and document the processes used to process and manage data and evidence as it flowed into, through, and out of the laboratory. Finally, it allowed us to explicitly explain how RFID works, what the potential applications are, and obtain feedback about the suitability of RFID for given processes, functions, and operations. While the visits to the laboratories in 2005 were helpful in informing us about laboratory operations, processes, and attitudes about data management and RFID, the visits to the two laboratories in 2006 were focused exclusively on RFID and provided information that was helpful in specifically evaluating applications and processes that are appropriate for RFID. This was due to the fact that, as a result of the previous year's visits, the researchers had a more informed understanding of the requirements that laboratories had for data management and the operational processes existing in most laboratories. In addition, because the laboratories that we visited in 2006 were selected because the management of these laboratories had expressed interest in and were knowledgeable about RFID, the personnel in the two laboratories had a well informed perspective about the capabilities of and potential applications

for RFID in their laboratory operations. The information that we obtained from the two sessions in 2006 was used directly in developing the applications, features, and operational capabilities of the prototype RFID system.

Prototype Development

One of the primary purposes of this research is to develop a prototype RFID application that is representative of the type of system that could eventually be developed for use in forensic criminalistics laboratories. The prototype RFID application was developed after information about both laboratory operations and data requirements was obtained from crime laboratories through site visits. The software development portion of the RFID project involved rapid software development techniques. The requirements for the system specified that several different data collection and management technologies be integrated into one stand alone, functional RFID prototype. The requirements for the primary components of the prototype include the following functions and technologies:

1. RFID technology: The prototype was required to operate in an integrated fashion with RFID hardware (e.g., antennas and interrogators), RFID system proprietary data management protocols (e.g., native XML), and proprietary RFID software development environments.
2. 2D barcoding technology: Similar to the requirements for RFID, the prototype was required to operation in an integrated fashion with barcode hardware (e.g., optical readers), barcode system proprietary data management protocols (e.g., native XML), and proprietary barcode software development environments. Barcode technology is often used in laboratories already; therefore, the researchers deemed that barcode

- technology should be integrated into the RFID prototype to demonstrate the options associated with collecting data using either RFID or barcodes.
3. Printer technology: The prototype was required to interface with two types of printers, 1) a portable, hand held label printer and 2) a stationary label printer/RFID read/write printer.
 4. Database connectivity: The prototype was required to manage data locally and to interface with server-based data stores so as to simulate the requirements that a fully functional system would have to interface with existing data stores such LIMS. The prototype needed to manage interactions with both a portable data store that resided on a hand held tablet computer and with the primary data repository on a server.
 5. Tablet PC-based, pen-writeable forms: The prototype was designed to simulate functionality that would be needed both by crime scene investigators and by laboratory personnel within the confines of the lab. Tablet computers were identified as the appropriate technology to be used in both field and bench science venues. Custom forms that could accommodate hand written data entry were required to enable form-based entry of data that could be then associated with barcodes and RFID tags.

The goal of the prototype development process was to build a system that would meet these requirements so that users would be able to identify the steps in the process where RFID was relevant. The system built to achieve this goal was designed to be used with tablet PCs so that a variety of users (e.g., crime scene investigators, laboratory analysts, evidence technicians, etc.) could enter data using handwriting as well as other modes of entry. The prototype mimics a specific process that we determined was typical of the steps taken by investigators and laboratory

personnel as evidence moved from the crime scene to the laboratory and through laboratory processing. The series of prototype screens representing this process are illustrated in Appendix B.

The prototype components were developed using a systematic development process that included several specific phases. The first step in the development of the prototype was to write an application front end that would simulate the types of forms that users would utilize when interacting with an RFID system. The forms were developed to operate on tablet computers with the goal of enabling users to use hand writing for data entry and form manipulation. An application shell with a navigation menu (i.e., a switchboard) and several data entry and data retrieval forms were created. These forms were designed to interact with a database that would be used to enter, store, and retrieve pertinent data about cases, evidence, and other parameters associated with a case. Following the development of the application shell and forms, the next step of the development process involved establishing a mechanism that enabled the prototype client application to interact with the RFID antenna. This involved querying the RFID network component using socket-based technologies and XML. By reading the raw XML data transmitted by the RFID tags, the client application program could retrieve tag numbers from the RFID tags and associate these data with other data about the object that was associated with each tag. Once the client application could interact with the RFID tags, a procedure was developed to allow the application to interact with the 2D barcoding technology. This involved first creating 2D barcodes and encoding the relevant information into the 2D image generated by the barcoding software. These barcodes were then printed on custom-made labels using either the portable barcode label printer or the barcode/RFID label printer. After printing the 2D barcodes,

the next step involved reading this information back into the program. This involved serial communication between the 2D barcode reader and the prototype.

The prototype was written in Visual Basic.NET. Special libraries for TabletPC forms development were used to allow pen-based entry. The system also coordinated the reading and writing of 2D barcodes and the reading of RFID tags as described above. Additionally, the system interacted with two different database technologies. For field applications, a Microsoft Access database was developed and used to store the relevant crime scene information. Once the investigator returns to the lab, the system was designed to upload these data to a master database on Microsoft SQL Server. Once in the laboratory, laboratory personnel could use the same forms to interact with the SQL Server database directly.

RESULTS

While there has been exceptional interest in RFID from the many crime labs with which we have been in contact, none see an immediate utilization opportunity. There are a number of reasons for this:

Cost

While many lab personnel indicate that there are certainly some potential benefits to the use of RFID, the cost per item remains too high to justify the investment at this time (given the performance improvements that they would expect to realize from their investment). Even at a per tag cost of \$00.25, RFID represents a significant increase over current bar-coding technologies.

Limited Utility

Even if the cost of RFID were not substantially higher, there are also perceived limitations on the process improvements that RFID can currently yield. Limitations that we and our lab partners have identified include:

- a. *Inability to easily tag very small items.* This is problematic because it requires two different mechanisms of labeling and tracking for large and small objects. An example of this challenge would be the tiny vials used in DNA analysis, which are far too small to affix an RFID tag to. They can be bar-coded (with a tiny label), but generally they have hand-written labels that identify critical information on the vial. The research team suggested placing the individual (hand-labeled) vials in bags with RFID, but lab personnel indicated that they felt that this would add relatively little value compared to cost, and would be somewhat disruptive procedurally.
- b. *Little Advantage Over Bar-coding.* Most labs believe that their current bar-coding system provides adequate item identification, and so it takes a fairly significant process improvement to warrant a system shift. The one big advantage that the RFID-based system can provide is full information about the item actually contained on the item tag, in a machine readable format. While this is an attractive potential, two-dimensional bar-codes provide the same capability to a great extent. The only remaining advantage to the RFID in terms of information is the ability of the RFID tag to carry updated information, but this was not seen as a significant enough capability to warrant a system change (again, considering the cost).

Process Improvement

While labs generally saw limited incentive to add RFID to their current operations, they do recognize that the tags will eventually be an important part of their inventory management when the costs per tag are reduced. Specifically, they identify the following process improvements that RFID will eventually confer:

Passive Item Tracking

This capacity, more than any other, is identified as the primary advantage of RFID. As costs come down, and RFID reading technologies continue to improve, the ability of an RFID tagged system to identify lab personnel, associate them with evidence items, and track the location of those items within the lab...all without personnel intervention...is seen as a terrific boon to quality control and throughput efficiency.

Active Item Tracking

While most labs do not like to admit that items are misplaced, there are acknowledged instances of items being “mis-shelved,” necessitating an item by item search of storage lockers. RFID can greatly simplify this infrequent process by allowing personnel to scan shelves electronically to find items. In more advanced future systems, the shelves themselves will scan the items and provide real-time information about item location, reducing some of the current burden of shelf-location record-keeping.

Dynamic Item Information

As noted earlier, having an item’s tag contain relevant information about the item is very useful, as it backs up the LIMS, and allows information retrieval when the LIMS is unavailable. This capability also allows items tagged in the field to carry their information to the lab, creating the potential for an item-based pre-logging system. However, two-dimensional bar-codes can

provide the same functionality (albeit without the passive readability) at a substantially lower current cost.

While two-dimensional bar-codes do offer many of the advantages in terms of informational complexity that are offered by RFID tags, RFID tags are unique in that they allow the information on the tag to be changed or added-to. This is an interesting capability, particularly once the item has entered the lab environment: with RFID, the item's tag can contain tracking information as to who has worked on the item, what tests have been performed, etc. While all of this information is currently contained in the LIMS, its existence on the tag backs up the LIMS and gives the item informational independence.

Although there is little current likelihood of RFID adoption, there is little doubt that it will eventually become part of the inventory management system of most labs at some point in the future. The advantages that the tags confer are useful, but do not justify the current cost and operational changes necessary for current deployment. All of our contacts agreed that the tags have potential, and that they look forward to lowered costs.

Given the inevitability of the tags' implementation, there are a number of processes that labs and agencies that provide services to the labs can undertake:

1. **Continued Cost Monitoring.** Labs interested in RFID need to establish a price-point at which the tags become acceptable, and then monitor the tag market regularly to see if tags are affordable. A regularly scheduled quarterly check with vendors can suffice for this, or in the alternative, labs can advise a number of vendors of their interest and ask for contact when tags are available at a given price level. Our conclusions related to the

utility of RFID tagging are based on discussions with a sample of laboratories; therefore, there is potential that our conclusions about the cost of tagging in relation to the benefits of tagging may not be generalizable to all laboratories. It is possible, for example, that the current cost per tag may not appear to be excessive for some applications or for particular laboratories with larger budgets. Furthermore, for felonies or high volume drug crimes it might be feasible to adapt RFID into current evidence management procedures. As with any analysis of a technology expenditure, the decision must be made based on a specific cost/benefit and risk analysis. For example, in a high profile case where an item of evidence is misplaced or lost and RFID might have prevented this outcome, then the high cost per tag might appear to be negligible compared to the negative repercussions associated with having lost the evidence.

2. **Implementation Planning.** It is not often that an organization has the latitude to plan so well in advance for a technological adoption at a later date. The inevitability of RFID is fairly established, so one challenge that labs must embrace is establishing an implantation plan for their future adoption. This may involve early purchase, for instance, of bar-code scanners that can also read RFID, or perhaps of planning shelving upgrades in storage lockers so that they are RFID-friendly (i.e., wood or plastic shelving). Finally, labs need to consider whether RFID will be a pervasive tagging technology, or only used for certain items or item aggregations (i.e., a bin that is RFID tagged that contains an entire case).
3. **LIMS Planning.** Although technically a subset of implementation planning (see above), LIMS planning deserves significant attention. In our work on this project and our earlier

LIMS study, we have noted (and have been advised by lab personnel) that many LIMS are difficult to integrate with new devices and tagging systems. Labs need to work with their LIMS development teams (whether they are in-house or outside vendors) to ensure that their LIMS can be easily modified to embrace RFID capabilities and RFID technologies. This is a non-trivial recommendation; many labs that have sought to embrace new technologies tied to their LIMS have been significantly slowed by the inability of LIMS developers to quickly interface with new machines, tagging systems, etc. Although not every contingency can be anticipated, LIMS revisions need to be RFID-ready.

A number of applications exist for RFID in criminalistics laboratories beyond the basic evidence tracking applications that we have focused on in this analysis. We have summarized in Appendix C several of these applications as well as limitations affecting the feasibility of adopting these applications in the short term. As with evidence tracking applications, laboratory stakeholders should monitor the prices and technology advances and periodically reevaluate the feasibility of these alternatives.

DISSEMINATION DISCUSSION

The objective of this report is to provide individual crime laboratories with useful documentation regarding our findings and recommendations on developing RFID-based inventory systems. Based on our own experience of developing an RFID system for this project and the subsequent feedback supplied by the site visits, we have developed an adoption guideline in Appendix D and corresponding matrix of commercially available RFID products and vendors in Appendix E. The guideline is a valuable tool in the decision making process for forensic labs

when determining whether or not to adopt this technology. The matrix of commercially available RFID products will save time when investigating which equipment is best suited for a lab's RFID requirements because it is an accumulation of information from various vendors.

There are two planned methods of dissemination that will be used in the near future to share the results for this research project. First, the report will be made available on the MFRC website for the benefit of the labs that have access. Second, we will be demonstrating the benefits and features of using RFID in a crime lab environment to the attendees of the American Society of Crime Laboratory Directors 34th Annual Symposium in San Francisco, California, on October 3-5, 2006. In the long term, the planned method of dissemination will be to publish our results in appropriate journals and forensic science trade publications. By developing a RFID solution and making the results available to the forensic lab industry through various available channels, this information has the potential to assist a lab's decision-making process and ultimately enhance the management of evidence and document tracking even further.

APPENDIX A – OVERVIEW OF RADIO FREQUENCY IDENTIFICATION

RFID History

Modern RFID systems came about as an offshoot of radio technology – the IFF transponder – which originally was used by the British Air Force in World War II to differentiate friendly and enemy aircraft (Asif & Mandviwalla, 2005). An early theoretical paper regarding RFID came in 1948 (Stockman, 1948), and Mario Cardullo’s 1973 patent (Cardullo & William L. Parks, 1973) marked the emergence of a “modern” RFID system which used a passive radio transponder with memory. Christopher Boone of IDC describes RFID as “the oldest new technology” (Krazit, 2004), and Venkatesan & Grauer describe modern RFID systems as new and attractive, as “the standardization and major reduction in cost are turning it into a highly feasible and advanced alternative to the venerable barcode solutions” (Venkatesan & Grauer, 2004). The vision of RFID has been iteratively enhanced and directed by the Auto-ID Center, a partnership of corporations and research universities. The Auto-ID Center (now re-christened Auto-ID Labs of EPCGlobal (Kinsella & Elliott, 2005)) directs research and development, enabling RFID to eventually provide “a global infrastructure that will enable computers to instantly identify any object in the world” (Atkinson, 2004).

RFID System Components

A modern complete RFID system contains integrated transceivers, tags, and a computer system (Davis & Luehlfing, 2004; Porter, Billo, & Mickle, 2004), and basic systems consist of an antenna, transceiver (with a decoder), and the tag itself (Venkatesan & Grauer, 2004). RFID tags need not be packaged inside rugged shells; “Smart Labels” are RFID tags that are mounted on a very thin substrate, and are covered with a printable paper surface (Venkatesan & Grauer,

2004). This allowance enables one tag to serve double-duty as both an RFID tag and also a more traditional barcode concurrently. It is important to keep in mind that the operating characteristics of RFID systems may vary greatly according to the nature of the operating environment as well as the demands placed upon the system; an organized and comprehensive battery of tests is given in Porter et al.'s 2004 account (Porter, Billo, & Mickle, 2004).

RFID Tags

When discussing RFID tags, it is important to realize that standards exist for methods and protocols for the processing of data as well as larger-scale connectivity to IT systems. Specifically, the Electronic Product Code (EPC) proposed RFID tag classification outlines five classes of RFID tags, ranging from read-only passive tags to those that are powered externally (via AC power sources) and described as being “essentially readers” (Pradhan et al., 2005). This document is principally concerned with tag types 1 (passive, write-once / read-many RFID tag) and 2 (passive, read/write tags with additional functionality). These RFID tags include an integrated circuit and an antenna, which is tuned to accept specific wave frequencies, which in turn dictates how the tag will respond under certain conditions. Table 2 in Bridgelall's 2003 conference publication (Bridgelall, 2003) demonstrates differences among key frequency ranges present within RFID tags. Two main types of RFID systems are available: High Frequency (HF) and Ultra-High Frequency (UHF), and RFID tags work by powering up by, and then responding to, an electromagnetic field. HF systems employ the magnetic component of this field to transfer data and power through inductive coupling, while UHF systems make use of an electric field and capacitive coupling (Hartman, 2004). In general, high-frequency tags have faster information transfer rates (Kinsella & Elliott, 2005) in addition to longer transmit distances than low-frequency tags (Wilding & Delgado, 2004b), but are less likely to pass signals through

non-metallic materials and typically require an air gap between the interrogator and the tag itself (Davis & Luehlhing, 2004). However, these properties exist outside of a “prescribed” scale – meaning that “[t]here will never be an ideal frequency for all RFID tags” (Thompson, 2004).

RFID versus Barcodes

RFID is typically thought of as a next-generation barcode, and provides the promise of storing data and meta-data *regarding* the item on or about the item. This method of having the data travel with an item opens the door for data exchange across dissimilar systems in much the same fashion as Electronic Data Interchange (EDI) and later eXtensible Markup Language (XML) frameworks provided. RFID helps enable modern warehousing operations, which have very different demands over their predecessors (Chow, Choy, & Lee, 2005). Additionally, RFID tags may be used through open-air gaps to track, trace, and identify tagged items within range of a reader, and enjoy enhanced processing speed (Reiner & Sullivan, 2005; Wilding & Delgado, 2004a) and range over barcodes, as well as providing the ability to mutate the information provided by the tag itself (Davis & Luehlhing, 2004). Unlike barcodes, RFID tags reliably operate under harsh environmental conditions that would render a barcode illegible, and can last for great lengths of time – often longer than the items they are attached to (Michael & McCathie, 2005). RFID tags, too, are “orientation-neutral”, meaning that they do not require a particular orientation for scanning, unlike barcodes (Michael & McCathie, 2005). The cost of RFID systems and tags (Katz, 2006), however, warrants more judicious use of this technology than of barcodes, with small, controlled, and stepwise phase-ins recommended (Barlow, 2005), as hasty implementations have yielded unsatisfactory results (Anonymous, 2005b) in practice. Additionally, software costs of \$50,000 to \$100,000 per location to implement RFID are typical (Kharif, 2004). This cost is appropriate, as Asif & Mandviwalla point out that available

middleware systems are not yet at a “plug-and-play” stage with respect to RFID integration with existing business processes (Asif & Mandviwalla, 2005). Given that adoption of an RFID system will include re-tooling existing software or purchasing new software (Smith, 2005), larger organizations will carry more associated cost with any new RFID deployment. Large warehouses, for instance, are accruing costs upwards of \$2 million (Kinsella, 2003), and large pharmaceutical manufacturers and distributors paying a premium of \$20 million (Becker, 2004) to fully retool software and processes and deploy new RFID systems. Part of this “retooling” that must be undertaken, but is seldom mentioned, is the possibility of having to alter shipping containers and materials (Kempfer, 2005) in order to best suit an RFID-tagged environment. With respect to cost, the price of *each tag* might be particularly off-putting to smaller enterprises that cannot possibly justify tracking an item that costs a nickel with a fifty-cent RFID tag (Biederman, 2006), and provides a much larger hurdle than software costs within a new RFID installation (Sarma, 2004).

2D Barcode Overview

A 2D barcode, also known as a matrix code, is a two-dimensional way of representing information. 2D barcodes- 2D meaning “two dimensional”- is similar to a linear (1-dimensional) barcode, but has more data storage capability. Conventional barcodes get wider as more data is encoded, while the 2D barcodes make use of the vertical dimension to pack in more data. 2D barcodes have become possible as auto scanning CCD and laser scanners have replaced the original 'light pen' type of scanner. There are different types of 2D Barcode; 2 of the most common are the PDF417 and Data Matrix.

PDF417

PDF417 is a high-capacity two dimensional bar code that can hold approximately 2,000 characters, whereas a traditional linear bar code has a limit of 30 characters. The key characteristic of the PDF417 is its large information capacity. PDF417 is designed with enough capacity to contain an entire data file of information. This type of barcode is the one included on the driver license in many states.

Data Matrix

Data Matrix can store up to 2,000 characters. The symbol is square and can range from 0.001 inch per side up to 14 inches per side. The information stored in this barcode depends on the mix of ASCII, numeric and hex data, as well as the compaction ratio. The compaction ratio largely depends on the composition of the data itself. The maximum number of ASCII characters is 2,335 and for numerical digits the maximum is 3,116.

Types of 2D Barcode Printers

There are two types of 2D Barcode Printers: Direct Thermal and Thermal Transfer.

Direct Thermal

Direct Thermal printers work by using the heat of the print head to cause a reaction in the coating of the label paper. Basically the printer burns the barcode onto the label. This direct process does not need a ribbon but it can only print on special labels made for direct thermal printers. The downside to this type of printing is that labels will not last a long time. After a period of time the barcode will start to fade and the label will start to blacken. The bottom line is that direct thermal printing is an inexpensive way to print labels intended for temporary use. If you need a label to last longer you should consider using a thermal transfer printer.

Thermal Transfer

Thermal transfer printing produces crisp images onto labels. Heat is still used in this process except the heat does not come in contact with the label. Instead the hot print head causes the resin of a ribbon to form a high quality image on the label. The downside to this kind of printing is the use of ribbons makes it an expensive solution. On the other hand it delivers higher quality print images and more durability, as well as more flexibility in the kind of paper in which is possible to print.

RFID Standards

With any relatively new technology comes the issue of standardization and interoperability. A recent and very telling report gives less than one-third of respondents agreeing that RFID has reached “an appropriate level of maturity” in its standards (Kirsche, 2005). The three key organizations with respect to RFID protocol and data standardization are the International Standards Organization (ISO), EPCglobal, and Wal-Mart. ISO provides three standards for RFID technology: “ISO 14443 (for contactless systems), ISO 15693 (for vicinity systems, such as ID badges), and ISO 18000 (to specify the air interface for a variety of RFID applications)” (Weinstein, 2005). EPCglobal, on the other hand, has proposed an Electronic Product Code (EPC) standard, covered more fully elsewhere in this document and in its entirety within Pradhan et al. (Pradhan et al., 2005). Paralleling Domain Name Service (DNS) in computing, EPCglobal has developed the Object Naming Service (ONS), which enables organizations to look up product (EPC) numbers on the Internet (Pradhan et al., 2005; Weinstein, 2005). EPCglobal’s proposed standards are largely incompatible with ISO 18000, with the exception of class 0 and 1 tags (Pradhan et al., 2005). In the midst of disagreements about standardization and RFID data structures, Wal-Mart – a member company of EPCglobal – rejected the ONS service and will instead develop a proprietary system of database and format

types. Without a framework of standards as robust and fixed as those supporting barcode technology, even researching RFID can be potentially cumbersome and expensive – in 2004, drug chains spent \$2 million in *studying* RFID (Kirsche, 2005). With the current lack of agreement and direction of industry standards, interoperability issues may arise at the data-store level and render a tag un-readable or –writeable. Additionally, a lack of standards may also hinder communication and tune-up at the air interface protocol level, leading to potential interoperability between equipment from different vendors (Asif & Mandviwalla, 2005).

Inventory Location (Item-Level Tracking)

Some Ford Truck plants are using RFID systems to enable employees to rapidly locate specific types of trucks (Davis & Luehlfing, 2004), as opposed to having to serially search each truck in succession. Location aside, RFID technology (when applied at the item level) enables individual items within a pallet or container to be read without having to open the container (Anonymous, 2003, Atkinson, 2004 #107). RFID giant Wal-Mart understands the importance of item-level tracking: this type of tracking can yield a real-time view of physical inventory within the store and subsequently take action when this inventory is low for any given item (Weinstein, 2005). Hospitals, too, are cognizant of the importance of inventory localization; in four of the top 15 hospitals, RFID tagging enables real-time reports on the removal of supplies from RFID-enabled cabinets (Anonymous, 2005c). In a stunning example of the cost savings possible through realization of inventory location via RFID over more traditional methods, Sun decided to RFID tag the contents of its Newark, CA testing lab. In doing so, Sun now has real-time environmental data about each object, even if it is not attached to a network – and spent \$200,000 rather than \$2 million in conducting the inventory (Bednarz, 2005).

Inventory Management

Through the item-level tracking capability that RFID provides, item inventories may be quickly taken, and the “data about location, design and history” (“Streamlining the Supply Chain Using Radio Frequency Identification”, 2004) may help to avoid out-of-stock scenarios and paint a clear picture of current inventory stocks (Reiner & Sullivan, 2005). The RFID Research Center at the University of Arkansas found a 16% lower out-of-stock rate when RFID and electronic product codes are used to track inventory than when not; furthermore, the items that *did* experience an out-of-stock condition were replenished three times faster when tagged with RFID as opposed to tagged with barcodes (Biederman, 2006). Research has also demonstrated out-of-stocks to occur 17% of the time for some fast-moving items (Michael & McCathie, 2005), while RFID-enabled environments are able to carry less stock on hand and still avoid an out-of-stock condition (Brown, 2006). This second point demonstrates the value of good inventory management control – being able to say *what* you have in stock with accuracy, as opposed to the current “dirty little secret of warehousing” in which “nobody really knows what is back there on the shelves” (Yano & Hartman, 2005). Building on the notion of using item-level tracking as an item inventory, one study (Anonymous, 2005d) has demonstrated that RFID-enabled stores are 63% more effective in stock re-ordering and replenishment than typical stores. This is an important concept, as Boston-based AMR Research has quantified the importance of tightly controlling inventory count through RFID technology: RFID tracking could “trim warehouse labor by 20%, slash inventory by 25% and boost sales by 3% to 4%” (Ward, 2004). Finally, inventory management through RFID tagging gives rise to enhanced quality control through allowing an individual item to be tracked at every stage of manufacturing and distribution (Earnshaw, 2004).

Supply Chain Management (SCM)

Supply Chain Management (SCM) describes the logical flow of product components and their finished products from the supplier to the consumer. Chappell et al. give a straightforward pictogram of this chain in Figure 1 of their work (Chappell et al., 2002). Even though SCM describes movement of product through a “chain” of resellers and distribution points, the analogy is not unlike what forensics laboratories face in creating an unbroken chain of custody. Indeed, in the subsequent discussion regarding retail distribution, Chappell et al. touch on problems faced by forensics laboratories: labor costs, inventory (evidence) accuracy, shrink (as it relates to inventory tracking and location awareness). Additional parallels may be found in the “Auto-ID in Distribution” section (Chappell et al., 2002), wherein the forensics laboratory may see maximal benefit of RFID tagging insofar as reducing “touches” within the overall business processes that underlie logging and moving evidence into, out of, and through the forensics laboratory. These business processes, it should be noted, are less constrained under RFID tagging and may therefore become more fully adaptive (Sutherland & Heuvel, 2006). RFID gives supply chain visibility, says Wal-Mart RFID strategy manager Simon Langford (Donoghue). RFID systems aid supply chain management (SCM) at many levels: SCM tasks may be automated, resulting in cost-saving labor reductions, items remain visible through the end to end supply chain, and shipping containers may be reused with the same RFID tag in place (Michael & McCathie, 2005). Additionally, product recalls and warranties are easier to enforce with RFID technology, and item security is also enhanced within the supply chain (Michael & McCathie, 2005). RFID gives partners on both sides of the supply chain the type of tracking technology that is able to resolve questions regarding what items were delivered and when (Caputo, Pelagagge, & Scacchia, 2003), and it is this type of information – along with the tracking capabilities implicit within the technology – that provide the potential for a robust

evidentiary chain of custody for forensics laboratories and thus allow firms to fully “rationalize” their supply chains and processes (Asif & Mandviwalla, 2005). When examining end-to-end supply chain and the potential for cost savings, Wal-Mart’s supply chain plays a large role. Wal-Mart, spurred on by an estimate from Sanford C. Bernstein & Co. demonstrating annual savings at nearly \$8.4 billion (Roberti, 2003) given RFID deployment in both the supply chain and in stores, mandated its top 100 suppliers to tag at the case- and pallet-level by January 2005 (“Healthcare Finding More Uses For Wireless”, 2003; Kinsella, 2003; McKelvin, Williams, & Berry, 2005; Mullen, 2004; Ward, 2004; Weinstein, 2005). This is a logical extension of large-scale SCM demands, and helps assure a “flattening” of product and inventory spikes and sags in the end-to-end process, instead yielding a flatter demand which may be used to more accurately forecast inventory ingress and egress (Lapide, 2004).

Pharmaceutical Use

Earlier, the staggering costs associated with RFID implementation were discussed. However, these costs are miniscule when compared to the potential annual savings of \$1 *billion*, as measured by the Healthcare Distribution Management Association’s Healthcare Foundation, to pharmaceutical manufacturers (Becker, 2004). Above and beyond this savings comes the secondary benefit in battling counterfeit drugs (Greenemeier, 2003; Havenstein, 2005; Malykhina, 2004) through serialization – at a hefty \$400 million (Becker, 2004) – as “there are too many opportunities to introduce counterfeits into the supply chain” (Kempfer, 2005). And RFID technologies may aid in the delivery and taking of drugs, mistakes in which cost \$75 billion annually in “medical care, lost work time and lawsuits” (Schoenberger, 2003). In addition to other benefits discussed above, RFID tags are also difficult to forge without a large degree of sophistication, thus enabling their use in securing item identity. Indeed, RFID

technology has been specifically showcased in the pharmaceutical industry as the “technology with the strongest potential for securing the supply chain” (“Combating Counterfeit Drugs”, 2004). Along with Wal-Mart’s January 2005 mandate to its top 100 suppliers to become RFID-compliant, Wal-Mart also extended this directive to include its top 30 pharmaceutical suppliers (Ward, 2004). RFID tagging helps to detect products that are unacceptable in some fashion (expired, discarded, returned, or recalled) (Caton, 2004; Reiner & Sullivan, 2005), and this is invaluable in the pharmaceutical arena.

Item Tracking and E-Pedigree

A key element present in RFID systems is the ability to transparently track and trace a tag as it goes through a process – be the process one of physical manufacturing or a logical process of chain of custody. Being able to trace a product’s “lineage” through a system is especially important when product failure can cost lives, as in transportation and pharmaceutical sectors. Airlines “track every part for engines and brakes and other components on each airplane, no matter how small the plane may be”, and drug manufacturers track the date of manufacture as well as process variables (Tryling, 2005). Pragmatically, too, in the face of skyrocketing drug counterfeiting cases (Soumilya & Priyanka, 2006), the RFID capabilities of tracking and tracing inventory are especially appealing. Although traditional security devices exist – such as packaging, holograms, special inks and material layers – RFID can act to augment existing security nets that surround products (Koroneos, 2005; Murphy, 2003) and provide properties that inks and dyes cannot. As between 2 and 7% of pharmaceuticals are counterfeit (Bednarz, 2004), the additional security offered by RFID-tagging has very real effects within the pharmaceuticals sector. Tracking an item’s progress through the manufacturing and distribution process by combining EPC with RFID creates an electronic pedigree (Thompson, 2004). To wit,

pharmaceutical manufacturers have been formalizing product tracking and are developing “e-Pedigree” programs, able to report both *authenticity* and *pedigree* of product (Burt, 2005; Caton, 2004). Some of this impetus has come in the form of legislation – Indiana, Florida and California, for example, all have drug pedigree laws (Forcinio, 2005; Kirsche, 2005), and more states are sure to follow suit (Kirsche, 2005).

Extra-Crime Laboratory Use

Typically, and for the primary thrust of this paper, RFID use in and around law enforcement environments centers around RFID within a forensics laboratory. Indeed, many of the points touched upon above (specifically item-level analysis, supply chain management advantages, tag durability, and parallelization of item scanning) are ideally suited for the forensics laboratory environment. However, the application of RFID technology can actually begin earlier in the evidentiary material’s lifespan – in the field with collection. If, for example, evidence collection were taking place within the field in coordination with RFID-tagged evidence containers (e.g. bags), then this single RFID identifier could follow the evidence through its examination lifecycle and provide a common identifier for the material, even across the domains of evidence collection and analysis. A system like the one presented and subsequently dubbed “MsSAM” (Baber, Smith, Cross, Zasikowski, & Hunter, 2005) prevents data-input replication, stores information about the item on an RFID tag, and has the added benefit of being able to interface with peripheral devices to give a more thorough and transparent collection experience to crime scene investigators. As such, the completion time (e.g. the time a novice respondent takes to fill out a dossier on a “case” comprised of three items) was significantly reduced over paper-methods, as was both volume and specificity of information provided (Baber, Smith, Cross, Zasikowski, & Hunter, 2005).

Intra-Crime Laboratory Use

RFID technologies have the capability to excel within a laboratory environment. One large vendor has developed a “Smart Test Tube System”, which allows 96 test tubes to be scanned in less than 36 seconds, making it “ideal for clinical trial, and other laboratory applications” (“Maxell RFID Systems and Products”, 2005). Individuals manually searching for a specific test tube in a rack of 100 RFID-tagged samples quickly and easily read all tags in under 3 seconds (Anonymous, 2005c). Additionally, as RFID systems offer “chain of custody, archiving, and data retention requirements, RFID technology is a progression toward meeting 21 CFR Part 11, CLIA, CAP or HIPAA compliance, particularly regarding information security and confidentiality” (“Maxell RFID at Work”, 2005). With augmentation such as microsensors, RFID technology can report real-time data that reflects the *condition* of the tagged item, as well as its *location* (Venkatesan & Grauer, 2004). Even now, however, RFID tags carry the ability to provide product-level data (e.g. an evidentiary item) *and also* meta-data that *describes* this item (e.g. a photograph of the item). This has been leveraged in pharmacies to conduct order verification (Anonymous, 2005a), but it is no small stretch of logic that describes its natural utility within the crime laboratory as well. Within a laboratory context, RFID tagging – specifically, Generation 2 RFID tags, which support authentication (Gruman, 2005) – can tie employees to items within the laboratory. NASA is using a system that correlates individual employees to the chemical containers they are handling, and can also dictate *which* employees are able to read RFID tag information. This system, located at the Dryden Flight Research Center, is also able to alert security staff if chemicals are moved improperly or used too heavily (Gruman, 2005). With respect to data security, a forensics laboratory must be judicious in its selection of data to apply to an RFID tag, especially if this tag is slated to remain with the item

throughout its judiciary life. While this is an ideal benefit of the technology, whenever a tag circulates in the public domain – as in the above instance in creating a vastly improved chain of custody accounting – privacy becomes an issue (McKelvin, Williams, & Berry, 2005). Coupled with this comes the fact that RFID tags may carry *so much* information with them; in this sense, RFID tags in the public space really serve to open a window into a forensic laboratories' inner workings and data fields and may prove too revealing, while a traditional UPC barcode may only identify a product type and manufacturer (Lapide, 2004).

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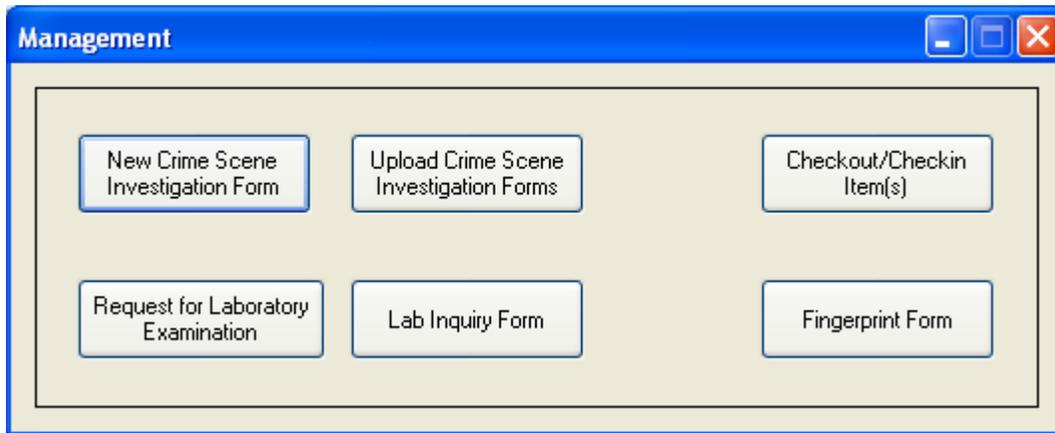
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APPENDIX B – COMPONENTS OF THE RFID PROTOTYPE

Prototype Switchboard Management Form

Description: This form is used to access all components of the RFID prototype.



Crime Scene Investigation Form

Description: This form represents a data entry form that could be used by crime scene investigators. Each field can be entered using either handwriting, typing, or selecting values from a combo box.

Offense Case ID:

Agency ID:

Officer ID:

Incident Location:

Case Type ID:

Agency Case ID:

Offense Date:

Incident County ID:

Victim

Victim	Date of Birth	Sex	Race
<input type="text"/>	<input type="text" value="10/25/2006"/>	<input type="text"/>	<input type="text"/>
John Doe	8/25/1976	Male	White

Suspect

Suspect	Date of Birth	Sex	Race
<input type="text"/>	<input type="text" value="10/25/2006"/>	<input type="text"/>	<input type="text"/>
Jane Doe	3/22/1973	Female	White
John Smith	4/2/1967	Male	White

Evidence

Item Number	Agency Item Number	Quantity	
<input type="text" value="1"/>	<input type="text" value="2"/>	<input type="text" value="1"/>	<input type="button" value="Browse"/>
<input type="text" value="pistol"/>			<input type="button" value="Remove"/>



Item Number	Agency Item Number	Quantity	Description
1	2	1	pistol
2	45	1	a knife

Crime Scene Synopsis

weapon found in dumpster

Evidence Item

Description: The Evidence Item form is presented to the user when the Crime Scene Investigation form is saved. The Evidence Item form is used to associate a piece of evidence with an RFID tag, prepare a 2-D barcode label, and print the label. The user would prepare the label and associated the RFID tag by selecting an evidence item and clicking “Scan RFID.”

The screenshot shows a software window titled "frmScanRFID". At the top, there is a table with the following data:

Item Number	Agency Item Number	Quantity	Description
5	6	1	a knife
6	7	1	a pistol

Below the table is a "Scan RFID" button. To the left of the main report area is a large QR code. The main report area, titled "Main Report", contains a preview of a printed label. The label is titled "Evidence Item" and includes the following information:

10/10/2006 7:58PM
Officer ID 4
Agency ID 3
Signature _____
Evidence Item Number Lab 5
Evidence Item Number Agency 6
Evidence Item Description a knife

Fingerprint Form

Description: The Fingerprint Form represents a data entry form that could be used by crime scene investigators to label and enter descriptions for individual fingerprint lift cards. All fields in the form with the exception of the Evidence Item Description are automatically populated with data from the primary crime scene investigation form. This will allow the field investigator to automate the process of filling out finger print cards.

Offense Case ID: 1

Agency Case ID: 5

Item Number: 9

Lifted By: 5

Lifted From:

Evidence Item Description:

Insert Fingerprint

Fingerprint

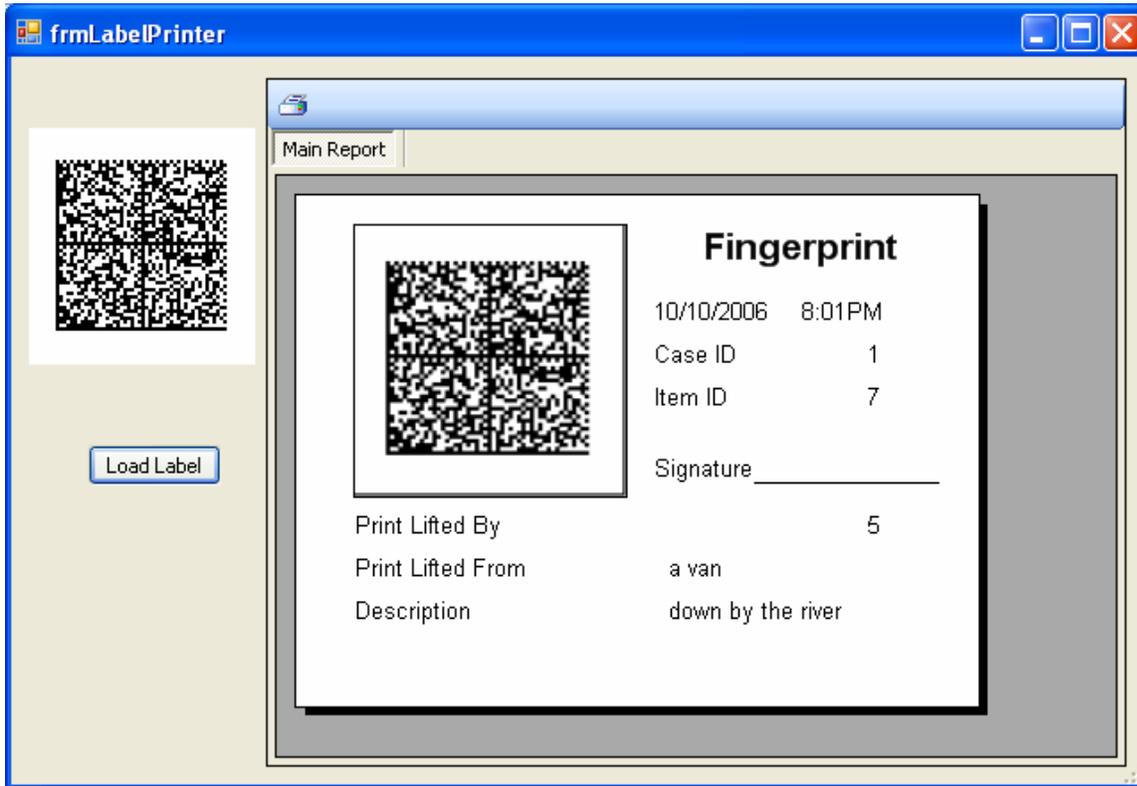
Evidence Item Number	Lifted By	Lifted From	Description
7	5	a van	down by the river
8	5	a car	up by the stream

Print Barcode

Save

Fingerprint Label Form

Description: The Fingerprint Label Form is presented to the user when the user selects Print Barcode on the Fingerprint Form. The Fingerprint Label Form is used to print a 2-D barcode label that can be affixed to the back of a fingerprint lift card. The user would prepare the label by clicking “Load Label” and then clicking the printer icon.



The screenshot shows a Windows-style application window titled "frmLabelPrinter". On the left side, there is a 2-D barcode and a "Load Label" button. The main area displays a "Main Report" window containing a fingerprint label form. The form includes a 2-D barcode, a title "Fingerprint", and various fields for case information, signature, and description.

Fingerprint	
10/10/2006	8:01PM
Case ID	1
Item ID	7
Signature	_____
Print Lifted By	5
Print Lifted From	a van
Description	down by the river

Scan Item

Description: The Scan Item form is designed to enable a user to select an evidence item and open a laboratory examination form. This form is designed to enable a user to use either a 2-D barcode scanner or an RFID reader to scan one or more evidence labels. The evidence items that are identified by the scanning process will be displayed in the window. Once displayed, a user may select an item and open an examination form.

Item Number	Agency Item Number	Quantity	Description
1	2	1	a knife
2	3	1	a pistol

Request for Laboratory Examination

Description: This form represents a data presentation, records update, and data entry form that could be used by bench scientists and criminalists. The form will be populated with existing case and evidentiary data when loaded by the analyst. The analyst can also add new data using either handwriting, typing, or selecting values from a combo box.

Request for Laboratory Examination Form

Offense Case ID	<input type="text" value="1"/>	Case Type ID	<input type="text" value="4"/>
Agency ID	<input type="text" value="2"/>	Agency Case ID	<input type="text" value="5"/>
Officer ID	<input type="text" value="3"/>	Offense Date	<input type="text" value="10/19/2006"/>
Incident Location	<input type="text"/>	Incident County ID	<input type="text" value="6"/>

Victim

Victim	Date of Birth	Sex	Race	
<input type="text"/>	<input type="text" value="10/23/2006"/>	<input type="text"/>	<input type="text"/>	<input type="button" value="Insert Victim"/>

Victim	Date Of Birth	Sex	Race
andy luse	10/19/2006	Female	White

Suspect

Suspect	Date of Birth	Sex	Race	
<input type="text"/>	<input type="text" value="10/23/2006"/>	<input type="text"/>	<input type="text"/>	<input type="button" value="Insert Suspect"/>

Suspect	Date Of Birth	Sex	Race
beth luse	10/19/2006	Female	White

Evidence

Item Number	Agency Item Number	Quantity			
<input type="text" value="1"/>	<input type="text" value="2"/>	<input type="text" value="1"/>	<input type="button" value="Browse"/>	<input type="button" value="Remove"/>	<input type="button" value="Insert Item"/>

Evidence Item Description



Exam Code	Comment	
<input type="text"/>	<input type="text"/>	<input type="button" value="Delete"/>

Item Number	Agency Item Number	Quantity	Description	Exam Code	Comment
1	2	1	a knife		

Crime Scene Synopsis

Checkout/Checkin Items

Description: The Checkout/Checkin Items form is designed to enable a user to select an evidence item and check it in or out of its current storage or analysis location. An analyst will first be asked to authenticate who they are by scanning their RFID tag (note: this process could be fully automated). A user could then use either a 2-D barcode scanner or an RFID reader to scan an evidence RFID/barcode label. The evidence items that are identified by the scanning process will be displayed in the window. Once displayed, a user may select an item and check it in or out; thus, transferring custody from one analyst or location to another.

Item Number	Agency Number	Description
<input checked="" type="checkbox"/> 2	3	a pistol

Lab Inquiry Form

Description: This form represents a data presentation, records update, and data entry form that could be used by bench scientists and criminalists. The form will be populated with existing case and evidentiary data when loaded by the analyst. The analyst can also add new data using either handwriting, typing, or selecting values from a combo box.

Lab Inquiry Form

Offense Case ID	<input type="text" value="1"/>	Case Type ID	<input type="text" value="4"/>
Agency ID	<input type="text" value="2"/>	Agency Case ID	<input type="text" value="5"/>
Officer ID	<input type="text" value="3"/>	Offense Date	<input type="text" value="10/19/2006"/>
Incident Location	<input type="text" value="kllfd"/>	Incident County ID	<input type="text" value="6"/>

Victim

Victim	Date of Birth	Sex	Race	
<input type="text"/>	<input type="text" value="10/25/2006"/>	<input type="text"/>	<input type="text"/>	<input type="button" value="Insert Victim"/>

Victim	Date Of Birth	Sex	Race
andy luse	10/19/2006	Female	White

Suspect

Suspect	Date of Birth	Sex	Race	
<input type="text"/>	<input type="text" value="10/25/2006"/>	<input type="text"/>	<input type="text"/>	<input type="button" value="Insert Suspect"/>

Suspect	Date Of Birth	Sex	Race
beth luse	10/19/2006	Female	White

Evidence

Item Number	Agency Item Number	Quantity			
<input type="text" value="1"/>	<input type="text" value="2"/>	<input type="text" value="1"/>			



Evidence Item Description

a knife

Exam Code **Comment**

<input type="text"/>	<input type="text"/>
----------------------	----------------------

Item Number	Agency Item Number	Quantity	Description	Exam Code	Comment
1	2	1	a knife		

Crime Scene Synopsis

wow yu

Item Num	Take Possession	Release Possession	Personel ID
1	10/19/2006 2:54:28 PM	10/19/2006 2:54:32 PM	Mennecke
1	10/25/2006 12:18:55 PM		Townsend

APPENDIX C– RFID: POTENTIAL AREAS OF USE

Area of Use	Benefits	Limitations
Inventory Management in the Lab	<p>Misplaced items can be recovered by their RFID tag with a search through all inventory items.</p> <p>The data from the RFID tag that is attached to the evidence can be updated with the chain of custody.</p>	<p>The current cost of tagging every item in inventory could be limiting.</p> <p>The lab’s shelving units could pose a problem if shelving units or containers (e.g., paint cans) are made primarily of metal.</p>
Field Data Collection	<p>Evidence items can be tagged at the point of contact. The advantage of associating evidence items with RFID tags in the field is that data would be more accurately captured and RFID tags have the potential to improve the logging of case and evidentiary data into LIMS.</p>	<p>The RFID printers are still large and not currently built for mobility.</p> <p>Keeping the equipment clean and free of cross-contamination would take changes in processes and greater care during handling and processing.</p>
Continuous Evidence Traceability from the Field to the Lab	<p>The tagged evidence could be monitored from the crime scene to the point of check-in into the lab. Chain of custody would be verified and monitored throughout the handling process from the location of the crime to the laboratory evidence intake station.</p>	<p>To establish complete minute to minute monitoring, more expensive active RFID tags would be required.</p> <p>If passive tags were used, specific checkpoints would be needed to be added to the field collection and management process to verify custody and provenance.</p>
Auditing Control	<p>If all items are tagged from the point of contact and proper procedures were in place for check-in and check-out, audits could be implemented to generate an accurate account of where all evidence is located at a given point in time.</p>	<p>As in other areas of use, the cost of tagging every item of evidence is costly.</p> <p>It would also be imperative that RFID middleware software could automatically log and verify for users the chain of custody so as to minimize any error.</p>
Data Management	<p>The use of RFID tagged evidence could be used to house data on the RFID tag itself as well as offer a means of electronic data transfer to a LIMS system without the need for paper.</p>	<p>It will be required that a laboratory’s LIMS system be capable of accepting data directly from the RFID middleware. Most RFID applications store and transfer data using XML</p>
Access Control and Cross-Contamination Control	<p>RFID tags on evidence could work much like employee access badges; thus, restricting or authorizing access into areas of the laboratory where the evidence either should not or should be located. This should help reduce the potential that evidence would</p>	<p>RFID, LIMS, and facilities management systems would need to be integrated.</p> <p>Evidence management processes and analysis sequences would need to be pre-specified and documented in the information systems.</p>

be analyzed out of a predefined order and/or reduce opportunities for cross-contamination of evidence

Currently, many laboratories do not integrate the analysis process into LIMS in such a way that restrictions and controls could easily be automated.

The technology may not be easily implemented to cover all scenarios of access control. For example, when large numbers of evidence bags containing small-sized evidence items are packaged together, it is possible that tags may not be read properly.

APPENDIX D– IMPLEMENTATION GUIDE

Adoption and Implementation Guidelines for RFID Systems

When adopting or building an RFID system, it is important to develop an implementation plan that considers all of the important steps in the systems development process. The systems development process is often described as the *Systems Development Life Cycle (SDLC)* and is a standard part of the process used by most organizations today to develop new information systems. This linear and methodical approach to building systems is designed to assist project team members (e.g., systems engineers, software analysts, programmers, project managers, etc.) and other stakeholders with a standard and systematic methodology for planning, implementing, maintaining, and controlling the projects (Enger, 1982). The typical phases of SDLC are shown in Figure 1. The first phase is systems investigation, which includes systems definition and problem identification. The second phase, systems analysis, includes feasibility analysis, on technical, operational, legal and schedule bases. The third step is systems design, which involves determining the requirements and how to satisfy them. Next is implementation, which includes hardware and software procurement, software programming, systems integration and testing, and data conversion. Finally, system maintenance continues for the life of the system. Some information systems professionals use slightly different terminology and package these steps differently, but these are the basic functions and tasks that must be completed in order for a new system to be properly built or bought.

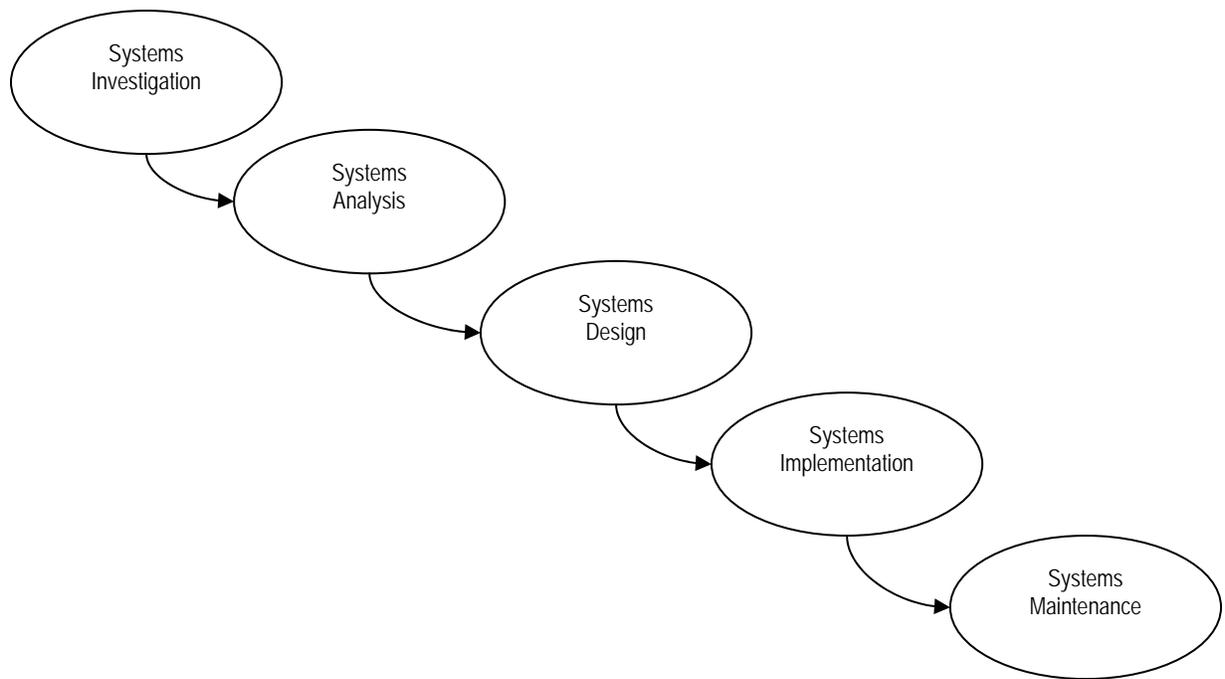


Figure 1: The Typical Systems Development Life Cycle

System Definition

Systems Investigation is the first phase and has the purpose of defining the nature of the development task and the boundaries for the project. This task is important because the definition that is developed sets the project's scope. For example, the agency or laboratory could define the system problem as a very broad RFID system which would incorporate all aspects of laboratory management or it could be focused very specifically on some specific laboratory function such as evidence inventory management or chain of custody. Problem definition and identification is the stage of the project where the scope of the proposed RFID solutions will be identified and specified. Failure to reach consensus on the definition of the scope of the system or the nature of the problem early in the project could lead to communication errors, development mistakes, and management debates in subsequent phases of the SDLC process. If an RFID project begins with

a poorly scoped and specified problem definition the project could ultimately culminate with an unsuccessful system implementation.

Feasibility Analysis

Feasibility analysis should generally be undertaken early in the process of acquiring a new RFID system. The feasibility of any system is constantly monitored throughout the development or acquisition process. Feasibility analysis begins at an early point in the process, but does not conclude until near the very end of the project. This concurrency is necessary since technical considerations, business function requirements, or economic changes may force the agency or laboratory to abandon an ongoing process if the new system no longer represents a viable solution due to a significant change in the problem.

The feasibility analysis must address several different types of issues. Often, feasibility is considered in terms of the financial or budgeting process (i.e., is it affordable?). However, there are a number of other issues that could make the proposed system infeasible.

Technical Feasibility. Technical feasibility pertains to assessing the technical practicality of the proposed RFID system. The analysis should consider the hardware, software, and networking requirements to operationalize the RFID system. Each RFID-solution will have specific requirements associated with hardware and operational standards. For example, because there are a variety of RFID standards, it is possible that one set of RFID components will not interoperate with other components that operate under a different set of standards. Furthermore, many types of RFID tags are more or less suitable for certain applications or environments. Requirements associated with a particular RFID solution could eliminate a specific RFID package from consideration if the incapability cannot be resolved.

Additionally, personnel issues should also be considered in relation to the technological characteristics of the RFID system being considered. Does the organization possess personnel who have the technical skill sets to develop and operate the RFID system? If not, then the laboratory or agency must assess the ability of their current personnel to acquire these skills through training, or consider hiring trained personnel. Alternatively, laboratories may need to consider hiring or contracting with consultants and RFID integrators to help design, build, and/or maintain the RFID system.

Operational Feasibility. Operational feasibility focuses on the appropriateness of the solution for the problem. The first question that should be asked is whether the problem is worth solving. Changes in operational context may render some problems inconsequential by the time a sophisticated RFID solution is developed. Once the law enforcement agency is confident that the problem is worth solving, the organization must assess the urgency of the problem and measure the feelings and thoughts of the end-users and laboratory management towards the proposed solution.

There are many aspects to the proposed solution that need to be addressed in terms of their ability to address the problem. These would include the following questions:

- Is the proposed RFID solution going to provide adequate throughput and performance?
- Will the solution be adaptable to the organization's processes and required operational activities?
- Does the RFID solution have adequate controls to ensure the system is working properly (e.g., can chain of custody be verified if the system fails)?
- Is the data provided by the RFID system adequate in terms of accuracy, timeliness, formatting, and relevance?

- Does the organization have adequate resources to operationalize the system?

Finally, cultural fit with the organization must be considered. Not all laboratories are managed alike. Some are highly centralized while others operate each unit more independently. If the RFID solution interferes with or clashes with the laboratories existing culture or operational norms, then the proposed solution will undoubtedly be met with resistance from both users and managers. Managers and users must feel comfortable with the role they play in any proposed solution. In order for users and managers to support the development and implementation of a new system, it must be user-friendly, easy to learn and use, and add value to the organization. It is often advisable to include these and other stakeholders in the process of designing, building, selecting, and implementing the new RFID solution to reduce potential resistance to the new system.

Legal or Regulatory Feasibility. A solution that meets all of the aforementioned feasibility requirements but is not *legally* viable or in some way violates regulatory constraints will need to be rejected.

Schedule Feasibility. Often organizations assess a multitude of issues concerning the feasibility of a new system. However, schedule feasibility is often given limited attention. Sometimes organizations assume that the only requirement to meet a project's conversion deadline is to add sufficient resources. This can be a serious mistake. Given the estimation of timetables and resource allocation, projects have inherent uncertainty; therefore, proposed schedules tied to projects are often inaccurate. Adequate contingency planning for schedule overruns must be incorporated into any new system implementation project.

Systems Analysis

The second phase of the SDLC is systems analysis. The goal of the systems analysis phase is for the organization to develop an understanding of the current process requirements. This enables the organization to design a feasible and appropriate system solution. The analysis is a two step procedure. The first step focuses on the functional aspects of the work unit processes. The second step examines the technical aspects of the current processes.

Functional Requirements

This first step in analyzing a new system is to determine what needs to be accomplished from a functional standpoint. This process includes an assessment of the functional activities done within the work unit so that the system can be designed to meet the functional demands of the work unit. The analysts must examine the current processes to understand the functions that need to be accomplished. The focus must remain on “what” is to be done and not “how” it is currently done.

Reporting Requirements. An effective way to determine what needs to be done in a process is to examine the reporting requirements. In other words, the question needs to be answered, “*Who* needs to receive *what* data?” The “who” is not a particular individual such as “Ryan Smith”, but a given role within the laboratory, such as “Evidence Technician.” By focusing on the information that needs to be provided, the system developers can determine the output requirements for each functional process.

Data Capture Requirements. The result of the analysis of the reporting requirements will be a set of data capture requirements. Once the output of a functional process has been determined, the process steps can be analyzed to determine what data must be captured in order to fulfill the reporting requirements. In general, the analyst will continue to be concerned with *what* data is acquired. In general, the best design will emphasize functional requirements over the

technical design. For example, a solution developed considering reporting requirements before the data capture requirements will tend to look for information to share that may have a lower information value or priority.

Technical Requirements

While the analysis process should be driven by functional analysis, technical requirements will also need to be considered. The analyst must document the overall architecture of the existing LIMS and consider how the RFID solution will fit within this architecture. For example, any new solution will likely have to be integrated with the existing bar code system, LIMS, and agency systems. This will require an analysis of not only the laboratory's systems and operations, but also those of partner agencies and clients.

Furthermore, many other technical considerations must be documented. These include networking infrastructure and connectivity, RFID system throughput and storage capacity, the number and positing of available antennas, interrogators, and other RFID network nodes, the volume of transactions handled by the RFID system, system interface requirements, and data exchange requirements. Furthermore, as with any technology a consideration must be made of how contingencies and exceptions will be handled when the RFID system fails or it is unable to handle exceptional processes.

Functional Design

Upon completion of the main steps associated with systems analysis, the design of a solution that will satisfy the functional requirements of the system is begun. As with functional analysis, the focus of functional design is on the process and not the technical aspects of the system. The focus of this activity is to develop a solution designed to meet the reporting requirements of the process. The solution will also need provide information about where the

data is created, updated, and deleted within the proposed solution. In this context, it is important to create process and data flow models that document the way that both the old system and the new system will operate.

Technical Design

The functional design will necessarily drive the technical design of the proposed solution. The primary focus of the technical design will be to provide developers with specifications for connectivity, data sharing, and data manipulation requirements of the functional design in order to meet the process requirements.

Implementation

Personnel Training

There are two types of personnel training; computer personnel and user training. Computer personnel, such as system developers and system operators will need to learn about issues and constraints associated with radio frequency technology, systems for managing and transferring data to and from RFID components, RFID hardware systems, and new software and data management tools (e.g., XML). This training will need to take place prior to the data conversion and system implementation stages. Training of the development team and operational personnel is one of the most overlooked aspects of systems development, yet training will generally need to be one of the first technical requirements to be completed.

Even users who work closely with the development team to create the system specifications will require user training. An RFID system will operate with unique and novel technologies and processes and will require that users are familiar with these technologies and their proper use. If adequate time and resources are not dedicated to user training, the project will likely encounter problems with morale, absenteeism, and system failures.

Data Conversion

Existing data and data management processes must be adapted to be used with an RFID system in a process called data conversion. There are several approaches to conversion. The direct approach entails cutting off the old system and starting up the new system without any intermediate steps. While the most straightforward, this is also the most risky approach because any problems that are subsequently discovered will not be able to be corrected in an orderly fashion. A second approach, a pilot conversion, is completed with the introduction of the new system to only a portion of the laboratory. For example, the system might only be implemented first in the Firearms section. This ensures that problems and issues will have only a limited impact on the laboratory as a whole and repairs or modifications can be made without disrupting the entire laboratory. The phased approach is very similar but requires the introduction of only a limited set of system functionality to the entire organization, thus mitigating the impact of any problems to only a few functions within the laboratory.

The parallel approach is the most resource-intensive approach to conversion. Parallel conversion involves operating both the old and the new systems simultaneously. It is the most robust and fail-safe approach and is probably the most appropriate approach for many laboratories, particularly those that currently use predominantly manual approaches or approaches that use bar codes technologies. The advantage of this approach is that the new system can be directly compared to the old system data for verification. If any inconsistencies are discovered, the old system remains in place and the impact on the accuracy and integrity of data is minimal.

System Creation

System creation represents either the code development or acquisition phases of development. In this phase, programmers create and unit test any code used to integrate or operate the RFID system to ensure that it meets the design specifications outlined in the design documents. In those cases where turnkey or packaged systems are purchased, the products need to be evaluated prior to purchase, integrated into the laboratory's processes, and tested for compliance and integrity. A variety of issues arise when considering purchasing equipment and software, but chief among the considerations that need to be made are the following:

- The relationship the laboratory has with the vendor
- The price of the RFID products and services
- The specific product features
- The reliability and reputation of the vendor and their products
- The technical dependencies that the vendors' products have that may limit scalability and future use.

The point of evaluating the vendor is that the selection of hardware and software is a long term decision, particularly with regard to standards and operational parameters associated with RFID technology. Industry standards associated with RFID tags and interrogators have evolved considerably over the last few years. It is important to examine whether a firm's RFID products meet current and prospective standards and protocols.

System Validation and System Integration

Ensuring that all combinations of transactions and data are handled properly requires that hardware and software be tested in a realistic manner. Failure to dedicate adequate resources to the testing phase will cause geometrically greater losses of data and system integrity once the system is in operation. During integration, hardware and software will be tested in a

comprehensive manner. This phase tests the accuracy and functioning of the system when it is coupled with other related systems, such as existing LIMS. The ability of data to flow and be processed accurately between systems and subsystems is complex and requires an adequate allocation of resources.

System Evaluation and Maintenance

The evaluation and maintenance phase is the final step of the development process. The new system will remain in this phase until it is replaced by a successor system. To assess its functioning and fulfillment of users needs, the RFID system should have periodic formal reviews. Unfortunately, it is commonly the case that systems continue to be used without formal review and enhancements or modifications are made only when users make requests for required changes or there are major problems associated with the existing system. As systems age, the cost and availability of hardware increases and the software language or hardware components used to create the system may become obsolete. As a result, the cost of implementing these changes and the cost of general maintenance tends to increase. Also, technologies such as RFID typically experience an “end of life” condition in which support is no longer available or feasible. Typically a system is maintained until these issues make further maintenance and enhancements more costly than the creation and benefits of a new replacement system.