NIST IR 8030
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http://dx.doi.org/10.6028/NIST.IR.8030

RFID Technology in Forensic Evidence Management

An Assessment of Barriers, Benefits, and Costs

Technical Working Group on Biological Evidence Preservation

Shannan Williams
Melissa Taylor
Jeffrey Irland
Anuj Mehta

National Institute of Standards and Technology
U.S. Department of Commerce

FORENSIC SCIENCES

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Shannan Williams
Special Programs Office
Laboratory Programs

Melissa Taylor
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Jeffrey Irland
Booz Allen Hamilton
Mclean, VA

Anuj Mehta
Booz Allen Hamilton
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November 2014

U.S. Department of Commerce
Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie May, Acting Under Secretary of Commerce for Standards and Technology and Acting Director

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1. INTRODUCTION

Forensic science laboratories and law enforcement agencies have increasingly used automated identification technology[1] (AIT), such as barcoding and radio frequency identification (RFID), to track and manage forensic evidence, firearms, and personnel. AIT streamlines the capture, collection, and transfer of data to track assets and people. RFID technology provides enhanced capabilities including precise location, environmental measurements, and automatic real-time updates of the position and condition of assets in an inventory. The need for further information on AIT's use in evidence management was identified by the Technical Working Group on Biological Evidence Preservation. During its deliberations, the working group commissioned a small study to gain a better understanding of the capabilities of advanced technologies to improve tracking and preservation of evidence broadly.

RFID Technology in Forensic Evidence Management: An Assessment of Barriers, Benefits, and Costs summarizes the study conducted and includes recommendations to law enforcement agencies responsible for the management and tracking of forensic evidence. It provides insight into the current business processes that can benefit from the utilization of RFID, the barriers facing the adoption of RFID within the law enforcement community, and the RFID vendors that provide solutions within the forensics sector. Several working group members provided their expertise and were interviewed to inform the findings of this report. The document also provides a return on investment (ROI) analysis, which is based upon the forensic evidence tracking solution developed by the Netherlands Forensic Institute (NFI). Based on its discoveries, the report concludes with a discussion of the foundational principles that must be established to achieve community-wide adoption and the strategic next steps that should be undertaken by local law enforcement agencies and high-level Federal stakeholders.

1.1 Authors

Shannan Williams, Project Leader, Associate, Forensic Science Program, Special Programs Office (SPO), Laboratory Programs, NIST

Melissa Taylor, Program Manager for Management Practices, Forensic Science Program, SPO, Laboratory Programs, NIST

Jeff Irland, AIT Subject Matter Expert, Booz Allen Hamilton

Anuj Mehta, AIT Subject Matter Expert, Booz Allen Hamilton

1.2 Technical Working Group on Biological Evidence Preservation

Susan Ballou, Senior Program Manager, Forensic Science Program, SPO, Laboratory Programs, NIST

Phylis S. Bamberger, Judge (Retired), Task Force on Wrongful Convictions, New York State Bar Association

Larry Brown, Property Manager, Los Gatos/Monte Sereno Police Department

Rebecca Brown, Director of State Policy Reform, Innocence Project

Yvette Burney, Commanding Officer, Scientific Investigation Division, Los Angeles Police Department

Dennis Davenport, Senior Crime Scene Investigator, Commerce City Police Department

Lindsay DePalma, Contractor, Office of Investigative and Forensic Science, NIJ

Ted Hunt, Chief Trial Attorney, Kansas City, MO Prosecutor's Office

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[1] AIT technologies are also known as Automated Identification and Data Capture Technologies or Automated Identification Systems and often used interchangeably in industry.

Cynthia Jones, Associate Professor of Law, American University

Ralph Keaton, Executive Director, American Society of Crime Laboratory Directors/Laboratory Accreditation Board

William Kiley, Deputy Police Chief (Retired), Past President, International Association for Property and Evidence (IAPE)

Margaret Kline, Research Biologist, Biomolecular Measurement Division, NIST

Karen Thiessen, Chief, Compliance and Oversight Unit, Federal Bureau of Investigation

Gerry LaPorte, Director, Office of Investigative and Forensic Sciences, NIJ

Joseph Latta, Police Lieutenant (Retired), Executive Director, Lead Instructor, IAPE

Linda E. Ledray, Director, Resource Center, Sexual Assault Nurse Examiners/Sexual Assault Response Team

Randy Nagy, Executive Director Business Development, Center for Advanced Forensic DNA Analysis

Brian E. Ostrom, Criminalist 4, Portland Metro Forensic Laboratory, Oregon State Police

Lisa Schwind, Unit Head, Forensic Service and Education, Office of the Public Defender, State of Delaware

Stephanie Stoiloff, Senior Police Bureau Commander, Forensic Services Bureau, Miami-Dade Police Department

Mark Stolorow, Director of Organization of Scientific Area Committee (OSAC) Affairs, SPO, Laboratory Programs, NIST

1.3 Sponsorship

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1.5 Acknowledgements

The authors of this document gratefully acknowledge the *Technical Working Group on Biological Evidence Preservation* in its support in providing data and feedback on the findings of this assessment. The following individuals are also acknowledged for their contributions to the development and review of this report. Reviewers and contributors were not asked to approve or endorse any conclusions or recommendations in the report.

David Novotny, RF Fields Group, Physical Measurement Laboratory, NIST
John Paul Jones, Associate Director of OSAC Affairs, SPO, NIST
Richard Cavanaugh, Director, SPO, NIST
Jim Cleveland, President, Quetel
Dennis Lamb, President, Erin Technology
David Miller, Owner, PERCS Index, Inc.
Steve Taylor, Former Vice President, Technology & Services, Provista
Kim Webley, Owner, File on Q

2. OVERVIEW OF AIT

AIT enables the capture, collection, and transfer of data about objects directly into computer systems with little to no human involvement. Increasingly, AIT is being used by law enforcement agencies to enhance the tracking of forensic evidence in crime laboratories and property and evidence rooms. Table 1-1 details potential uses of AIT in forensic evidence management.

Table 2-1: Potential Applications for AIT in Forensic Evidence Management

Area of Use	Description
Inventory Management	Managing forensic evidence intake, analysis, disposition, and workflows
Chain of Custody	Documenting chain of custody for all forensic items throughout their life cycles and documenting hand-off points between different forensics practitioners
Total Asset Visibility	Providing real-time or near real-time visibility to the location of individual forensic items
In-Transit Tracking	Tracking forensic items as they are in transit between locations or between custodians
Access Control and Authentication	Using AIT to authenticate forensic examiners or designated handlers during the analysis process and to control their access based on defined roles and responsibilities

There are many forms of AIT, but the most commonly used are barcodes and radio frequency identification (RFID). Barcodes are ubiquitous in everyday life, from items at the grocery store to wrist bands tracking hospital patient care. RFID tags, while not as common, are expanding in use as asset management industries recognize the enhanced benefits of the technology. Similarly, while barcodes are used routinely to manage evidence in forensic laboratories and property and evidence rooms, RFID adoption has been limited. Instead of using an optical image to store data about an object, RFID tags use a microchip and an antenna. This key distinction makes them more expensive and complex to implement, but allows greater automation in evidence intake, inventory, and search processes. RFID tags that are operated with batteries, or active RFID tags (described later in section 2.2) provide even greater capabilities such as sensors that monitor the temperature or environment of assets like biological evidence. Barcodes cannot enable direct monitoring in that form.

The enhanced capabilities of RFID in many ways closely match the requirements of the property and evidence management community. Therefore, the primary focus of this document is to describe the capabilities, costs, and benefits of such systems and provide recommendations to agencies looking to implement them. Information on additional forms of AIT can be found in the appendix.

2.1 Barcodes

Barcodes are the oldest, most commonly used form of AIT and are most often compared with RFID. A barcode is an optical machine-readable representation of data about an object. One of the most commonly used forms of barcode is the Universal Product Code (UPC). The UPC is a barcode widely used in North America, the United Kingdom, Australia, and New Zealand for tracking items in retail stores. Table 2-2 describes two types of barcodes, linear and 2D.

Table 2-2: Barcodes

Type	Description	Example
Linear Barcodes	Linear barcodes are composed of bars and spaces all in a single line. Linear barcodes cannot store much data. They can typically store nine data characters for every inch of horizontal barcode space. Linear barcodes can be read worldwide with low-cost scanners and are easy to print. The UPC is an example of a linear barcode.	NIST
2D Barcodes	2D barcodes consist of black and white "cells" or modules arranged in either a square or rectangular. The information to be encoded can be text or raw data. Unlike linear barcodes, 2D barcodes can store up to 2 kilobytes of data. A translation key is needed to decode most barcodes. To comply with REAL-ID Act requirements, most state motor vehicle departments use 2D barcodes when issuing drivers' licenses. (U.S. Department of Homeland Security 2005)	

Barcoding offers law enforcement agencies a low-cost means to identify or track its property and evidence. Individual pieces of property and evidence can be tagged with barcodes, and every time personnel check the evidence in or out, the item must be scanned to ensure and document the chain of custody.

2.2 RFID

RFID is an established AIT that uses radio waves to perform automatic data acquisition. Several methods of identifying objects using RFID exist today, but the most common is to store a serial number that identifies an item, as well as status, access, or timing information, on a microchip attached to an antenna. This self-contained miniature data device enables the chip to transmit the stored information to a reader. The combined chip and antenna, commonly called an RFID tag, is attached to the item being tracked and a core component of an RFID system. It is increasingly being used in supply chain, asset management, identity management, and security applications.

This report mostly refers to ultra high-frequency (UHF) tags, which have greater read distances than high frequency (HF) tags—the more mature though less widely used—form of RFID tags today. HF tags can support robust authentication and encryption because they tend to have more available power from the source field.

A typical RFID system is illustrated in Figure 2-1. It includes the following components:

- **RFID Tags**—A tag is comprised of an antenna connected to a microchip or integrated circuit. The tag contains programmed information, such as a unique ID number and information space for asset identification. Some tags have chips that can sense conditions, such as movement, or can support environment sensing.
- **Reader/Antenna**—A reader/antenna is a fixed or mobile data capture device that retrieves the data from all tags in a receiving area. Rugged readers/antennas can be attached to vehicles provided as handheld devices or even incorporated into cellphones.
- **RFID Middleware**—Middleware refers to the servers/software that support a reader's ability to extract unique information from the read data, enforce business rules, and communicate with upstream applications and databases.
- **Enterprise Applications and Database**—Enterprise applications and databases must be integrated to support process changes and provide full business value from the RFID technology.

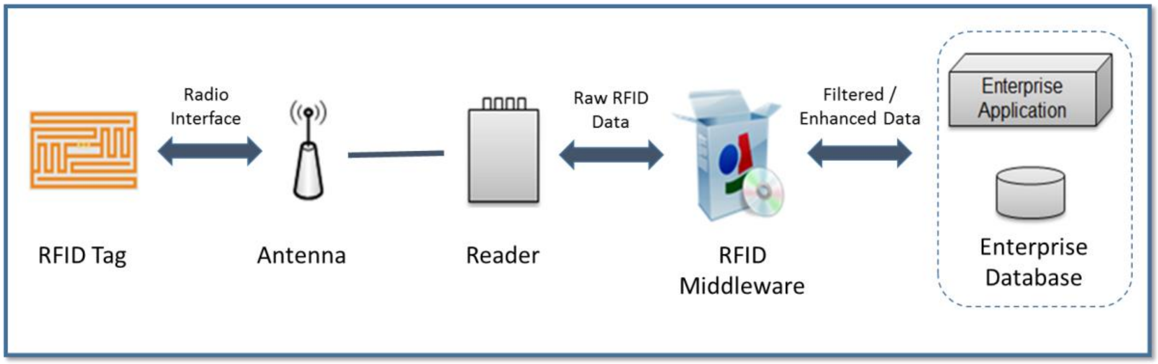


Figure 2-1: RFID system.

In today's industry, RFID tags can be classified within three general types, described in Table 2-3.

Table 2-3: Types of RFID Tags

Type	Description
Active RFID	An active RFID is an RFID tag that is equipped with a battery that can be used as a partial or complete source of power for the tag's circuitry and antenna. It can be read at distances of 30 meters or more. The onboard battery can also be used to power sensors (i.e., temperature and open/close status). The lifespan of an active RFID tag depends on the power of the battery and how often it is used. Lifespans can range from one year to a decade. Some active tags are designed to continue to respond to queries of ID and serial numbers even after the batteries lose power, essentially becoming passive RFID tags as described below. There are also active RFID tags with rechargeable batteries. Some can recharge through movement of the tagged item.
Passive RFID	A passive RFID is an RFID tag that does not contain a battery; the power is supplied by the reader. When radio waves from the reader are encountered by a passive RFID tag, the antenna within the tag generates current from the field. The tag draws power from it, energizing the circuits in the tag. The tag then sends the information encoded in the tag's memory. The tag can be read only at very short distances, typically a few inches for HF and up to 10 meters for UHF. It is typically not possible to include sensors on passive tags because they lack an onboard power source. Passive RFID tags can last for at least a decade depending on the conditions they are kept in. Well-kept tags, those in low humidity and moderate temperatures, can last indefinitely.
Battery-Assisted Passive (BAP)	BAP RFID tags, or semi-active RFID tags, are a third class of tags that are a hybrid of both passive and active tags. They contain an integrated power source that can gather energy from the battery, instead of the reader, to wake up the chip. BAP tags are much less expensive than active RFID tags and some can also support sensors. The lifespan of a BAP RFID tag depends on the power of the battery and how often it is used. Lifespans can range from one year to a decade. As in active tags, some batteries are rechargeable.

2.3 RFID versus Barcoding

Conceptually, RFID and barcodes are similar; both are intended to provide rapid and reliable item identification and tracking capabilities. However, the added value of RFID is evident in the differences between them. Table 2-4 compares RFID and barcodes.

Table 2-4: RFID and Barcode Capability Comparison

	RFID	Barcodes
Read Rate *Time taken for user to electronically scan individual inventory item using AIT.*	• Very high throughput, reads several to hundreds of labels in seconds. • Anti-collision systems allow for many tags to be in field of vision at one time.	• Slow throughput, labels have to be read one at a time. • Reading overlapping or multiple tags can lead to errors.
Line of Sight *Item in view of scanner or oriented in a specific manner.*	• Not required as long as tags in the read range and appropriate shelving materials are used (certain metals may shield some tag types). • Items can be oriented in any manner.	• Required. • All items need to be in plain view. Hidden items can be difficult to find or lost during inventory.
Robustness *Ability to read AIT in varying environmental conditions.*	• Can work under challenging conditions. Some tags are specifically made to endure variable or extreme temperatures.	• Cannot be read through snow, dirt, grime, and other challenging conditions. • Labels are vulnerable to "scratching" or loss of data from physical contact.
Security Level	• Moderate to high. • Data can be encrypted and password protected so information stored is secure.	• Low. • Labels easy to reproduce or counterfeit.
Directional Tracking *Ability of AIT to track direction of inventory items.*	• Capable. • Tags can be used to track the direction in which an asset is moving to capture process flow.	• Not capable. • Labels cannot be used for directional tracking.
Sensory *Ability of AIT to track external environment of inventory items.*	• Capable. • Systems and tags can be engineered to sense the environment: open/closed, temperature, motion, etc.	• Not capable.
Level of Automation *Freedom from end user involvement in use of AIT.*	• High. • Wireless and intelligent capabilities support complex automation.	• Low. • Reading labels often requires user involvement, and the label itself has no intelligence.
Event Triggering *Ability of AIT to trigger automated external actions.*	• Capable. • Tags can be used to trigger certain events (such as door openings and alarms).	• Limited capability. • Labels hard to use for triggering events because they require line of sight.
Adherence *Ability of AIT to adhere to items.*	• Tags can be internally attached, embedded in packaging, inserted within container, or adhered via external labels.	• Only use external labels, which can be damaged or removed.
Cost	• Moderate to high. • Cost range from $0.07 to $70.00.	• Low. • Costs approximately $0.02 per label.
Enterprise-Wide Search *Readers in other areas announce reads to entire system.*	• Capable with standards coordination in collaboration with organizations such as EPCglobal Discovery.	• Limited capability. Limited location visibility renders capability useless for enterprise wide exception searches.

Advantages of Barcodes

Barcodes have two primary advantages.

- Barcodes are the least expensive way to identify evidence items
- Barcodes offer a simple method to automate capture of the data on a barcode.

Barcode labels cost less than 2 cents per label while RFID tags are at least three times more expensive per tag. The precise cost of RFID tags varies depending on the underlying RFID technology. For both RFID and barcodes, the cost of tags and labels can decrease as the number of evidence items increases. Typically, active RFID tags are priced between $20 and $70, whereas passive RFID tags are between 7 and 20 cents. BAP tags have similar capabilities to active RFID tags but at much lower cost. Because of the high cost of active RFID and BAP tags and the long battery life, these technologies are deployed in environments where the tag can be recycled and reused (i.e., container tracking, vehicle tracking, and toll tags). Barcode labels and passive RFID tags are usually discarded after they have been used by an organization. Middleware and reader are fixed infrastructure costs which, due to the more complex nature of RFID systems, are also more expensive than those used those used with barcodes.

Advantages of RFID

Both barcodes and RFID tags can be read at a distance, however, UHF and BAP RFID can be read at far greater distances, scanned much faster, and automatically scanned. RFID tags can also be read and written in large numbers. Barcodes require some deliberate action because the reader has to "see" the optical image. An RFID tag, in effect, automatically announces itself to a nearby reader by means of its radio signal and therefore does not need to be in line of sight with a reader. Since the data obtained is continuous, items can be tracked in real time. This facilitates rapid, bulk interaction with tagged items that reduces the time needed to conduct evidence intake, inventory, and searches, therefore reducing costs. Although the price of barcode labels is fairly low, the labor and time cost of a barcode-based system grows with the size of the solution. A barcode typically requires a manual scan at each process step that is required to be recorded. As more items with barcodes are introduced into the business process, more time will be required to process and scan all items.

By taking advantage of the inherent features of RFID, more powerful applications can be created that can take action at a distance. The RF nature of RFID enables users to establish zones where activity can be monitored automatically. RFID-enabled applications can be engineered in such a way that the movement, number, and specific type of items, as well as timing and frequency of events, can all be monitored at a distance. For example, taking the inventory of a property and evidence room can be done with a single RFID read and without handling each item individually.

Another unique characteristic of RFID technologies is their embedded intelligence. An RFID tag contains a silicon chip to support its core function of communicating its identity, but many RFID tags can also support other intelligent functions. Even without the aid of the upstream enterprise applications, or the RFID middleware, some of these intelligent chips can be programmed to accumulate data for local storage (log data, count the number of events, etc.), sense their environment (light, temperature, humidity, movement, open/close contact switch, etc.), go dormant, or periodically wake up to perform functions and protect their data or onboard functions with encryption or passwords. Not all RFID tags can perform this wide range of functions, and those that do, intelligent chips, have relatively high costs. By selecting the right RFID tag and application an organization can enable the tag to process physical events that are sensed and take appropriate action. This enables the RFID tag to perform useful functions locally and untethered by the RFID middleware. For high-value goods, cash, or drugs, for example, power-assisted RFID electronic seals can record when they were opened and who opened them and report that information at a later time/location. Other examples include, password-protected tags that make it more difficult for unauthorized users to release information stored on them until a password is supplied.

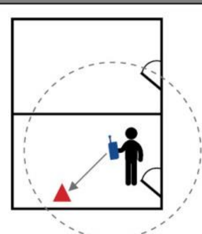
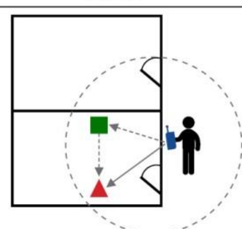
2.4 RFID Capabilities

RFID technology uses radio-frequency energy to transfer data from tagged items as it passes within the range of a reader to enable identification, categorization, and tracking. RFID uses two characteristics for determining location:

- **Presence—**an object's availability at a specific time and location
- **Location Awareness—**an object's proximity (e.g., "room number" or "building code" or who has possession).

The presence method allows users to know that an object is present at a given place and time. For example, an RFID tag could be read as it moves past a specific location or while the object is being searched for by someone with a handheld reader. This methodology (illustrated in Table 2-5) is typically used when objects are being inventoried, arriving or departing, or being physically searched for. If all pieces of evidence are tagged with RFID, a property and evidence manager can periodically walk through an evidence storage facility with a handheld mobile reader to conduct an inventory of the pieces of evidence within the facility.[2] The presence method can also be used in barcoding systems. The benefit of RFID in this system, however, would be the increased number of items that can be read at once. Opportunistic presence, or any of the other capabilities described below, would not be possible with barcodes alone. Although this approach does not provide constant real-time inventory data, it can improve the accuracy of that data and help identify items that are missing from the storage facility.

Table 2-5: Presence Method

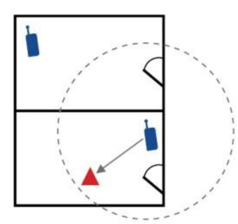
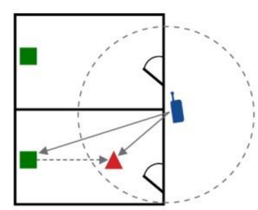
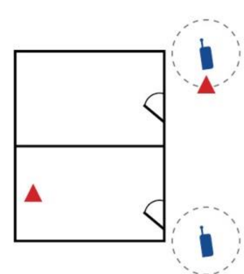
Name	Description	Example	Pros and Cons
Presence	Using a mobile reader, a person moves throughout the building capturing property identity and manually entering location information.		• **Position Data Obtained:** Room location (manually entered by human) • **Pros:** Manual operation assures property is recorded and enables human involvement • **Cons:** Human intensive operation and location is assumed until reader arrives
Opportunistic Presence	Using a mobile reader, a person or cart moves randomly throughout the building capturing property location via reference tag position.		• **Position Data Obtained:** Room location (automatically entered by mobile reader) • **Pros:** Inexpensive and simple reader infrastructure • **Cons:** Location is assumed until random arrival of the mobile reader

Key: ▲ Asset Tag ■ Reference Tag Antenna Read Zone

[2] The effectiveness of this method is enhanced when the proper materials are used for evidence shelving. For example, propagation to power UHF tags can be blocked by metal therefore, wood or plastic shelving in this case is recommended. Other types of tags, such as Rubee or Zigbee, are more resistant to disruption from metal shelving.

Using the Location Awareness method (see Table 2-6), a reader interrogates an RFID tag, and the tag is associated with the reader's antenna location. An antenna's coverage area can be a defined space such as a doorway or room, and therefore, the very act of reading a tag can define the location of the tagged asset. In many applications, this is sufficient location resolution. One does not need an exact fix on the location but only its proximity to some fixed landmark or read point. When this methodology is used, the technology is called a portal or zonal solution. Some companies create shelving with built in readers for even greater location resolution.

Table 2-6: Location Awareness Method—Portal Zonal Solution

Name	Description	Example	Pros and Cons
Zone	Zone uses a fixed reader at known positions, and the property location is detected as it moves throughout the building. The whole building would be blanketed in reader zones.		• **Position Data Obtained:** Zone location (automatically by fixed reader) • **Pros:** Location is known at all times without any human involvement • **Cons:** Expensive and large infrastructure load
Zone by Association	Zone by association uses a fixed reader and reference tags at known positions, and the property location is detected as it moves throughout the building.		• **Position Data Obtained:** Room location (automatically by fixed reference tag) • **Pros:** Location is known at all times without human involvement • **Cons:** Many carefully placed reference tags may be needed
Portal	Fixed reader and reference tags are at unknown positions, and the property location is detected as it moves throughout the building. The whole building would be blanketed in reader zones.		• **Position Data Obtained:** Choke-point location (automatically by fixed reader and reference tags) • **Pros:** Location is bounded by the choke points without any human involvement and is the least expensive of these options • **Cons:** Location area could be large and dictated by building layout

Key: Asset Tag Reference Tag Antenna Read Zone

The NFI RFID system is a good example of the portal/zonal solution described above. The system enables officials to document each item's chain of custody and warns if any items are moved without permission. The system uses passive RFID portal readers that are installed at 50 doorways within the facility. As evidence moves in and around the facility, the reader infrastructure can determine the approximate location of the tagged evidence. More information on NFI's system is in section 5.1.

2.4.1 Real-Time Location Systems

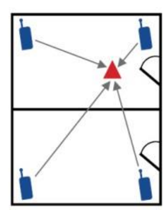
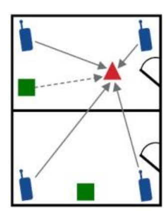
An RTLS is a system based on a wireless technology that can be used to continuously determine and track the location of assets and personnel. RTLS is considered a specific type of RFID technology and therefore has the same benefits provided by RFID. Within an RTLS, however, tags are read automatically and continuously independent of a business process. In traditional passive RFID-based systems, tags are read as they pass fixed points in a structure process. Within the industry, RTLS can be classified by two technologies—Wi-Fi-based RTLS and non-Wi-Fi-based RTLS. The following sections expand on these RTLS classifications.

Wi-Fi RTLS Solutions

Wi-Fi-based asset tracking systems are among the newest technologies to provide RTLS capabilities. The appeal of this technology is that RTLS can be enabled to use a Wi-Fi wireless local area network (WLAN) operating on the widely used 802.11a/b/g or ZigBee (see appendix: Types of AIT) 802.15 standards that are ubiquitous throughout the world. The tags are, in fact, specialized and simplified Wi-Fi devices that use the imbedded Wi-Fi infrastructure as their readers and antennas. Wi-Fi RFID tags can readily communicate directly with a standard Wi-Fi infrastructure without any special hardware or firmware modifications and can coexist alongside other Wi-Fi clients, such as laptop computers.

Some WLAN vendors have a location engine built into their Wi-Fi system, but more likely, a separate dedicated RTLS or location engine is used to calculate the location of tags. This location engine tracks the Wi-Fi tags within a building and reports their locations in the floor plans provided. It then calculates the probable location of the Wi-Fi tag, through a process referred to as localization, by measuring the radio frequency (RF) signal travel time or the RF signal strength of at least three neighboring access points whose locations are already known. Using RTLS for property and evidence management can greatly improve searching or inventory. Localization, described in Table 2-7, can help continuously monitor and track evidence as it moves throughout a facility.

Table 2-7: Determining Location via Localization

Name	Description	Example	Pros and Cons
RTLS	Fixed readers are at known positions within the building. The property location is calculated using the tag signal reading via multiple reader points.		• **Position Data Obtained:** Exact location (automatically via tag signal at multiple fixed readers) • **Pros:** Location accuracy can be determined within several feet • **Cons:** Location can be ambiguous and has greatest engineering complexity
Assisted RTLS	Fixed readers are at known positions within the building. The property location is calculated using the tag signal reading plus a reference point for greater accuracy.		• **Position Data Obtained:** Exact location (automatically via tag signal at multiple fixed readers) • **Pros:** Location accuracy can be determined within a few feet • **Cons:** Highest reader density and higher cost

Key: Asset Tag Reference Tag Antenna

Active-networked RFID tags, which include Wi-Fi tags and other technologies such as ZigBee and Bluetooth (see appendix A for more information) are battery-operated devices, which may be 2.5 cm^2 to 5 cm^2 and about 1 cm tall. Generally speaking, active RFID tags have shorter life spans due to battery requirements however, newer tags have rechargeable features and lengthened battery life. To save battery power, tags are often optimized not to send information to the access points when the objects to which they are attached are stationary. Some tags designed for items that are frequently transported generate power through movement. Optional temperature/heat sensors can be integrated into these tags to make them communicate specific information to the location engine based on real-time temperature/heat parameters.

Active-networked RFID tags can have a location accuracy as low as 1 to 2 meters and a large number of tags can communicate simultaneously with a single access point. The location accuracy of active-networked systems can be increased depending on the number of nodes and overlap of coverage. These tags are generally capable of bi-directional data exchange so data can be pushed to or pulled from the tag. There could also be choke points, like the entry/exit door of a property and evidence room, which could be connected with readers such that when objects containing these tags passed through them, the tags would automatically tell the location engine about the movement of evidence or property. In addition, the RTLS could associate that movement with an individual carrying an RFID-enabled badge and be programmed to trigger an alarm.

In an active-networked RTLS solution, fulfillment of location accuracy and required resolution depend on the access point or reader infrastructure and configuration. Gaining room-level resolution is most commonly achieved by adding additional access points to the existing infrastructure in required areas.

Non-Wi-Fi RTLS Solutions

One of the main criticisms of a Wi-Fi RTLS solution is that it uses the same RF band as other applications, such as data networking and wireless telephones. Some vendors have established different approaches that do not have these constraints. Instead of using Wi-Fi, some vendors have adopted the approach of using active RFID in creating an RTLS product. These products most commonly use 433 megahertz (MHz) or 915 MHz frequency ranges and specialized electronics specifically engineered to perform location scans, thereby avoiding some of the compromises needed to support the type of data networking performed in Wi-Fi.

Another alternative to Wi-Fi RTLS is Ultra-Wideband3 (UWB) technology. UWB uses short-duration pulses at a very low energy level. These short pulses operate in a wide frequency band, well outside the band used by Wi-Fi and other devices. The short duration of the UWB radio pulse can give it superior accuracy for its location measurements. In essence, the UWB solution uses a high-precision timing mechanism to measure the time it takes for its radio pulses to travel from fixed antennas to the tag. Using this measurement from multiple antennas, the UWB solution can provide accuracy to about a 10 cm range.

An advantage of a non-Wi-Fi RTLS solution is that it is not limited by Wi-Fi standards, and as a result, the solution is optimized for location accuracy, reliability, and overall superior performance. The tags and antennas can be specially engineered for the particular application, which often results (over time) in smaller and more attractive packaging. However, by not supporting existing Wi-Fi standards, the application loses the advantages of the large economies of scale that a highly deployed technology like Wi-Fi can bring to a solution.

[3] Ultra-wideband is a family of technologies that use a wide band of high radio frequencies (3.1 gigahertz [GHz] to 10.6 GHz) at a low energy level.

3. CURRENT SOLUTIONS FOR PROPERTY AND EVIDENCE MANAGEMENT

In today's marketplace, there is an abundance of AIT-enabled tracking solutions and vendors. However, for the purposes of managing and tracking property and evidence, the solutions and vendors can be categorized in two areas:

- property and evidence management systems
- custom developed AIT-based property and evidence tracking systems.

The following sections describe these two categories.

3.1 Property and Evidence Management Systems

The increase in property and evidence within law enforcement agencies coupled with staff budget cuts have caused agencies to look for more efficient ways to manage and track property and evidence. There are many property and evidence management systems that focus on the collection, intake, and storage of evidence within the property room. Most of these property and evidence management systems focus on property and evidence room processes but have also been deployed to track other areas of evidence handling, such as crime labs and courts. Most of the property and evidence management systems support barcodes as a means to identify and track evidence, but in the last couple of years, property and evidence management systems have begun supporting RFID. Table 3-1 provides a comparison of features available in property and evidence management system vendors and their support for AIT.

Table 3-1: Property and Evidence Management System Support for AIT

	Company A	Company B	Company C	Company D	Company E	Company F
Supported AIT						
Linear Barcode	x	x	x		x	x
2D Barcode	x	x	x	x	x	x
Passive RFID	x				x	x
Active RFID	x					x
Custom RFID Integration Support					x	x
AIT Features						
Barcode Printing		x	x	x	x	x
Barcode Management	x	x	x		x	x
RFID Management	x				x	
RFID Filtering and Collection	x				x	
Platform/Hosting						
Web-based	x	x			x	x
Server Required	x	x	x	x		x
Remote Hosting		x			x	x
Integration						
Custom Integration (by Vendor)		x	x		x	x
Application Programming Interface (API)	x	x				x
Web Services	x	x	x		x	x

	Company A	Company B	Company C	Company D	Company E	Company F
Web Services Integration	x	x	x		x	x
Flat file integration	x	x	x	x	x	x
XML Support	x	x	x		x	x
Workflow						
Real-time Metadata	x	x	x		x	x
Automated Processes (note, all products claim automation)	x	x	x	x	x	x
Accessioning	x	x	x			x
Chain of Custody	x	x	x	x	x	x
Process Multiple Items	x	x	x	x	x	x
Parent/Child Tracking	x	x		x	x	x
Valuation	x	x	x	x	x	x
Discrepancy Reports	x	x	x	x	x	x
Attach Pictures	x	x	x	x	x	x
Task Assignment/Management	x	x			x	x
Document Tracking	x	x		x		x
Asset Tracking	x	x	x	x		x
Quarter Master		x	x	x		x
Mobile Compatibility						
Crime Scene Data on Handheld	x	x				x
Evidence at Crime Scene on Handheld	x	x		x		x
Crime Scene Data on Computer	x	x	x			x
Evidence at Crime Scene on Computer	x	x	x			x
Server/Workflows Compatibility on Handheld (from above)	x	x				x

3.2 Custom RFID-Based Property and Evidence Tracking Systems

Several vendors provide integrated support of RFID within their services (see section 3.1, Table 3-1); however, if a law enforcement agency wishes to implement a custom RFID evidence tracking solution, it must procure all the various components for the solution separately, which include tags, readers, middleware, and personnel training.

Tags and Readers

An RFID tag is one of the three main components of any RFID-based solution. The most common method to identify an item is to store a serial number, and perhaps other information, that identifies an item. This RFID tag is physically attached to the item or person that is being tracked. Today there are many RFID vendors that provide tags for different frequencies and solutions. Table 3-2 shows a subset of RFID tag vendors that exist today that have been used or can be used within law enforcement agencies. Most of the active RFID and RTLS vendors listed in the Table 3-2 which provide self-contained solutions that include integrated tags, readers, and applications, support only one type of RFID technology (active, passive, RTLS, etc.). Other vendors may sell tags but do not manufacture RFID readers.

Table 3-2: RFID Tag and Reader Vendors

Vendor Name	Passive UHF Tags (900Mhz)	Active Tags (2.4Ghz)	Active Tags (430Mhz)	RTLS Tags (2.4GHz)	RTLS Tags (UWB)	Readers (Fixed)	Readers (Mobile)
Company G				X			
Company H	X					X	
Company I	X						
Company J				X			
Company K	X					X	
Company L	X					X	X
Company M						X	
Company N	X					X	X
Company O	X	X	X			X	X
Company P			X			X	
Company Q						X	X
Company R					X	X	
Company S	X						

Middleware and Integration to Enterprise Applications

The RFID middleware, the third part of any RFID solution, is the software component that takes the raw RFID data from the readers and integrates it into an enterprise system. The importance of an effective middleware solution cannot be overstated. Middleware enables the actual tracking of assets by collecting, filtering, and aggregating raw data obtained from the reader. In addition, the middleware adds business context to the raw data. For example, as reads occur at the reader, the middleware aggregates the data and appends the date, time, location, and status of all evidence being checked in before storing the data in the backend database or enterprise application. Some advanced RFID readers allow for the middleware software component to reside directly on the reader, thus reducing the amount of information technology infrastructure required for the middleware component.

There are very few integrated evidence tracking systems that track evidence through its entire lifecycle—from point of collection through storage, processing, presentation in the courtroom, and disposition. Enterprise level software can take the data produced by many middleware systems to track evidence from many systems and as they travel from different agencies. Because middleware can also integrate the data collected with any backend database or existing property and evidence management system, agencies often use more than one system to track evidence at different points in the process. If a law enforcement agency decides to implement an RFID-based solution to help track evidence, then it must decide whether to build the solution from scratch or buy the various components and integrate them. The main difference between the build and buy approaches is that in the build approach the law enforcement agency designs and builds its own tracking application. In the buy approach, the law enforcement agency procures a commercially available property and evidence management system and must integrate RFID components with that system.[4] It is critical that a good expandable logical data structure is developed that can be easily translated between systems, and is accessible by many enterprise applications in case the system is scaled beyond one agency or jurisdiction.

[4] The *Handbook on Biological Evidence Preservation* contains additional information on the evidence tracking systems/middleware solutions in Section IV.

4. BARRIERS TO RFID ADOPTION

Despite the potential benefits of RFID adoption in forensic evidence management, many barriers exist that prevent law enforcement agencies from fully embracing and investing in the technology. The following section explains the primary barriers faced by State and local governments looking to improve evidence management practices.

4.1 Magnitude of Startup Cost

The current economic downturn has forced State and local governments to change the way they manage their budgets. This also holds true for the law enforcement agencies, who are now being asked to "do more with less." As a result, smaller law enforcement agencies across the nation are much less likely to employ a technology-based property and evidence management system due to the costs required to build and maintain such a system. Some agencies do have an information technology system to track property and evidence but cannot afford to purchase simple linear barcode labels and barcode readers. Advanced AIT-based systems, such as RFID, require an even more costly infrastructure investment. This investment includes RFID tags, readers, middleware, and integration with an existing property and evidence management system or the development of a property and evidence management system. The largest costs include entering data of existing evidence, the price of overcoming bureaucratic inertia, training staff on a new system, and correcting errors in entry for the first few years. Table 4-1 provides a small example of typical costs that law enforcement agencies may face when implementing a relatively low-volume passive RFID-based evidence tracking system.

Table 4-1: Typical AIT Cost Factors

Cost Factors	Barcode Unit Cost	RFID Unit Cost
Hardware		
Tags	$0.02	$0.25
Fix Readers	N/A	$1,500
Fix Antennas	N/A	$1,000
Handheld Reader	$100	$1,500
Software		
Middleware	N/A	$1,000
Maintenance		
Hardware Maintenance	Varies depending on type	Varies depending on type
Software Maintenance	15% per annum	15% per annum
Labor		
Integration Services	N/A	$100,000
Process Re-Engineering	$100,000	$100,000

4.2 Reliability of Technology

One of the advantages of RFID over barcodes is the ability to read multiple items (tags) within seconds, whereas barcodes must be read one at a time. However, there is a perception within the forensic industry that RFID is not reliable enough to read all tagged items at a given time. This perceived lack of reliability from the point of view of law enforcement agencies is one of the reasons RFID has not gained traction within property and evidence rooms.

The pharmaceutical industry demonstrated the reliability of RFID by using the technology to help secure its supply chain. For example, in various pilots, pharmaceutical distributors demonstrated the ability to automatically read and verify items in a case of tablet bottles from a manufacturer without ever having to open the case and scan each individual bottle. This was achieved because of the uniformity of the items and the way they were placed within the case, which was a direct result of Food and Drug Administration approved standards for handling and storage of pharmaceutical drugs.

Within property and evidence rooms, evidence for a case is never uniform, nor is it stored in a box or envelope in a standard method. This is a direct result of a lack of industry-approved property and evidence handling standards. Figure 4-1 illustrates examples of property and evidence containers used by law enforcement agencies.

Figure 4-1: Sample evidence containers.

The key factor in improving the reliability of RFID technology is to implement standard packaging and business processes for handling evidence. Once the standards are in place, RFID vendors and system integrators can engineer and tailor solutions for specific evidence handling processes. Without standards, personnel may be required to manually inspect each evidence item individually, which negates the true value of RFID technology.

4.3 Standardization of Processes

As mentioned in the previous section, clear and defined industry-approved processes and standards for handling property and evidence and enforcement of those standards should be a prerequisite for the adoption of RFID technology. Currently, there is no consistent manner for handling property and evidence across cities, counties, and States within the United States. Each law enforcement agency processes, stores, inventories, and disposes of evidence uniquely. This poses a challenge to AIT solution vendors because designing and engineering a solution for a non-standardized process is difficult. A standard data structure for evidence needs to be developed so every system developed is speaking the same language. For example, RFID solution vendors developed dock-door portal readers for use in warehousing shipping and receiving processes. RFID solution vendors were able to develop a solution for these processes because dock-door configurations and most shipping and receiving processes and the data transferred at each location are standardized across multiple industries.

Tracking and tracing forensic property and evidence is also complicated by the multiple people or organizations that handle it throughout its lifespan. Evidence can potentially be handled by law enforcement personnel, crime laboratory scientists or examiners, attorneys, hospital staff, and/or court staff. Many organizations may have responsibility for an individual evidence item once it is in their possession. In supply chain management terms, this chain of custody is known as an open loop. A closed loop scenario would be one in which an organization is tracking assets for which only that organization has responsibility, for example, a law enforcement agency tracking the vehicles in inventory in an impound lot. To provide detailed tracking and visibility for each piece of evidence in an open loop scenario, standardized AIT infrastructure would need to be installed at each potential location of evidence. As described in section 4.1, the cost would be incrementally higher for an RFID-based tracking solution.

The creation of standard processes and procedures covering the major aspects of evidence handling will help mitigate these issues. Standards will help increase the adoption of advanced AIT in supporting agencies which can, in turn, lower costs and simplify the implementation process. For example, several countries worked together to create standards to develop e-passports, passports with RFID chips containing biometric information in them. E-passports are now required for citizens or nationals who would like to qualify for visa waivers in the US and have been implemented in countries throughout the world. (U.S. Department of Homeland Security 2012)

5. RFID IMPLEMENTATION

Because of the existing barriers to adoption, there are only a handful of law enforcement agencies that have successfully implemented advanced RFID-based property and evidence management solutions. However, successful implementation in various other industries can be a basis of reference for future law enforcement solutions. The following sections discuss AIT implementation in a law enforcement agency, pharmaceutical company, and retail company.

5.1 Law Enforcement: Netherlands Forensic Institute

The NFI, a Netherlands Government agency that collects and analyzes crime-scene evidence, implemented an RFID system. (Wessel 2008) The NFI system enables officials to document each item's chain of custody and provides warnings if any items are moved without permission. NFI needed to meet Government compliance standards requiring all pieces of criminal evidence material to be traceable and identifiable. They also required a solution that could guarantee chain of custody of crime scene evidence by tracking material through the investigation process.

NFI developed a custom RFID-enabled solution using commercially available software and hardware components. Table 5-1 highlights the features and benefits of NFI's solution. The NFI RFID-enabled implementation serves as a model for the return on investment (ROI) analysis discussed in Section 6.

Table 5-1: NFI RFID Application Features and Benefits.

Features	Benefits
• Uses passive RFID (UHF Gen 2) • Leverages RFID badges for employees • Installed RFID readers within 50 doorways within facility • Leverages audio and visual alarms for notification • Stores data within central database	• Automates real-time track and trace data collection • Expedites evidence processing for law enforcement agencies • Minimizes risk of evidence being compromised • Supports Government evidence compliance standards • Safeguards and monitors crime scene evidence during storage and analysis process

5.2 Commercial: Purdue Electronic Pedigree Pilot

In the mid-2000s, Purdue Pharmaceuticals faced a challenge to respond to new requirements demanded by Walmart for all pharmaceutical drug suppliers to implement RFID-enabled manufacturing and packaging processes because of emerging Federal and State prescription drug safety pedigree regulations. The Walmart supplier mandate stated that all suppliers of consumer product goods would tag their goods at the pallet and case level for all shipments to Walmart distribution centers. In addition, all suppliers of class II narcotic drugs would tag each individual pill bottle with passive UHF RFID tags.

At the same time, the State of Florida was developing the Prescription Drug Safety program, which would require all prescription drugs to have a paper or electronic pedigree starting in July 2006. California was developing legislation that would require electronic pedigrees beginning in January 2007. Other States, including Connecticut, Indiana, Nevada, and Texas, have passed or are nearing passage of similar legislation.

The challenge facing Purdue was how to leverage their RFID investment to meet future paper and electronic pedigree legislation. Purdue decided to conduct a pilot with their trading partner, HD Smith, to show that secure electronic pedigree documents can be sent automatically to supply chain partners using RFID and can be stored and retrieved cost effectively. Purdue implemented SupplyScape's Electronic Pedigree system. (US Food and Drug Administration 2006) When the drug shipment is sent to HD Smith, the electronic pedigree solution sends an electronic pedigree message from Purdue to HD Smith. As a result of the electronic pedigree pilot, EPCglobal's[5] Health and Life Sciences Business Action Group began developing an electronic pedigree messaging standard. This standard enabled interoperability among many electronic pedigree vendors as well as complied with pedigree legislation across the nation. In this case, the standardization was critical to success. As the drug changes hands, the electronic pedigree message gets appended with the necessary transactional information. (See Figure 5-1.)

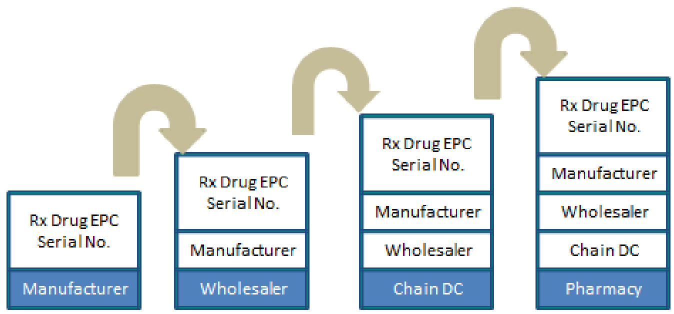


Figure 5-1: Electronic pedigree message flow.

The solution was a web-based system that used standards-based integration from Purdue's ERP system and HD Smith's warehouse management system to the electronic pedigree solution. The electronic pedigree software was fully integrated into the manufacturing, packaging, and shipping processes of the manufacturer and the receiving processes of the distributor. As a result of this pilot, Purdue was able to prove that RFID-enabled electronic pedigree documents can be securely and safely sent to trading partners. In addition, Purdue's new electronic pedigree integrated packaging and shipping processes would be the basis for future implementations.

5.3 Commercial: Bloomingdale's Inventory Management Study

In 2008, the RFID Research Center, which is a part of the Information Technology Research Institute at the Sam M. Walton College of Business at the University of Arkansas, conducted a 13-week tagging study at Bloomingdale's stores (O'Connor 2009). The study focused on the inventory management processes of two stores, a control store and a test store. At the test store, passive UHF RFID tags were placed on men's and women's jeans since these were high-cost items that were more likely to be shoplifted. The RFID tags were designed to provide item-level location capability. Sales associates could identify whether a pair of jeans was missing by scanning a large area of items on shelves or in the back rooms. More information is known about the location of the item than at the pallet or case level. (Hardgrave, Miles, & Mitchell 2009) During the study, the test store had between 800 to 10,500 tagged pieces of merchandise in inventory. The results and benefits of the study are detailed in Table 5-2.

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[5] EPCglobal is the organization responsible for standardizing and achieving worldwide adoption of the electronic product code (EPC), a universal identifier aimed at providing unique identities for physical objects based on an encoding framework.

Table 5-2: Bloomingdale RFID Study Results

Focus Area	Solution	Result	Overall Benefit
Inventory Cycle Counts	Handheld RFID readers used in test store to count inventory along with handheld barcode readers	With barcodes, staff able to read **209 items/hour** With RFID, staff able to read **4,767 items/hour**	Inventory cycle count time reduced by **95 percent** with RFID
Inventory Accuracy (Overstocks/Understocks)	RFID data integrated with Bloomingdale's inventory management system	With no RFID integration, inventory accuracy was reduced over time; With RFID real-time integration inventory accuracy increased by **27 percent**	Overstocks decreased by **6 percent** Understocks reduced by **21 percent**
Security	Fixed RFID readers mounted at the store entrance/exit points	Data from RFID read points compared with barcode data from points of sale determined that some items were stolen and thieves were apprehended	RFID helpful in product theft knowledge to refrain inventory level

In summary, using RFID improved the inventory cycle counts and inventory accuracy by 95 percent and 27 percent respectively. In addition, using RFID within security would not only reduce the amount of loss due to thefts but also help refine inventory accuracy. Since this study, several major retailers have begun to implement RFID for item-level tracking including JC Penny and Wal-Mart. Wal-Mart's implementation of item-level tagging of their jeans has been a major development in the industry. The scale at which Wal-Mart purchases RFID tags was projected to drive down the costs of the technology leading to greater use of RFID in other industries. (Bustillo 2010)

6. RFID RETURN ON INVESTMENT ANALYSIS

Establishing a chain of custody for an item of evidence throughout the process of investigation, transportation, storage, and legal proceedings is a huge challenge for law enforcement. While RFID can contribute to improving efficiency in each of these areas, it is difficult to quantify the savings or return on investment (ROI) due to the varying agencies and handlers involved in managing evidence. Estimating ROI within a property and evidence department, however, is possible since the time spent inventorying and searching for forensic evidence can be quantified based on assumed labor rates and hours in addition to the technical specifications of the solution within one building. Because the potential savings are tangible in these areas, the analysis described in this section focuses specifically on the ROI of implementing an RFID system based on improvements in evidence storage and inventory processes. In this analysis, ROI is calculated using payback period; a method which estimates the time period in which an investment pays for itself through annual cost savings.

6.1 Overview of Hypothetical RFID Enabled Tracking Solution

In order to calculate the relative savings of an RFID-enabled evidence tracking solution versus a paper-based solution, a hypothetical solution must be modeled. For this analysis, a real-life forensic evidence tracking solution developed by the NFI is loosely followed, as discussed in Section 5. The NFI's RFID system monitors changes or movements of evidence. This information can be used to detect when evidence has been accessed or moved without permission. More important for this discussion, the NFI system reduces the workload for office clerks and the incidence of lost articles of evidence by tracking every movement of evidence shared among the investigators and prosecutors. (Wessel 2008)

For this analysis, the model assumes that all property and evidence items submitted to the unit for retention are tagged using a smart label, either at the crime scene or during arrival at the storage facility intake or forensic laboratory. A smart label is a printable label with a barcode, readable text, and a built-in RFID tag. The tag contains data stored in a standard, which uniquely identifies the item, linking it to a case. In addition, this model assumes that personnel are issued an RFID-embedded ID (smart-label IDs) so their association with evidence can be sensed. The label numbering is unique. Number ranges are distributed to the local police organizations, which can print or order their smart labels accordingly.

This model also assumes that in the building, key doors are equipped with an RFID reader and antennas to track all movement of items and personnel. This information is stored in a central system so the whereabouts of all items can be shown on-line. Audible and visible alarms are present at the doors to inform employees when all tags have been read and whether certain items may or may not enter the investigation area. All events are monitored, and any deviation from the process flow instantly triggers an alarm. For example, when property and evidence items leave the building without proper authorization, an audible alarm is sounded immediately. In addition, the information in the central system can document that two items were never present in the same room together, thus excluding the possibility of cross contamination.

6.2 Inventory and Search Process

To help quantify the potential savings of implementing RFID in the ROI analysis, specific tasks performed within the evidence storage and inventory processes needed to be defined. The following three tasks indicate where this solution can provide tangible savings. (See Table 6-1 for more details.)

1. Inventory: This is the mandatory, periodic recording of the precise location (or absence) of evidence under one's control.
2. Standard Search: For the typical evidence handling process, this is the effort spent in the normal search for a piece of forensic evidence.

3. Exception Search: Sometimes evidence can be misplaced. This is a process exception situation and requires a wide-area, systematic, visual search for the missing item.

Table 6-1: As-Is versus To-Be Process Comparison

Task	Old Process	New Process
Inventory	Using paper reports, people directly handle the stored forensic evidence and record its presence within the facility.	Using a handheld RFID reader, people move through the facility and electronically record the presence of forensic items.
Standard Search	Using paper records of the last recorded location of an item, people visually search for the desired item.	Using the last recorded location of an item, people go to that location and find the item using a handheld RFID reader.
Exception Search	Paper records are of no use. People need to perform a systematic, visual search for the missing item.	Using the last RFID reading of the item, the search is narrowed to a specific room. A handheld RFID reader is then swept through the room to find the item.

6.3 ROI Calculation Parameters

Critical to the ROI model are several parameters used to perform the financial calculations. (See Table 6-2.) The well-documented NFI model, expertise within the NIST/NIJ Technical Working Group for Biological Evidence Preservation, and analogous studies for asset management (Omni-ID 2009) were used to derive these parameters.

Table 6-2: Calculation Parameters

Task	Calculation Parameters
Inventory	On average, one person takes 60 seconds to process an inventory item manually. An RFID can reduce this inventory time by a factor of 12.
Standard Search	Manual search and processing typically takes one person 2 minutes. An RFID cuts this search time in half.
Exception Search	When evidence is misplaced, one person typically takes 1 hour to find it. An RFID can reduce this search time to 10 minutes.

Physical and Process Design

Key inputs to the model are assumptions about the physical structure of the building where the evidence is managed. It is assumed that the RFID equipment is in place at entry/exit points and at key locations, or zones, within the building. Also, evidence-handling personnel use handheld RFID readers and smart label IDs.

The specifics of the physical infrastructure assumptions are detailed in Table 6-3. A “zone” is a room where forensic evidence is stored or in some way processed.

Table 6-3: Hardware Mapping

Physical Design	Small *less than 100,000 items*	Medium *100,000-200,000 items*	Large *more than 200,000 items*
Zones	2	8	25
Entry/Exit per Zone	1	1	1.5
Handhelds per Zone	1	1	2
Readers per Zone	0	0.25	0.5
Antennas per Entry/Exit	0	2	2

Additional assumptions that are made are about the tasks being performed. Key factors in the ROI calculations are the number of annual inventories performed, the frequency with which evidence searches are performed, and the frequency with which those searches result in exceptions. These parameters are listed in Table 6-4.

Table 6-4: Task Design

Task Design	Old Process	New Process
Inventories per Year	2	2
Number of times each piece of evidence is handled (i.e., searched for) per year	2% of all items are handled twice per year	2% of all items are handled twice per year
Percentage of searches that result in an exception	5.0%	0.10%

Hardware, Software, and Labor Costs

The ROI calculation also requires documenting the investment required to create the new RFID-enable process. This is a combination of RFID hardware/software products and the engineering/integration services required. Also required is the loaded hourly labor rate for the staff conducting the inventory and search processes. The hardware, software, and labor cost assumptions are detailed in Table 6-5.

Table 6-5: Cost Basis

	Unit Cost	Cost per Hour	% of Total Annual Cost
Hardware			
Tags	$0.25	-	-
Fix Readers	$1,500.00	-	-
Fix Antennas	$1,000.00	-	-
Handheld Reader	$1,500.00	-	-
Software			
Middleware	$1,000.00	-	-
Evidence Management System	$0.00	-	-

	Unit Cost	Cost per Hour	% of Total Annual Cost
Maintenance			
Hardware Maintenance	-	-	15%
Software Maintenance	-	-	15%
Labor			
Integration Services	$100,000.00	-	-
Process Re-Engineering	$100,000.00	-	-
Staff Labor Rate	-	$50.00	-

Process Cost

A critical cost parameter is the savings that result from changing the inventory and search processes. The savings is the difference between the old process cost and the new process cost. Typically, costs decrease as the model grows and when the system is successful. These process costs are listed in Table 6-6, and all costs are derived from the other parameters listed above.

Table 6-6: Process Costs

	Process Cost per Item	
Task	**Old Process**	**New Process**
Inventory	$0.83	$0.07
Standard Search	$1.67	$0.83
Exception Search	$50	$8.33
Initial Application of Smart Labels (labels with RFID tags) to Existing Inventory	N/A	$0.83

6.4 Results

The period of time to payback an investment is a function of the quantity of evidence items being managed. Increasing the number of items managed slowly increases the solution cost (because additional RFID tags are required) but the savings substantially increases with the increasing number of evidence items being managed.

There is a payback on an initial investment after approximately 2 years when there are 100,000 or more items, or in a medium sized solution. But if the costs of the integration and process re-engineering services are shared across multiple organizations, there are substantial savings. In reality, this is likely to occur in medium to large property and evidence rooms which have the capacity to store evidence items for multiple jurisdictions or if the initial investment costs are covered in part by a grant of some sort. Figure 6-1 shows the payback for when integration and engineering costs are *shared* with another agency or jurisdiction. The payback comes in about 2 years when managing as few as 25,000 items in this scenario.

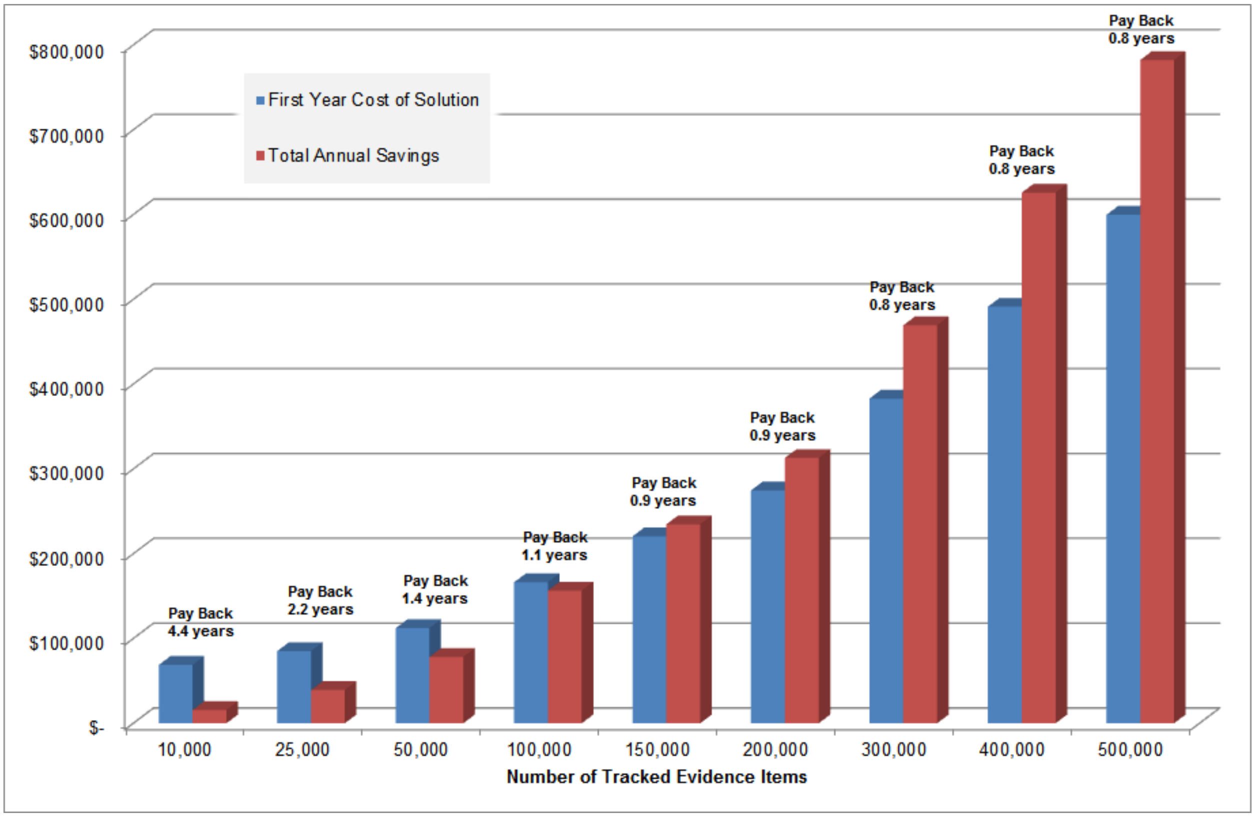


Figure 6-1: Investment payback when costs are shared.

6.5 Analysis

In a scenario, as described above, in which a jurisdiction shares the costs of an initial investment, it is reasonable to expect a good return on an investment when there are more than 25,000 forensic evidence items being managed. If an agency seeks to implement RFID as a capital investment to improve its internal processes on its own, the payback period would be expected to be at least 2 years for agencies with over 100,000 items and longer for agencies with fewer items.

This analysis calculates some of the most tangible savings in labor costs, but other potential financial benefits that may result from more accurate and timely evidence processing were not taken into account. For example, the savings from reduced frequency of punitive damage payouts for wrongful convictions resulting from misplaced or mishandled evidence was not calculated. There are additional savings that could potentially be harvested from other tasks imbedded in the forensic evidence process such as more efficient or timely evidence disposition.

Further, this particular model looks at a one system within one facility. A multi-system search could provide even greater capabilities and possible savings across potential locations for evidence, i.e., property rooms, courts, and laboratories.

The success of any AIT-based property and evidence solution within the forensic community depends on understanding the fundamental evidence handling business processes, the current weaknesses of the processes, and the benefits and advantages of AIT insertion. After a law enforcement agency has taken the steps to understand these issues, selecting and implementing the technology is straightforward. In addition, for a sufficiently large number of managed forensic evidence items, the technology insertion and process modifications can result in a positive return on investment.

7. VISION FOR THE FUTURE OF AIT IN FORENSICS

In an ideal world, law enforcement agencies and the organizations with which they collaborate would have instant visibility into the status and location of the property and evidence that has been collected, analyzed, tested, and stored. The implementation of RFID and the use of advanced information systems can help enable this vision. The following section proposes recommendations to assist the community in achieving enhanced tracking and storage of biological evidence.

7.1 Standardization of Technology and Data

It is difficult, if not impossible, to envision the future of forensic evidence management enabled with AIT technology without creating standards. To reduce costs and enable successful implementation, standards must exist as a foundation for technology development. Similar to the integration of other technologies, implementing AIT would require addressing the principles outlined in Table 7-1. Once these foundational principles have been established, AIT can be more easily implemented.

Table 7-1: Principles of Technology Integration

Principle	Description	Potential Focus Areas
Standards Based	Selecting hardware, software, and data formatting should leverage standards to minimize cost and take advantage of technology evolution.	**Technical Standards** Can ease the selection of appropriate hardware and software to enable seamless exchange of data and accelerate implementation.
Compatibility	Whenever an agency plans to start leveraging AIT technology in its forensic evidence process, its investment in its current processes and technology selection should be preserved.	**Evidence Labeling Standards** Can enable the sharing of information among agencies with or without new technology (i.e., Smart Labels with barcodes and RFID tags).
Interoperability	An agency's decision to use AIT technology <u>should not require</u> the other interfacing agencies to make process/technology changes; however an agency's decision to use AIT technology <u>should motivate</u> other interfacing agencies to make process/technology changes.	**Standard Data Exchange Methodology** Can ensure information systems containing forensic evidence data are interoperable if an agency chooses to adopt AIT technology.

Creating numbering standards, evidence labeling standards, and data exchange methodologies is needed at the State and regional level to facilitate the adoption of AIT. Fortunately, there are many examples that demonstrate the successful development of standards that can be used.

Numbering Standards

Law enforcement agencies can leverage existing data encoding standards and item-unique identifiers to develop a property and evidence numbering standard. EPCglobal data encoding standards, as mentioned in Section 5 for example, define how data are encoded on the tag and how this encoded data can be used by upstream information systems. Another example is the Item Unique Identification (IUID), a globally unique, unambiguous identifier used to track assets that are derived from discrete component data elements encoded in a two-dimensional data matrix (i.e., barcode). These numbering schemes ensure that the data integrates well with existing EPC- and IUID- compliant hardware and software products. Also, compliance with these standards ensures that data can be shared among partners without conversion or confusion. Figure 7-1 shows the numbering schemes for both the EPC data encoding and IUID standard.

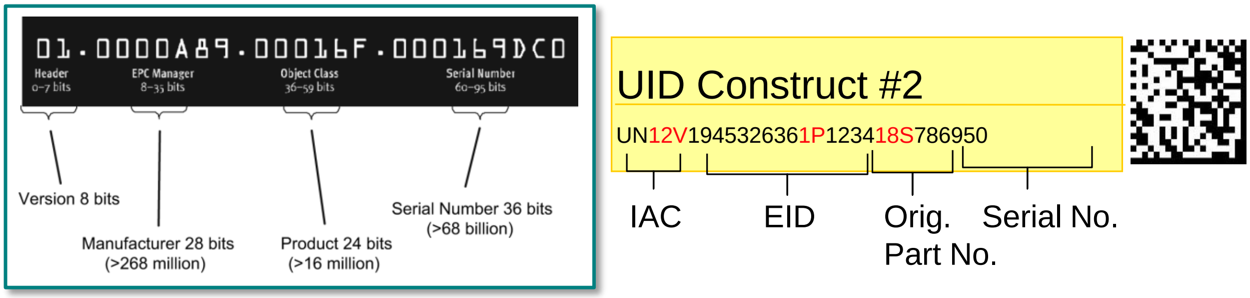


Figure 7-1: EPC encoding standard versus IUID data standard.

The most important benefit for law enforcement agencies is that a numbering data standard ensures that evidence management solutions can take maximum advantage of the wide range of hardware and software products on the market. This eases the development and integration of applications and helps control cost of those applications. Another important benefit is the ability to exchange data among jurisdictions with minimal conversion of data. This data sharing could take place via either an RFID or 2D barcode when the evidence is physically shared with another jurisdiction or via electronic exchange between systems. Figure 7-2 depicts a potential numbering standard that can be developed for property and evidence.

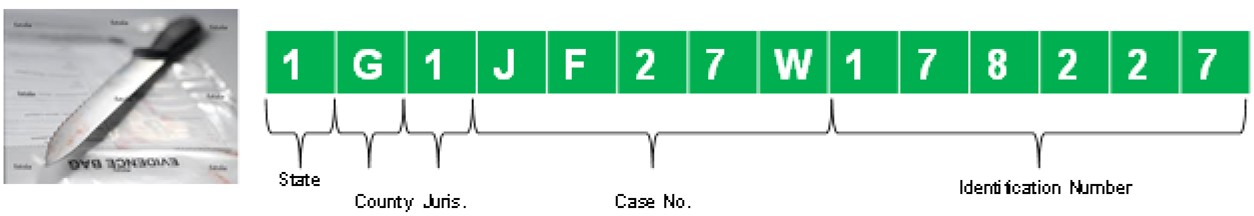


Figure 7-2: Forensic Evidence Identification.

Evidence Labeling Standards

Developing process and technology standards helps enable law enforcement agencies move forward in achieving improvements in management of forensic evidence. One of the keys to achieving this vision is developing specific property and evidence labeling requirements and standards. By combining evidence labeling and numbering standards, law enforcement agencies and the organizations they collaborate with will be able to remove the redundant labeling practices by the various organizations that handle evidence. For example, the MIL-STD-129 (Defense Acquisition Community of Practice 2005) is the United States Department of Defense-approved standard that is used for maintaining uniformity while marking military equipment and supplies that are transported through ships. The marking helps military personnel fill the necessary requisition when a particular stock goes short of the balance level. Per the MIL-STD-129 standard, shipping containers carrying military items can be categorized into three types: exterior containers, intermediate containers, and unit containers. (See Figure 7-3.) The MIL-STD-129 also addresses RFID encoded labels.

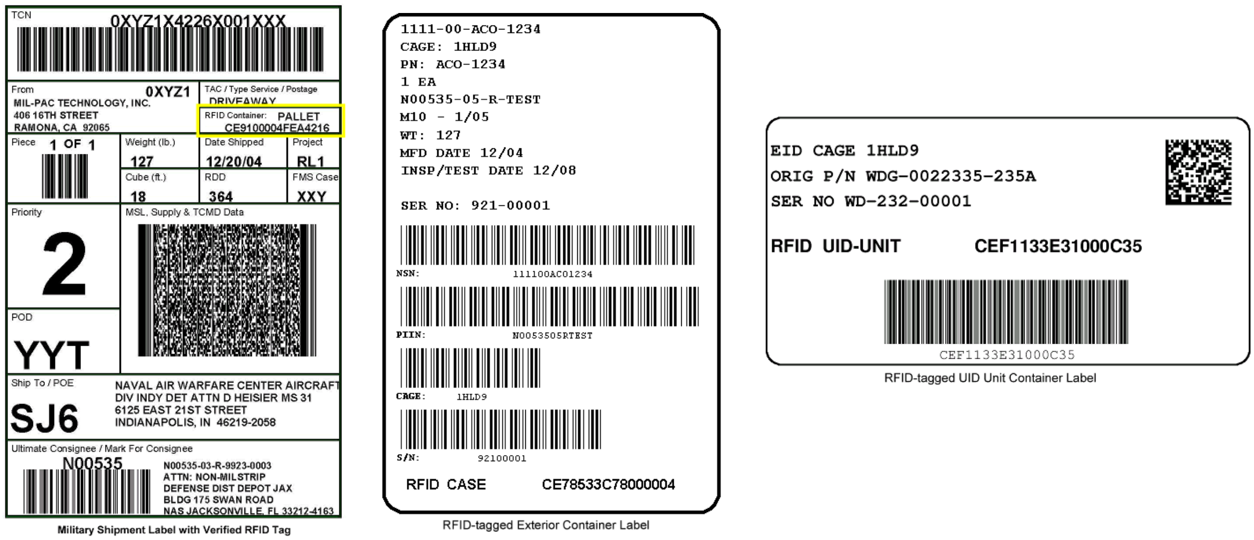


Figure 7-3: MIL-STD-129 sample labels.

By using the MIL-STD-129 as a reference model, property and evidence labeling standards can be developed. In addition, by developing this standard, organizations can leverage the same label without being required to make purchase new technology to incorporate it into evidence handling processes. The label can be used in manual and automated systems. Similar to the MIL-STD-129, some requirements for the property and evidence labels can include us of the following:

- adhesive-backed, paper evidence label with embedded RFID tag
- fixed label layout to support multiple process needs
- human-readable, barcode-scanable, and RFID-enabled label content
- universal standard data elements
- information encoding to support an evolving data exchange architecture

Data Exchange Methodologies

As mentioned previously, one of the key principles to help law enforcement agencies achieve the vision for enhanced property and evidence management is the interoperability among the various agencies and organizations that handle evidence. This interoperability can be achieved by the free flow of information among these various organizations. Currently, there are three categories of data exchange methodologies that are employed by commercial and government agencies: label-based data exchange, centralized data exchange, and distributed data exchange. These data exchange methodologies are described in the following sections.

Label-Based Data Exchange

One of the simplest and least expensive ways to share data with other law enforcement organizations is to exchange information via the label. In this method, all the pertinent information is either written or typed onto the label. Many current small- to medium-sized law enforcement agencies use this method of writing the case information on the evidence package. Figure 7-4 illustrates the movement of information among the various organizations that handle evidence.

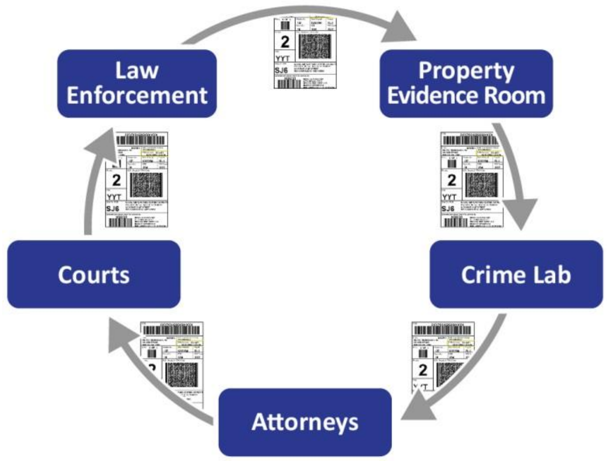


Figure 7-4: Label-based data exchange methodology.

In addition to evidence information, some agencies place the chain of custody form on or in the evidence package. This way anyone who handles the package can see the entire movement and handling history of that piece of evidence. By using this label-based data exchange methodology, agencies can share evidence information via the label without the aid of an intermediate system. Label-based data exchange can also serve as a contingency if an agency has issues with lost power and is left with no alternative to obtain data about evidence items. Organizations are free to choose to use human-readable, barcode, or RFID-encoding formats. With RFID-encoding formats, the critical information about the piece of evidence would be encoded onto the RFID tag. This method would require a tag with a sufficient amount of memory. For example, the U.S. Army Product Manager Joint-AIT RF In-Transit Visibility system tracks shipping containers throughout the U.S. Army supply chain using active RFID tags (US Army 2003). These tags are encoded with the contents of the container as they are packed and shipped to their destinations. The logistics staff at various destinations across the globe use active RFID interrogators to scan the tags and capture information about the contents of the container.

The limitation of this model, however, is that it is most effective when one jurisdiction is handling evidence. The larger problem in evidence management is tracking evidence across various locations, which have different data repositories. While a common machine- and human readable-label contains information about an evidence item, the actual storage of the information may be different depending on the system and interface used. This can create problems documenting one reliable chain of custody.

Centralized Data Exchange

The next method for sharing information is to use a centralized data repository to share information among the various evidence handling organizations. To implement this methodology, several agencies must collaborate to establish a central data repository to act as a data exchange. (See Figure 7-5.) Ideally, the data repository should leverage open standards for information integration by the various agencies. Open standards allow agencies to have flexibility in developing interfaces to the data repository and do not require them to build and maintain costly system interfaces.

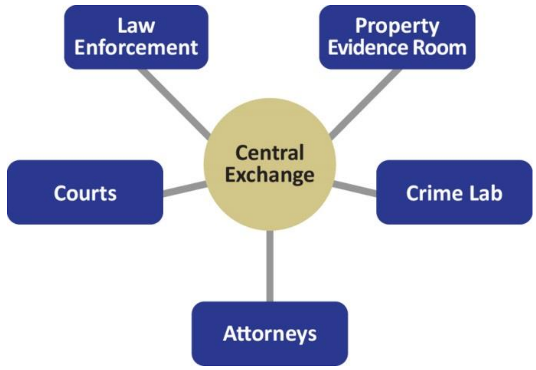


Figure 7-5: Centralized data exchange methodology.

The Department of Defense (DoD) uses this methodology to track DoD IUID data. The DoD IUID Registry is a relational database sponsored by the Defense Procurement and Acquisition Policy Office in the Office of the Secretary of Defense, Acquisition, Technology and Logistics (US Department of Defense 2013). It is the authoritative repository for all DoD IUID data. Using the machine readable Unique Item Identifier on DoD assets, DoD components can track, catalog, and inventory using commercially available technology. When a DoD organization manages equipment, spare parts, or any DoD serially managed item, IUID affects its processes and planning. By implementing and using IUID, the DoD is moving forward on the path to a common DoD standard for item management. The IUID registry captures data from many systems and submitters via open standard interfaces.

Distributed Data Exchange

EPCglobal has developed the EPC Information Services (EPCIS) standard to help trading partners share information. This is a standards-based approach to securely share product movement information that provides visibility and improves businesses processes. This standard is the foundation for increasing visibility, accuracy, and automation throughout the supply chain. The standard is industry- and application- agnostic. In addition, the EPCIS standard provides for a secure information exchange, where all partners control their own data and share it only with those with whom they choose to share it and leverage established security mechanisms. Figure 7-6 illustrates the distributed nature of the EPCIS standard.

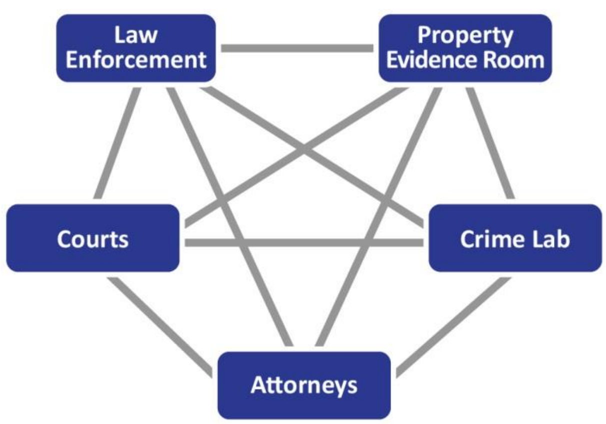


Figure 7-6: Distributed data exchange methodology.

Evidence identification can be captured in the form of passive RFID, barcodes, and human-readable formats. For example, if an EPCIS interface exists at each agency along the property and evidence management chain and if that the evidence is tagged with unique barcodes, each agency records the event in its local EPCIS as the evidence is moved through it. If an agency would like to query the chain-of-custody history for the piece of evidence, it can query the EPCIS of its partner organizations to pull up the historical events associated with that piece of evidence. The benefit of this model is security. Since the data is not stored centrally, the information shared can be regulated by the individual agencies who decide what should and should not be shared.

7.2 Recommendations

In order to assist the community in achieving enhanced tracking and storage of biological evidence using AIT such as RFID, the following recommendations are suggested. These recommendations were developed based on the research supporting this document and with input from the Technical Working Group on Biological Evidence.

1. To facilitate the adoption of AIT, State and regional level agencies should establish the following:

- **numbering standards**
- **evidence-labeling standards**
- **standard data-exchange methodology.**

Increasing the visibility of forensic evidence within the law enforcement community is beneficial not only due to tangible savings but also due to the intangible benefits of enhancing an agency's ability to administer justice. Although agencies decide individually on the adoption of AIT, actions at the State or regional level can ease transition through the creation of numbering, evidence-labeling and data-exchange standards. The previous section describes the development of these standards in other government sectors and can serve as a roadmap to their development within the domain of forensic evidence management.

2. Individual law enforcement agencies should analyze current evidence handling processes to identify areas that can benefit from AIT adoption.

Re-engineering property and evidence management processes are a key step in helping law enforcement agencies and their partners realize the benefits of AIT. Injecting AIT into existing processes without re-thinking the status quo can result in a cumbersome or inefficient system. Current processes must be scrutinized and re-tooled to fully take advantage of the added capabilities of AIT. Further, all processes may not require the use of a certain AIT technology. For example, in some cases a hybrid solution, one that uses both RFID and barcodes (such as a smart label), or even more advanced AIT, such as RTLS, may be required depending on the needs of a specific business process.

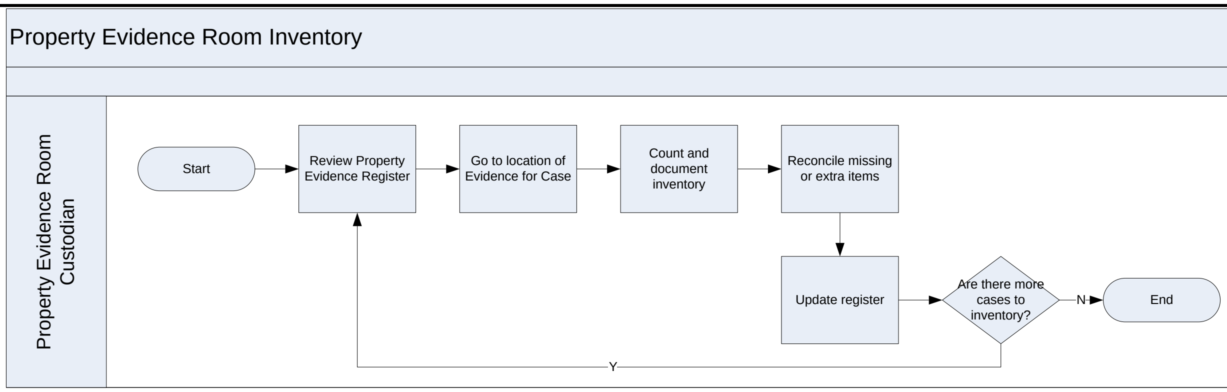
Table 7-2 displays an example of how current business processes might be enhanced with the use of AIT. Figure 7-7 following the chart is an example of a business process flow before and after the injection of RFID. A more detailed process flow could display the sequence of process steps and the average time spent on each step for better clarity on the pros and cons of a manual versus AIT-enabled process.

Table 7-2: As-Is versus To-Be Business Processes Comparison

Process Name	As-Is	To-Be	Potential Benefits
Package Evidence	• Collection is manual. • Identification method is organization specific. • Paper-based chain-of-custody initiation.	• RFID used in collection of evidence by labeling and entering evidence information at crime scene. • Unique identifiers applied to evidence during collection. • Electronic chain of custody.	• Reduced time for cataloging of evidence. • Automated initiation of chain of custody. • Evidence is logged and able to be searched immediately in real-time location systems.
Complete Submission for Processing	• Manual documentation of case details. • Manual application of evidence identification. • Paper-based chain of custody.	• Documentation of case details via IT system. • Electronic chain of custody. • Correlation of multiple pieces of evidence is automatic.	• Reduced time for evidence submission. • Automated chain of custody. • Allows for immediate cross reference for other cases/searches.
Evidence Receipt	• Visual verification of each item of evidence by custodian. • Manual documentation in property record. • Paper-based property record. • Paper-based chain of custody.	• Automated verification of evidence using RFID. • Comparison of expected items with what has been scanned in. • Alert sent to user when discrepancies detected. • Automated registration of evidence in IT-based property register. • Electronic chain of custody.	• Automation of human readable and electronic labels. • Automated chain of custody.
Evidence Storage	• Manual documentation of location in property record.	• Automated registration of location IT-based property register.	• Reduced time in searching for evidence.
Temporary Evidence Release	• Paper-based chain of custody.	• Electronic chain of custody.	• Improved visibility into items released to other organizations. • Automated chain of custody.
Property and Evidence Room Inventory	• Manual property and evidence room inventory process. • Manual reconciliation of missing or extra items. • Visually inspect each item within case.	• Use of RFID readers for inventory. • Automated reconciliation of missing or misfiled items. • Comparison of expected items with what has been scanned in Alert to user when discrepancies detected.	• Labor savings for conducting evidence inventory. • More accurate inventory and visibility into property and evidence room. • Allows other agencies to search for related evidence if needed in other cases.

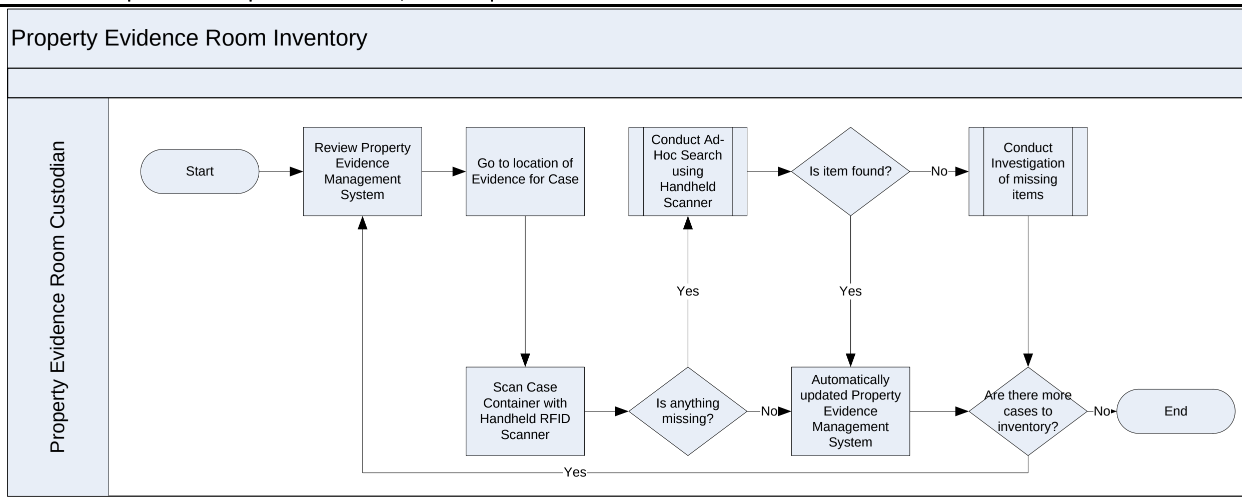
Figure 7-7: Example As-Is and To-Be business process mapping.

As-Is



- Manual property and evidence room inventory process
- Manual reconciliation of missing or extra items
- Visual inspection of each item within case
- Fewer process steps than below, but steps are time intensive

To-Be



- Use of RFID readers for inventory
- Automated reconciliation of missing or misfiled items
- Comparison of expected items with info that has been scanned in
- Alert sent to user when discrepancies detected
- More steps, but with drastically shorter time duration

POTENTIAL BENEFITS OF AIT

- Labor savings for conducting evidence inventory
- More accurate inventory and visibility into property and evidence room

3. **Law enforcement agencies should work to optimize the use of AIT technologies such as RFID by enhancing agency coordination, data exchange methods, process management, and automation.**

A Capability Maturity Model is a tool used to aid in the improvement of business processes that is often used in software development, but applicable to many sectors. Maturity, in this context, refers to the level at which an organization's behaviors and processes can produce reliable and sustainable outcomes. (Paulk, Curtis, Chrissis, & Weber 1993) Figure 7-8 depicts a Capability Maturity Model in the context of forensic evidence management. It can be used by law enforcement agencies to assess their property and evidence management capabilities and highlights the areas that an organization can focus on to improve the maturity of its evidence management processes and systems. A capability that is *optimizing* its processes integrates mechanisms for continuous improvement (data on performance of systems and personnel) and utilizes appropriate innovations in technology. Each step describes the elements needed to eventually achieve optimization of business processes. Using the Capability Maturity Model, for example, the majority of law enforcement agencies across the nation, from a property and evidence management capability maturity perspective, would be categorized as *ad hoc.* Agency coordination is limited, data are exchanged via manual paper-based systems, many processes are undocumented, and inventories are conducted with no AIT. For example, a police department in Texas that uses a log book to manage inventory and does not leverage any technology would be categorized as ad hoc. However, an organization in New York that is using an evidence management system enabled with barcode readers to help track and manage property and evidence and has documented processes and procedures would be categorized as *defined*.

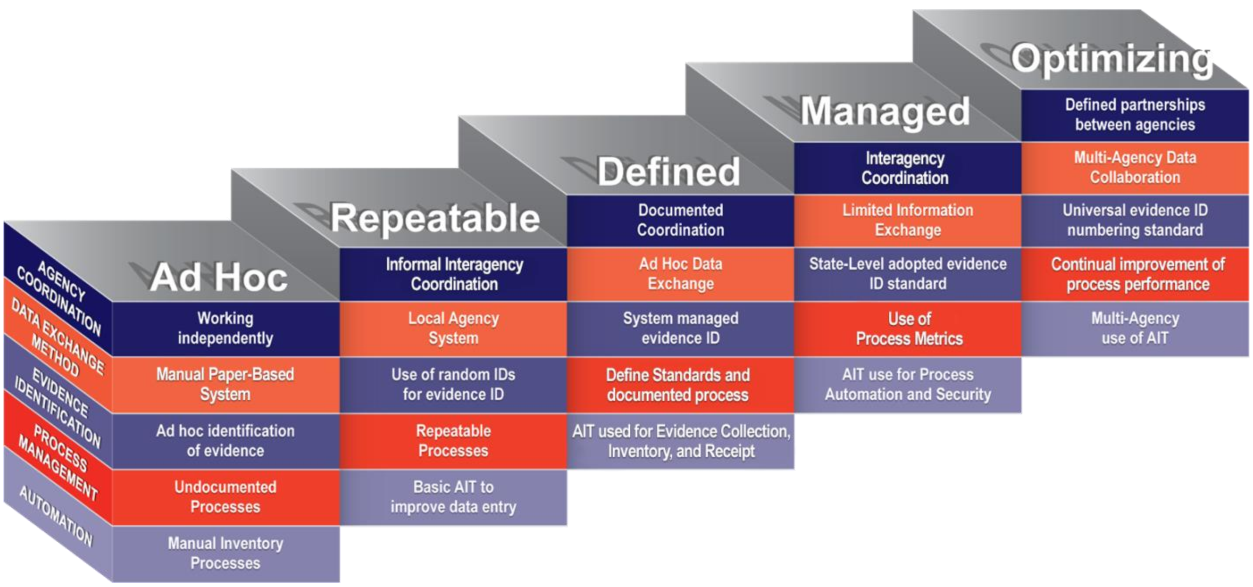


Figure 7-8: Property and evidence management capability maturity model.

Implementing an automated identification technology alone will not fully optimize the processes used to manage forensic evidence. Due to the nature of forensic evidence, law enforcement agencies must also consider the level of agency coordination, the methods used to exchange data, and the management of processes in addition to the level of automation in order to improve evidence management. Addressing each of these areas can facilitate improvements throughout the system instead of within one agency alone.

4. Law enforcement agency management should use the experiences of commercial organizations to overcome barriers to adoption in law enforcement.

As stated previously, most law enforcement agencies fall to the left of the property and evidence management capability maturity model illustrated above. The perception of most law enforcement organizations is that there are a variety of barriers preventing them from moving up to a higher property and evidence management maturity level. There are many examples of commercial organizations that have faced similar barriers in higher asset management maturity level using AIT. (See Section 5.) These successful organizations have overcome these barriers by collaborating with similar organizations, trading partners, and solution vendors to define standard business processes and technology standards. Table 7-3 illustrates how law enforcement agencies can utilize the similar experiences of commercial organizations in overcoming similar hurdles.

Table 7-3: Overcoming Barriers for AIT Adoption

Barrier	Description	Resolution	Commercial Example
Forensic Evidence Lacks Compatible Management Solutions	Some vendors have applied AIT technology to the forensic evidence process, but the lack of common processes and common data format has resulted in incompatible solutions.	Law enforcement organizations (labs, courts, attorneys, etc.) should work together to develop and define standards and processes for handling evidence. Once standards are in place, engineers and system integrators can tailor and design compatible solutions.	RFID solution vendors developed dock door portal readers for use in warehouse shipping and receiving processes. RFID solution vendors were able to develop a solution for these processes because dock door configurations and most shipping and receiving processes are standardized across multiple industries.
Forensic Evidence is Different	Law enforcement agencies believe that because of the nature of property and evidence and the manner in which it is stored advanced AIT technologies are not reliable.	The key factor in improving the reliability of the technology is to have industry-approved standards and processes for handling and storing evidence. Once standard processes have been established, many of the advantages AIT has provided to other applications will also apply to forensic evidence.	In various pilots, pharmaceutical distributors demonstrated the ability to automatically read and verify items in a case of tablet bottles from a manufacturer without ever having to open the case and scan each individual bottle. This was achieved due to the standard approach in labeling of tablet bottles and the placement of the labels on the bottles.
Forensic Evidence is Complex	Some believe that AIT would be costly and show little benefit because of law enforcements' multi-agency environment and the multitude of unique processes being used for handling evidence.	For a law enforcement agency to achieve the full benefits of implementing AIT, standard processes and procedures must be established. These standards and procedures should cover all aspects of evidence handling.	Commercial industries also work with many partners with unique processes, but over time, these processes have been harmonized to capture cost savings that are mutually beneficial. For example, supply chain distribution processes (shipping, receiving, packing, etc.) have become standardized at a high level. This has allowed vendors to create solutions for these specific processes.

4. **Federal level stakeholders should take steps to coordinate standards development efforts that enable law enforcement's use of AIT.**

Federal agencies such as NIST and NIJ serve a prominent role in facilitating the development of standards for law enforcement. The community can benefit from the establishment of an initiative or program aimed at strengthening the foundation on which AIT's adoption can be expanded. The International Organization for Standardization and the industry group EPCglobal are prominent organizations that have created and developed a variety of AIT standards. Other standards organizations exist that may also be relevant to AIT in forensics. These organizations play a role in helping to develop a market for vendors who sell AIT solutions. The community could benefit from internal coordination to help to organize its presence in these standards bodies for the use of AIT in forensic evidence management.

8. CONCLUSION

RFID and other AIT technologies can enhance the management of forensic evidence and, to a certain extent, improve the administration of justice. For law enforcement agencies to adopt the use of AIT to improve their property and evidence management processes, a foundation must be established that educates, promotes, and helps facilitate the fast path to using this technology by addressing the multiple barriers agencies face when making these improvements.

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10. GLOSSARY[6]

802.11a/b/g standards—Technical standards, or specifications, for wireless local area network technology developed by the Institute of Electrical and Electronics Engineers. The standards create a basis for computer communication used to create wireless network products.

Automated identification technology (AIT)—Devices and systems that enable the capture, collection, and transfer of data to automatically identify objects and enter data about that object directly into computer systems with little to no human involvement.

Antenna—A component of an RFID system that enables the microchip on an RFID tag to transmit the stored information to a reader.

Anti-collision systems—Systems designed to prevent the collision of signals when one interrogator reads multiple tags. Signal collision can cause errors in reading of tags.

Asset Tag—An RFID tag that is affixed to the item being tracked in an AIT system.

Asset Management—Any system that monitors and maintains items of value for an organization or entity.

Barcode—An optical machine-readable representation of data about an object; one of the oldest and most widely used forms of AIT.

Bi-directional data exchange—An exchange that occurs when data can be pushed to or pulled from an RFID tag.

Choke points—In the context of this report and area in which assets enter or exit.

Enterprise Application—Computer software that an entity uses to solve organizational problems.

High frequency—Radio frequency range that is used for long-distance communication applications, such as aviation communication.

Infrared transmitters—In the context of this report, passive identification devices that direct infrared light to the tags on the devices to enable real-time location tracking of an inventory asset.

Intelligent functions—Capabilities that allow an entity to make observations via the use of sensors and perform actions that affect its environment to achieve a particular goal. For example, microchips with intelligent functions can be programmed to accumulate data for local storage (log data, count the number of events, etc.), sense their environment (light, temperature, humidity, movement, open/close contact switch, etc.), go dormant, or periodically wake up to perform functions and protect their data or onboard functions with encryption or passwords to meet security goals.

Location Awareness—An object's proximity to a location, for example, "room number" or "building code" or the person or agency that has possession.

Location Engine—A computational application that calculates the best-estimates of a location based on algorithms using geometry and topography and that is used in real time locating systems and navigation systems.

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[6] Some definitions have been adapted from *RFID Journal*. ("Glossary of RFID Terms" 2014).

Localization—A method used to determine the specific location of assets. The location engine calculates the probable location of the Wi-Fi tag by measuring the RF signal travel time or the RF signal strength of at least three neighboring access points whose location is already known.

Middleware—Computer software that enables communication between two disparate systems or programs; servers/software that support readers' ability to extract unique information from the read data, enforce business rules, and communicate with upstream applications and databases.

Presence—An object's availability at a specific time and location.

Property and evidence—A term used to describe all possible items of investigative value which may come into possession of a law enforcement agency.

Supply chain management—The management of the production, transport, and distribution of products or services to maximize customer value and sustainability.

Radio-Frequency (RF) Band—A small section of a spectrum of radio communication frequencies. Different parts of a radio spectrum are used for different purposes; for example, some are used to broadcast television stations while others are used for cellular phone operations. The radio spectrum and its uses are regulated by the Government.

Radio-Frequency Identification (RFID)—A form of automatic identification and data capture technology that uses electric or magnetic fields at radio frequencies to transmit information.

Reader/Antenna—A fixed or mobile data capture device that reads the tags and retrieves the data from all tags in a receiving area. Rugged readers/antennas can be attached to vehicles or provided as handheld devices.

Real-Time Location Systems—An IT system based on a wireless technology that can be used to continuously determine and track the location of assets and personnel. In traditional RFID-based systems, tags are read as they pass fixed points in a structure process. Within an RTLS, tags are read automatically and continuously, independent of a business process.

Reference tag—An RFID tag that is affixed to a specific location or choke point to which the asset tag can be tracked.

RFID tag—A device comprised of an antenna connected to a microchip or integrated circuit. The tag is a component of an RFID system and has information programmed into it, such as a unique ID number.

Wireless local area network (WLAN)—A technology that connects two or more devices via wireless technology and provide a connection to the internet.

Ultra high-frequency (UHF)—Radio-frequency range of 300 MHz to 3 GHz to which propagates mainly by line of sight used for applications such as television broadcasting and satellite communications.

11. APPENDIX: TYPES OF AIT

Type	Description
µ-chip	The µ-chip is the world's smallest RFID integrated circuit. It stores ID numbers in memory but has limited usage because of its high cost.
Active RFID + Global Positioning System (GPS)	Active RFID + GPS is a hybrid RFID tag that combines active RFID and GPS capabilities. Some are designed to track goods geographically in a supply chain.
Barcode	A barcode is an optical machine-readable representation of data about an object. It is one of the oldest and most widely used forms of AIT.
BAP RFID	BAP RFID tags contain an integrated power source. This power source eliminates the need to gather energy from the reader and wake up the chip. For management's budget, BAP tags are much less expensive than active RFID tags.
Beaconing Active RFID	Beaconing active RFID tags consist of a long-range RFID tag that uses beaconing technology to send data to a mobile or fixed reader up to 300 feet.
Cellular + GPS	Cellular + GPS hybrid RFID tags combine RFID and cellular capabilities.
Electronic Article Surveillance (EAS)	EAS technologies consist of RFID tags that can be turned on and off. EAS tags are imbedded in pharmaceutical packaging, retail items, or library books. The tags are turned off before, for example, someone passes through a gate or undesignated area. If the tag isn't turned off, an alarm sounds.
High–Frequency (HF)/Near Field Passive RFID	HF/ Near-Field Passive RFID tags do not contain a battery; the power is supplied by the reader. The tag can be read only at very short distances, typically a several centimeters for HF and up to 7 meters for ultra-HF. It is typically not possible to include sensors on passive tags because they lack an onboard power source.
Low-Frequency (LF)/Near Field Passive RFID	LF /Near-Field Passive RFID tags also do not contain a battery; the power is supplied by the reader. LF RFID is used most commonly for physical access control systems, such as where employees tap their badges on door controllers to gain access to secure areas.
Non-Beaconing Active RFID	Non-beaconing active RFID tags are equipped with a battery that can be used as a partial or complete source of power for the tag's circuitry and antenna. It can be read at distances of 30 meters or more, greatly improving the use of the device. The onboard battery can also be used to power sensors (temperature, open/close status, etc.).
RuBee	Rubee tags use an active wireless protocol that uses long-wave magnetic signals to send and receive data. Tags function successfully in harsh environments (through steel, water) where other RFID tags don't function as well.
Surface Acoustic Wave (SAW) Passive RFID	SAW passive RFID tags rely on surface acoustic waves converted from radio wave pulses from interdigital transducers, components of the microchip. These tags have not gained wide acceptance but have the built-in capability to measure an object's temperature and estimate real-time location.
TV-GPS	Technology uses TV-based positioning to identify the location of people or items.
Ultra High-Frequency (UHF)/Far Field Passive RFID	RFID Tag that does not contain a battery; the power is supplied by the reader. When radio waves from the reader are encountered by a passive RFID tag, the coiled antenna within the tag forms a magnetic field. The tag draws power from it, energizing the circuits in the tag. The tag then sends the information encoded in the tag's memory. The tag can be read only at very short distances, typically up to 7 meters for UHF. It is typically not possible to include sensors on passive tags because they lack an onboard power source.
Ultra-Low Power Wi-Fi	Wireless chips that operate on extremely low power and can be embedded in a variety of objects, such as weight scales, thermostats, and security cameras.

Type	Description
Ultra-Wide Band (UWB) RTLS	An RTLS is an IT system based on a wireless technology that can be used to continuously determine and track the location of assets and personnel. UWB RTLS uses very-short duration pulses but at a very low energy level. These short pulses operate in a wide frequency band, well outside the band used by Wi-Fi and other devices. The short duration of the UWB radio pulse can give it superior accuracy for its location measurements.
Wide-Area Tracking and Telemetry	Wide Area Tracking and Telemetry systems consist of highly automated communications processes by which information is tracked at remote or inaccessible points and transmitted to receiving equipment for monitoring. Transfer mechanisms include using radio, hypersonic or infrared systems that are picked up by the sensors and undergo "data fusion," which converts the information into easily interpreted forms.
Wi-Fi RTLS	An RTLS is an IT system based on a wireless technology that can be used to continuously determine and track the location of assets and personnel. Wi-Fi RFID tags can readily communicate directly with a standard Wi-Fi infrastructure without any special hardware or firmware modifications and can coexist alongside other Wi-Fi clients, such as laptop computers.
ZigBee	Zigbee is a low-cost radio standard in which tiny low-powered radios form networks by passing data among themselves creating a mesh network. ZigBee is used in applications that require low data rate, long battery life, and secure networking.