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Martin O'Malley, *Governor*
Anthony G. Brown, *Lt. Governor*

James T. Smith, Jr., *Secretary*
Melinda B. Peters, *Administrator*

# STATE HIGHWAY ADMINISTRATION RESEARCH REPORT

# UTILIZING AUTOMATIC IDENTIFICATION TRACKING SYSTEMS TO COMPILE OPERATIONAL FIELD AND STRUCTURE DATA

**UNIVERSITY OF MARYLAND**

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16. Abstract

The Maryland State Highway Administration's (SHA) Office of Materials Technology (OMT) ensures that the quality of materials used on Maryland's roadway system are properly designed, produced, and built to the approved codes and standards. The Materials Quality divisions of OMT are structured into the Asphalt Technology, Concrete Technology, Soils and Aggregate Technology, and Structural Materials and Pavement Markings divisions. Each division is responsible for the quality assurance/control testing, evaluation, and clearance of the materials used in transportation facility construction. From the time the materials are sampled in the field, the management of these materials relies on a series of intensive human processes involving sample collection and delivery, written reports and log books to record materials' laboratory test results and track logistical information. As the materials travel throughout the six different laboratories, material information is manually recorded into a localized network database and the Material Management System (MMS) separately. The current amount of human involvement necessary in the generation of sample reports and manual data entry process can be streamlined with the integration of Automatic Identification Technology (AIT). This study investigates past implementations of AIT into civil engineering and construction applications to detail necessary modifications to OMT's existing material clearance and MMS processes; as well as AIT system hardware recommendations, software development and integration considerations, estimated investment costs, and estimated return on investment.

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# Utilizing Automatic Identification Tracking Systems to Compile Operational Field and Structure Data

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| SHA | Maryland State Highway Administration |
| OMT | Office of Materials Technology |
| QA | Quality Assurance |
| MMS | Materials Management System |
| AIT, Auto-Id | Automatic Identification Technology |
| RFID | Radio Frequency Identification |
| DOT | Department of Transportation |
| GPS | Global Positioning System |
| CMB | Contact Memory Buttons |
| 1D/2D Barcodes | One-, Two-Dimensional Barcodes |
| XML | Extensible Markup Language |
| URL | Uniform Resource Locator |
| HTTP | Hypertext Transfer Protocol |
| UPC | Universal Product Code |
| FHWA | Federal Highway Administration |
| ECPTA | European Conference of Postal and Telecommunications Administrations |
| ISO | International Organization of Standards |
| MIT | Massachusetts Institute of Technology |
| EPC | Electronic Product Code |
| DoD | Department of Defense |
| Dpi | Dots Per Inch |
| DHS | Department of Homeland Security |
| CMTS | Construction Material Tracking System |
| CMMS | Concrete Maturity Monitoring System |
| HMA | Hot-Mixed Asphalt |
| UCC | Uniform Code Council |
| GTIN | Global Trade Item Number |
| GLN | Global Location Number |
| SSCC | Serial Shipping Container Code |
| DPM | Direction Path Mark |
| CCD | Charge-Coupled Device |
| LED | Light Emitting Diodes |
| LCD | Liquid Crystal Display |
| DSP | Digital Signal Process |
| OS | Operating System |
| SDK | Software Development Kits |
| API | Application Program Interfaces |
| ASCII | American Standard Code For Information Interchange |
| TCP/IP | Transmission Control Protocol/Internet Protocol |
| DHCP | Dynamic Host Configurations |
| UDP/IP | User Diagram Protocol |
| Wi-Fi, 802.11 | Wireless Fidelity |
| WLAN | Wireless Local Area Network |
| NFC | Near Field Communication |
| SD | Secure Digital |
| SDiD | Secure Digital Identification |

| | |
|---|---|
| UHF | Ultra-High Frequency |
| ONS | Object Naming Service |
| EPCIS | Electronic Product Code Information Service |
| ERP | Enterprise Resource Planning |
| WMS | Warehouse Management System |
| URI | Uniform Resource Identifier |
| WAN | Wide Area Network |
| LAN | Local Area Network |
| UHF EPC Gen 2 | Ultra-High Frequency Electronic Product Code Generation 2 Radio Frequency Identification Tags |
| AIDC | Automatic Identification And Data Capture |
| FOD | Foreign Object Debris |
| FTP | File Transfer Protocols |
| WCDMA | Wideband Code Division Multiple Access |
| WiMAX | Worldwide Interoperability for Microwave Access |
| GSM | Global System for Mobile Communication |
| EAP | Extensible Authentication Protocol |
| 3G | Third Generation Mobile Communication Network |
| LTE | Long Term Evolution Communication Network |
| AASHTO | American Association of State Highway Transportation Officials |
| ASTM | American Society for Testing and Materials |
| MCMS | Maryland Construction Management System |
| FMIS | Financial Management Information System |
| PMS | Pavement Management System |
| BMS | Bridge Management System |
| LIMS | Laboratory Information Management System |
| SATD | Soils and Aggregate Technology Division |
| ATD | Asphalt Technology Division |
| QPL | Qualified Products List |
| CTD | Concrete Technology Division |
| SMPMD | Structural Materials and Pavement Markings Division |
| IEEE | Institute of Electrical and Electronics Engineers |
| ROI | Return on Investment |

# Chapter One: Introduction and Overview

## 1.1 Problem Statement

The federally mandated materials clearance process requires state highway administrations and all state transportation agencies to submit construction field samples for quality control and quality assurance testing in order to pass standardized state inspections. These material field samples are delivered to the Office of Materials Technology's (OMT) laboratories from a variety of contractors, producers, and manufacturers from across the country and are often taken by quality control technicians or personnel who may be unfamiliar with the exact details required to be entered on the materials sample forms. This uncertainty in the field typically results in frequent transcription errors when transferring data from material certifications, labels or data sheets onto these forms. Although such errors may initially go unnoticed by the material manufacturer producer, the inaccuracies either come to light when the form is reviewed by the Quality Assurance (QA) Technician or when the material is delivered to the lab for testing. In such event, the QA technicians must travel from Western Maryland to the specific site in order to make necessary corrections to the forms, resulting in a significant burden on the field team's labor resources.

Once the materials are delivered to OMT laboratories they are moved to their proper testing facilities and tracked using written identification numbers. Each material is accompanied by a "General Materials Sample Form" (SHA73.0-88 or OMT Form 88), which is continuously updated with new information and details during the material clearance process. As the materials are moved throughout the laboratories, decisions are made about the type of testing required and the number of tests to be done. In its current form, the testing information is printed as a hard copy, then results are manually entered into a computer database, known as the Material Management System (MMS), and often scanned or faxed to Project Engineers or Contractors for future reference and incorporated in the project files.

This study explored the various applications of two main types of Automatic Identification Technology (AIT) in civil engineering fields to provide the OMT laboratories with methods to minimize the consumption of resources in current business operations and for future extensions within state Department of Transportation (DOTs).

## 1.2 Background

Innovations in AITs were developed to minimize the level of human involvement, increase flexibility, maintain low costs, and yield a higher quality. Barcodes, Radio Frequency Identification (RFID), Satellite/GPS tags, and Contact Memory Buttons (CMB) have been identified as technologies typically implemented into business enterprise environments. During the late 1960s, the first type of AIT was implemented in the retail industry (Rasdorf, et al., 2003). Made of a composition of black bars varying in widths, barcodes are the most commonly used type of unique identifier implemented in today's enterprise operations. Although the traditional barcode system can improve item visibility, it does not achieve real time visibility due to line of sight requirements and low reading speeds in comparison to RFID (Su, et al., 2007). As one of the most advanced AIT, RFID has high-speed reading capabilities, does not have line of sight requirements, and requires minimal human involvement (Su, et al., 2007). Currently the construction, manufacturing, and automotive industries have begun to follow in the footsteps of the retail industry to enhance the coordination of production or tracking material.

AITs are gradually becoming integrated into specific areas of civil engineering such as material tracking, progress monitoring and quality assurance. Unique identifiers such as barcodes or RFIDs can be implemented in business operations to identify and describe a variety of objects, locations, asset types as well as documents. This type of automated data storage would be beneficial on construction sites where paper based tracking systems are used because resources are commonly wasted to execute activities such as:

- locating and identifying construction components or sub-assemblies;
- managing resource availability; and
- maintaining contract compliance.

Without timely resource availability within a construction site, such activities cannot be performed despite the level of proficiency of the existing business process. For instance, when site samples are sent to OMT for standardized compliance testing, the results must be sent back to the construction site in a timely manner. If not, construction operations will either continue as scheduled or be put on hold. However if test results conclude the sample is not in compliance, it may cause disruptions in the schedule. Past studies and industry experience have shown that the dynamics of the construction process can be enhanced using AITs for warehouse logistics, inventory control, and material management. Such data capture systems have at least three key components: (1) data capture technology, (2) automatic identification reader, and (3) database that associate data with the tag/label as shown in Figure 1.1.

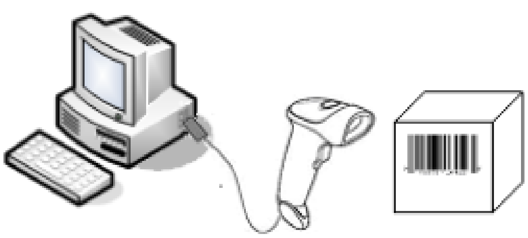


**Figure 1.1 - Three necessary components of a basic barcode system(Su, et al., 2007)**

The system's readers can be connected to computers or wireless handheld devices. When utilizing computers or handheld devices, the system's software processes the identification information collected from the reader and is manipulated as needed. Although the applications of unique identifiers have the ability to aid in the automation of existing component tracking systems, the implementation of such technology in the construction industry may increase the level of complexity due to the industry's hostile, dynamic site conditions, and potential limited interoperability between the AIT and existing hardware and management software systems.

The Maryland State Highway Administration (SHA) expressed interest in integrating AIT into the current material clearance process to ensure the quality of materials utilized on the Maryland roadway system. To illustrate the advantages an automated data system could provide SHA, previous integrations of AIT in construction applications were investigated. AITs applicable to OMT laboratories were studied to outline each automated system's architecture and characteristic benefits, as well as system hardware and software recommendations. This report will provides SHA with a preliminary implementation guide for integrating AIT into the material clearance process and possibly other areas within the organization.

## 1.3 Objective and Scope of Work

The objective of this project was to present background information related to AITs, with hardware recommendations, system architecture components, and software development considerations. The implementation of different types of AITs in construction, material management, and assembly applications, is included to provide SHA with an understanding of the time and resource savings Automated Identification Data Capture (AIDC) systems can provide in the construction industry. This report also provides an overview of the system architecture of the two types of AITs predominantly utilized in the civil engineering and construction fields (barcode and RFID unique identifiers) to illustrate each AIT system's required components, functionalities, capabilities, and limitations. Utilizing the information collected from case studies, past AIT implementations, and data capture specialists, recommendations were developed to ensure that if and when the SHA decides to implement AIT into the material clearance process, it has the necessary tools to make proper decisions.

## 1.4 Outline of Report

The main objective of this report is to recommend AITs that would be beneficial to SHA. A description of popular AITs is found in Chapter Two. The report focuses on two AITs, namely barcode and RFID unique identifiers. Chapter Two describes how barcode and RFID technology have been used by the construction industry or closely related industries for the management of materials. The chapter addresses business practices related to material planning, material tracking, material inventory, and material infrastructure and monitoring. Chapter Three expands on barcode technology in full detail and illustrates the various types of barcodes, their various symbologies, and the currently available barcode hardware in the marketplace. Chapter Four expands on RFID technology and gives details on the various types of RFID tags, RFID readers, operational frequencies, network architecture, and currently available RFID hardware. Chapter Five describes the wireless network infrastructure needed to connect the AITs into existing database systems. This chapter details the parameters involved in the process and architecture to transfer data. Chapter Six provides a short discussion of the survey that was sent to selected states to see how AIT was or planned to be implemented in their Department of Transportation. Chapter Seven outlines the current material management system used by OMT. This chapter provides a detailed description of the daily material management operations in OMT's divisions and the duties of SHA field and laboratory personnel.  The chapter also discusses how the daily operations can be enhanced with the addition of AITs.  Source of supply lists were made to display the various components of auto-ID implementation that companies offer. Detailed recommendations on the implementation of auto-ID systems into OMT operations, costs and return on investment are provided in Chapter Seven. The brief conclusions and summary of OMT's enhanced material management system recommendations are included in Chapter Eight. Information on the Source of Supply (SOS) Lists; SHA Material Sample Forms and the OMT Flowchart are compiled in Appendix A.

# Chapter Two: Auto-ID Technologies in Material Management Systems

## 2.1 Introduction

Identification is a powerful tool necessary in classifying, counting, and organizing objects or items. These operations are essential to business processes including manufacturing, the logistics of distribution, and the various stages of supply chains that operate on scales ranging from the level of the individual consumer to that of global trade (NRC, 2004). With technological innovations over the past decade, multiple automatic identification methods have been developed to ensure quality, high return on investment, and to streamline business operations. AIT describes a group of technologies generally associated with methods to identify objects and automatically capture and enter data into databases autonomously. While there are numerous types of AITs, this chapter focuses on the following:

1) Barcodes (linear, 2D or 3D)
2) Radio Frequency Identification (RFID)
3) Contact Memory Buttons (CMB)
4) Satellite/GPS tags

Two popular types of automatic identification and data storage technologies that have been utilized in a multitude of industries due to their wide range of functionalities and relative ease of integration are barcodes and Radio Frequency Identification (RFID) technologies. Barcode unique identifiers are the most commonly used AIT. In barcode systems information is encoded in a series of bars at various widths and spaces. Digital readers capture, scan, and convert the barcode's visual image to computer-compatible data (i.e. XML or text formats). Unlike barcode labels, RFID tags utilize radio signals to verify the identification of objects and transfer data without line-of-sight requirements and allow multiple tags to be read simultaneously. This ability may prove to be a drawback, however, if the user is attempting to read a specific tag among many (Ala-Risku, 2006).

Contact memory technology uses a microchip housed in a rugged container to store and transfer data. Like RFID technologies, the button sized chip interfaces with a reading device to transfer information associated with the asset (CTE, 2012). Due to the storage container, contact memory technologies have been proven to be "ideal for use in harsh industrial applications" (Chung, et al., 2011). Contact Memory Buttons (CMB) have been used to mark hazardous and radioactive waste for long-term storage, track the maintenance of airplane brakes, and store repair diagrams. The storage capacity of a CMB is also larger than RFID chips and has been shown to store up to four gigabytes of data, including photos, PDF copies of repair orders and recurring inspection requirements (Coop, 2012). More recently, contact memory buttons have proved to be an effective companion to RFID technologies; CMB and RFID technology is further discussed in section 2.2.2.4.

A Global Positioning System (GPS) is a satellite based navigation system used to provide the time and location information of any object with an attached receiver. The receiver calculates its distance from at least three satellites at a time in order to determine its position on Earth. A GPS system is a popular method for remote asset tracking over a wide geographic area. Integrating RFID tags with GPS allows for all the benefits of an RFID system, and supplemented with accurate real-time data collection that could be used in the transportation and construction industries. When these technologies are used with objects, the information from RFID tags can be transferred to a GPS receiver. The GPS receiver not only transmits its location, but additional information related to the object (Chung, et al., 2011).

Each of these technologies has unique characteristics that make it advantageous to specific applications. Satellite/GPS tags are best implemented in systems for tracking the progress of an object, whereas CMB technology is typically implemented to enhance information management systems and introduce automation into existing business practices. Despite the capabilities of these types of AIT, barcode and RFID technologies have been widely accepted as suitable business operation enhancements. Barcode applications have also been used to automate business processes, improve tracking systems, and manage large inflows of information. Generally, RFID has been considered the most advanced automatic technology because it has the capabilities of all three previous AITs and overcomes their limitations. Table 2.1 displays the comparable features of each AIT that should be considered when selecting an automated identification system (i.e. storage capacity, life span, reading distance, technical limitations, and costs).

**Table 2.1 - Comparison of Automatic Identification Technology**

| Technology Features | Barcodes[1] | Radio Frequency Identification[2] | Contact Memory Buttons[3] | Satellite Tags/GPS[4] |
|---|---|---|---|---|
| **Modification Capability** | Not Modifiable | Modifiable | Modifiable | Modifiable |
| **Storage Capacity** | Linear barcodes can hold 8-30 characters; 2-D barcodes hold up to 7,200 numbers | Up to 64KB | Up to 8MB | Up to 8MB |
| **Life Span** | Short unless laser-etched into metal | Unlimited | Long | 3-5 year battery life |
| **Reading Distance** | Line of Sight (3 – 5 feet) | No contact or line of sight required; distance up to 50 feet | Contact required | No contact or line of sight; distance up to 100 meters and beyond |
| **Potential Interference** | Optical barriers such as dirt or objects placed between tag and reader | Environments or field that affect transmission of radio frequency | Contact blockage | Limited barriers since the broadcast signal from the tag is strong |
| **Costs** | Low (pennies or fraction of a penny per label) | Medium (< 25 cents per tag) | High (> $1 per button) | Very High ($10 – 100 per tag) |

[1] Gareth R.T. White, Georgina Gardiner, Guru Prabhakar, and Azley Abd Razak. A Comparison of Barcoding and RFID Technologies in Practice. Journal of Information, Information Technology, and Organizations, Vol 2. 2007

[2] Hunt V. Daniel, Puglia Albert and Puglia Mike. RFID A Guide to Radio Frequency Identification [Book]. - Hoboken, NJ : A John Wiley & Sons, Inc. 2007.

[3] William J. Rasdorf, and Mark J. Herbert. Introduction to Automated Identification System – With a Focus on Bar Coding. Journal of Computing in Civil Engineering, ASCE. 2003.

[4] Mikko Kärkkäinen and Timo Ala-Risku. Automatic Identification – Applications and Technologies. 2006.

## 2.2 Automated Management of Materials Systems

Management of materials in the construction industry can be characterized as complex, integrated, and dynamic (Ren, et al., 2010). By introducing AIT into construction materials management, complex manual data collection processes can be eliminated and the smooth flow of information between phases of the material management process can be streamlined. The many phases of materials within construction management system include: material planning, material tracking and control, material inventory, and material and infrastructure monitoring. The hierarchy shown in Figure 2.1 best illustrates the organization of how AIT is used in construction management.

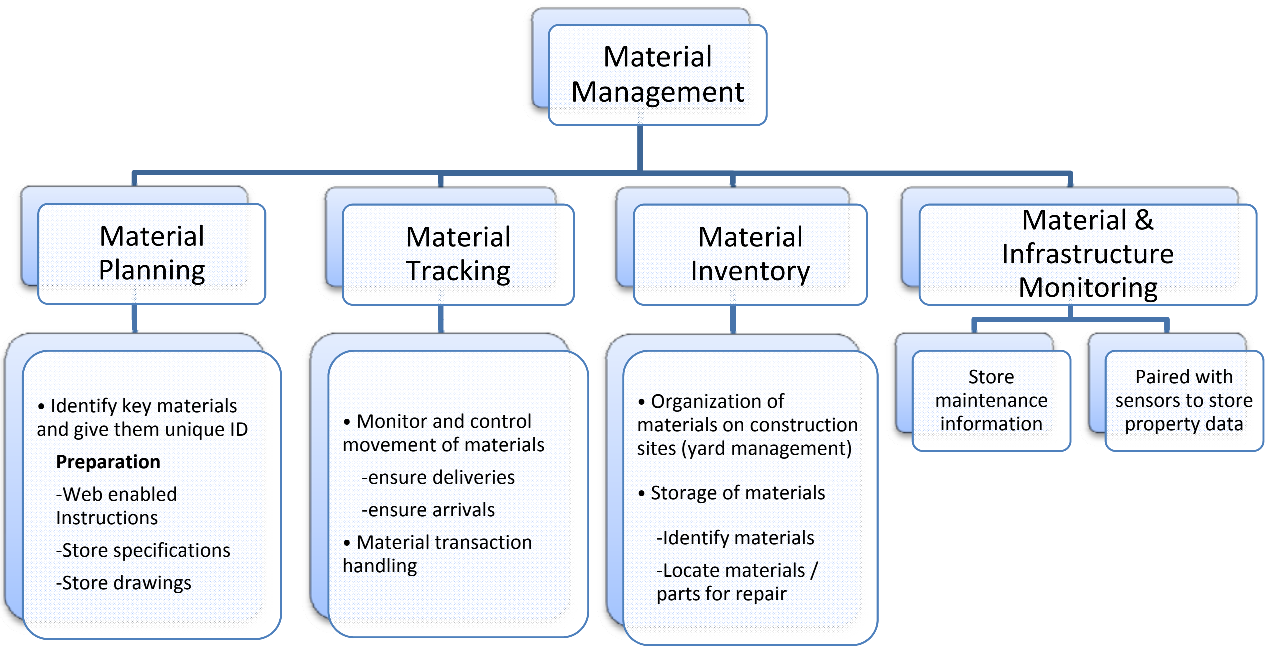



**Figure 2.1 - Hierarchy to illustrate the use of auto-ID technology in construction management**

During the planning phases of construction, technical drawings are used to visually communicate the assemblage and functionality of various materials or discrete building components. Depending on the scale of the construction, technical drawings could take hundreds of pages to illustrate the details of the engineered designs. Generally, these drawings must be presented to all personnel involved in the construction process. However, in practice, technical drawings may be lost or damaged, which results in personnel making quick decisions that may not be the best informed choice for resolution.

The advantages of using AIT within the material management system are that it can maintain a record of the material's history throughout the construction process and provide a full audit trail of all changes made to materials, drawings, or contracts (Ren, et al., 2010). Figure 2.2 best illustrates how the phases are related to each other within the construction material management lifecycle.

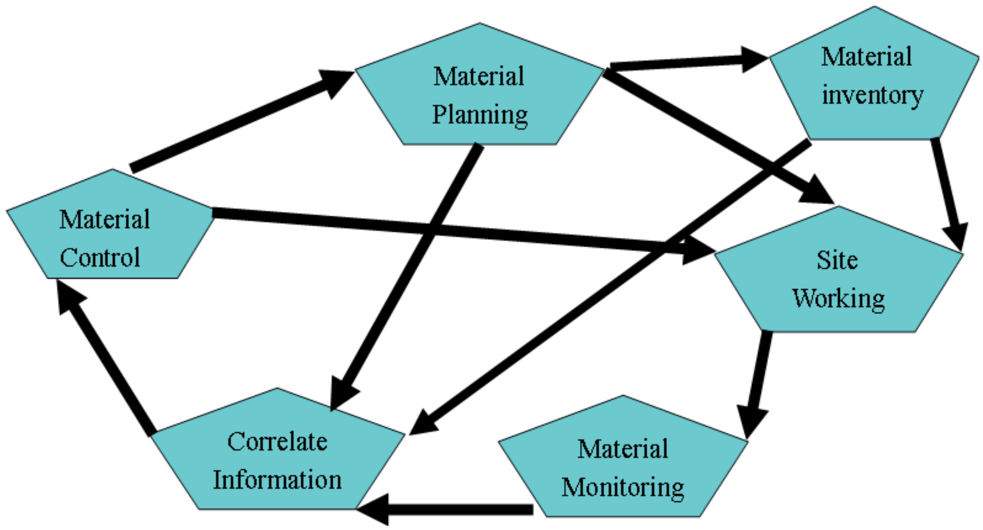



Figure 2.2 - Construction Material Management Lifecycle (Ren, et al., 2010).

The implementation of integrated barcode and RFID systems to enhance business operations is proving to have significant impacts in civil engineering and construction applications. Both unique identifiers are capable of (1) reducing man-hours, (2) eliminating human errors in inventory management, (3) identifying areas to reduce documentation or productivity loss, and (4) improving mobility within the organization. The benefits of AIT in construction, transportation, and manufacturing applications are illustrated in the case studies discussed in this section.

Barcode systems are recommended in cases, where a large volume of labels are utilized due to their low production costs. Barcode labels are also capable of withstanding signal interference from items containing liquids or made from metal and can withstand impacts from magnetic surges. Also within a barcode system, when objects are read they are instantly verified and sent to the reader. Despite some advantages, barcode technology faces many drawbacks: (1) the digital reader must be in close or line-of-sight distance to the label to scan and verify it, (2) the labels hold a limited amount of data, (3) information encoded on the barcode cannot be changed once it is stored, (4) barcode tags can easily be damaged or lost; especially in harsh conditions that are characteristic to construction environments, and (5) barcodes must be read one label at a time. (Moselhi, et al., 2006). While barcode technology has seen much success in management systems, the many limitations involved in a barcode system can be overcome with RFID. RFID technology provides a high return on investment in the material management process, because it can automate a number of the construction processes (i.e. improve planning, tracking, inventory and monitoring operations), and reduce errors. RFID has been used more broadly in construction and has proven to be useful. While barcodes have the advantage of being a low cost technology, the costs of RFID tags are continuing to decrease with further development in the field.

### 2.2.1 Barcode Integrated Business Practices in Civil Engineering Applications

Considered the first generation of AITs, barcodes first experienced industry acceptance and widespread use when implemented in the supermarket industry in the late 1960s. As the supermarket industry expanded in the twentieth century, stores began carrying an inventory of thousands of items, some of which were perishable items from various suppliers. Manual data input used in inventory tracking qualified as an ineffective method due to the large inflow of items and resulting transcription errors. Therefore barcode technology prevailed as a favorable automated data capturing solution due to its ability to reduce labor costs and improve inventory control. It also has the capability of improving the speed and accuracy of data entered or auto-populated into computer databases (Bell, et al., 1988). By April 1973, the Universal Product Code (UPC) was selected as the universal product identification system for use in barcode technology (Jones, et al., 2011). As computing technologies became more efficient, an increasing number of applications that could utilize barcode technology became more prevalent in society. Barcode identifiers remain a reliable tool for resource management and are now used in retail, warehousing and transportation applications. Barcode technology has also been extended to applications in the construction industry to identify materials, equipment, drawings, containers, and automatically generate reports that control these items (Bell, et al., 1988).

Barcode identifiers are typically used for entering data into databases by relating the unique identifiers to an external database. In a typical barcode automated identification system, the digital reader “reads” and translates the data from the barcode, sends the data to a remote database, and the reader displays information associated to the item from the database. There are three types of existing barcodes that are widely produced, however only two types have been implemented in civil engineering applications. One dimensional barcodes, also known as linear barcodes, are a combination of both narrow and wide bars read horizontally. This arrangement allows the barcode to hold information about an item as a product code or identification number that can be looked up or referenced from a remote database. Information encoded on the one dimensional barcode cannot be modified once printed, however two dimensional barcodes, also known as Quick Response Codes, allow encoded information to be modified. Second generation barcodes are graphical images with greater storage capacities because of their ability to store information both horizontally and vertically. This format allows additional information to be stored in the same amount of space as a linear barcode. Two dimensional barcodes can also be used to encode Uniform Resource Locators (URLs) or remote website addresses, allowing the front-end user to visit a website instantly after reading the barcode. When implemented in business enterprise applications, remote data related to both one and two dimensional barcodes are readily changeable. Three dimensional barcodes have the same storage capabilities as two dimensional barcodes however, this technology is more durable and can withstand extreme conditions. One dimensional barcodes are preferred on large projects when a large volume of labels are required due to lower production costs, easier implementation, and the handheld scanning devices are generally cheaper than two-dimensional barcodes devices (Moselhi, et al., 2006). In Section 3.2 one, two, and three-dimensional barcodes are further discussed.

#### *2.2.1.1 Material Inventory*

Barcode identifiers are advantageous because they offer instant and complete product recognition, while keeping current and accurate records of the product (McCraven, 2011). The use of barcodes in the construction industry offers a systematic solution to the management of inventory and accurate records of product data. Terre Hill Concrete Products Incorporated, a precast concrete producer, found much difficulty in managing their inventory when project delays caused products to pile up in their prefabrication yard. To overcome this difficulty, in 2011 Terre Hill switched from the traditional machine-cut stencils and ink rollers to two dimensional barcodes. The company found barcodes to be more durable, professional looking, and legible; "barcode labels are easy to read from a distance with their bright, white background, and crisp dark print" (McCraven, 2011). In combination with handheld scanners, employees at Terre Hill were able track the location of 'special' or custom made items, which reduced the time spent scouring the yard searching for a certain product to load on the truck. Terre Hill also recognized that barcodes have made their products increasingly organized and have provided accurate recordings of production time, deliveries, invoices, and year-end inventory counts. The system's component costs include approximately $2,500 per thermal industrial-grade printer, $0.35 per barcode label (assuming 500 labels are purchased at a time), and the barcode reader's cost is dependent on its capabilities (McCraven, 2011).

#### *2.2.1.2 Material Tracking System*

Due to harsh construction environments, two dimensional barcodes are often recommended because of their high fault tolerance and anti-corruption capabilities (Yu-Cheng Lin, 2010). In 2009, DPR Construction utilized a barcode system during the construction of the University of California, Santa Cruz College. Utilizing preprinted barcode labels, asset tracking software, and barcode scanning capable Windows tablets, DPR was able to accelerate their project schedule, minimize reorders, and improve on-site coordination. As the door assemblies arrived on the site, they were attached with barcodes. As the assemblies moved through various stages of the installation process the field personnel used the tablets to scan the barcodes in order to instantly access component information (i.e. shipping information, quality assurance, quality control issues) and update the status of the component. After implementation of the automated system, DPR reported a 70 percent time savings in recording, documentation, communication, and reporting, which ultimately led to a 20 percent time savings in work productivity (Vela Systems, 2009).

#### *2.2.1.3 Material and Infrastructure Monitoring*

Barcode systems have the ability to provide staff with detailed information regarding equipment or facilities. Personnel can access maintenance related information (i.e. maintenance schedules, conditions, previous inspection reports) using handheld devices (Yu-Cheng Lin, 2010). TDS Telecommunications Corporation, a business solution provider, retains both digital and hard copies of schematics that detail the buried locations of cable lines. Although the existing system was relatively efficient, in cases where there were failed or broken lines it proved to be challenging to access specific engineered drawings. Therefore TDS implemented a barcode system using facility management software to manage engineering schematics, drawings, and maintenance reports (Wells, 2008).

### 2.2.2 RFID Integrated Business Practices in Civil Engineering Applications

RFID is a type of wireless communication technology that uniquely identifies tagged objects using radio waves. As a forthcoming product of AITs, RFID technology is currently employed in business enterprise operations because it is more efficient and accurate than other types of AITs. It is also increasingly becoming a cost-effective technology, especially in instances where cost of failure is great. The main advantage of RFID is the ability to identify, track, locate, collect and store data, and monitor personnel and objects without a clear line of sight between the tag and the reader. The main differences between barcode and different types of RFID technologies can be found in Table 2.2, and are discussed in more detail in Chapter Four.

RFID technology first experienced an explosion of development in the 1970s when various companies, academic institutions, and government laboratories began making advances in radio frequency research. It was during this time period that the U.S. Federal Highway Administration (FHWA) first convened a conference to explore the use of electronic identification technology in the transportation industry. By the 1980s, RFID technology could be found in various commercial applications such as livestock management, keyless entries, and personnel access systems. Following the FHWA conference, RFID was implemented in transportation applications; in 1987 the world’s first toll application was implemented in Norway, and Dallas followed suit in 1989. Subsequently, it was in the 1990s where RFID technology was widely employed and became a part of everyday life. By the middle of the decade, RFID toll systems could function with a vehicle moving at highway speeds. With the combination of RFID tags and toll cameras, RFID technology saw widespread deployment in the United States for toll collection enforcement.

**Table 2.2 - Comparison between Barcode and RFID technology**

| | Barcode | RFID tags | |
|---|---|---|---|
| | | **Passive** | **Active** |
| **Scanning** | Requires line of site | Does not require line of site | |
| **Durability** | Easily damaged in harsh conditions[3] | Durable Casing allows tags to withstand dust, moisture, and physical impact or vibrations[2] | |
| **Information (Read/Write Capability)** | Cannot be changed | Read/write capabilities | |
| **Power Source** | None | External electromagnetic antenna field[4] | Onboard power source (small battery) [4] |
| **Range** | Measured in inches | Close proximity to reader (usually 10-20 ft.) [4] | 300 ft. or more[4] |
| **Size** | Large enough to be read by a reader: 1inx1in [1] | Range in size from a grain of rice to a paperback book[1] | |
| **Cost** | About 1 Cent | 7 to 15 U.S. cents[4] | $25 and up[4] |
| **Data Storage** | Number or alpha-numeric code | 2 kilobytes (KB) of data[4] | |
| **Security** | Can be easily duplicated and therefore counterfeited[1] | Identity code or serial number from the manufacturer: embedded digitally on the microchip and cannot be changed[1] | |

[1] 4hSolutions. *RFID vs barcode.* 2010. www.4hsolutions.com/technologies/rfid-vs-barcode.aspx (accessed August 13, 2012).

[2] Hammersmith Group, The, and Constantine A. Valhouli. *Clicks & Mortar: The use of RFIDs in construction.* New York, New York: The Hammersmith Group, 2009.

[3] Moselhi, Osama, and Samir El-Omari. "Integrating Bar Coding and RFID to Automate Data Collection From Construction Sites." *Joint International Conference on Computing and Decision Making in Civil and Building Engineering.* Montreal, Canada, 2006. 1734-1741.

[4] RFID Journal. *RFID Journal: The Cost of RFID Equipment.* 2012. www.rfidjournal.com/faq/#18 (accessed August 13, 2012).

However, before the expansion of RFID technology in the 1990s, RFID systems were previously integrated in proprietary systems, which the AIT industry recognized as a barrier to growth. Proprietary systems resulted in interoperability between systems and little competition, which kept costs high and impeded industry growth in RFID development. As a result, standards organizations, such as the European Conference of Postal and Telecommunications Administrations (ECPT) and the International Organization of Standards (ISO) began publishing guidelines for implementing RFID automated identification systems. By 1999, the Auto-ID Center at MIT was established to develop a global system for tracking goods using a single numbering system called the Electronic Product Code (EPC) (Hunt, et al., 2007). Some of the current uses of RFID technology include:

- Security Access/Control
- Transportation
- Toll Collection
- Retail and Sales
- Automated Vehicle Identification (AVI) systems
- Asset management/tracking (Finkenzeller, 2003)
- Animal identification
- Baggage tracking and handling
- Warehouse management and logistics
- Product tracking in a supply chain
- Raw material tracking/parts movement within factories
- Railroad car tracking (Thornton, et al., 2006)

In 2003, with the aim of enabling pallet-level tracking of inventory, Wal-Mart issued a mandate requiring its top suppliers to tag pallets of merchandise with EPC labels (Hunt, et al., 2007). The Department of Defense (DoD) issued a similar mandate to its top 100 suppliers. These mandates created growth within the RFID industry and lowered deployment costs (Hunt, et al., 2007). Furthermore, these mandates united the RFID industry behind a single technology standard, the EPCglobal's EPC standard.

Federal and local governments are also taking part in the advancement of RFID technology. The DoD has been the government's leader in RFID technologies and has employed the technology for tracking items within its warehouse supply chain, tracking armaments, food, personnel and clothing. Another branch of government that has employed RFID technology is the Department of Homeland Security (DHS). RFID technologies also support location determination systems that are helpful to controlling the US border and protecting transportation systems. Two major initiatives by the DHS include increasing the security of international shipping containers and the creation of "smart borders," which verify and process the entry of people, while preventing the entrance of contraband, unauthorized aliens, and potential terrorists (Hunt, et al., 2007).

In recent years, RFID technologies have been researched and implemented by both public and private sector organizations in the construction industry to optimize production processes and achieve sustainable engineering practices. States such as Alaska, Iowa, Maryland, Virginia, and Michigan, have determined that RFID technology can improve efficiency in transportation applications and highway maintenance programs. RFID technologies can be advantageous to engineering and construction firms by reducing delays, minimizing labor hours, detecting problems and increasing the security and safety on a construction site. Due to its many capabilities, cost effective applications of RFID technologies in the construction industry are attained through the management of materials (Wing, 2006).

#### *2.2.2.1 Material Planning*

During the "Material Planning Stage" of a construction project, the key materials required on the project are identified. These materials are numbered and assigned unique identification numbers which correspond with a database that stores information such as name, usage, design, drawing number, manufacturer, and other additional data related to the material. Once the materials are ready to go into storage, RFID tags are applied. The RFID tags identify the materials in the database, which transmits the relevant information, such as measurements, weight, serial number, and production history that were previously stored in the database. These RFID tags are later used in the material tracking phase to control and monitor material deliveries, storage on site, and installation. Consequently, a Danish construction and design firm, Dalton Betonelementer A/S, found that the integration of RFID tags with a PDA/PC-solution allowed users to connect to a website or database where all mounting instructions, specifications, technical drawings, and even videos were available electronically. Dalton Betonelementer A/S estimated that one third of working hours were either used to determine if the correct material was delivered or spent correcting clerical mistakes (Erabuild, 2006). The introduction of RFID embedment in building components, in combination with remote access websites can save costs, paperwork, and reduce the number of errors during a construction process.

#### *2.2.2.2 Material Tracking*

In addition to proper planning and preparation of materials, RFID also provides an efficient means for material tracking and control. During the construction phase of a project, construction materials are moved from their production facilities, to testing laboratories, and then to their respective installation sites. These various construction materials include steel bars, metal sheets, glass panels, concrete pre-cast concrete beams, wooden planks, composite materials, chemical material, hot-mixed asphalt and others (Intensecomp, 2004). RFID technology can be integrated with global positioning systems (GPS) to provide real-time data collection and location of construction materials. Using automatic identification and global tracking of these discrete construction components provides logistical information to ensure the accountability, quality, and reliability of required construction materials.

In order to improve the traceability and accountability of construction materials, while also ensuring the reliability of material testing results, Intensecomp Pte Ltd. proposed a *Construction Material Tracking System* (CMTS). The basis of the CMTS relies on an effective RFID tagging system, which provides the required security (write protection and encryption) and information storage of the materials. The CMTS consists of a single database server, a web server, a testing and client station for all material testing, and a set of RFID peripherals (Intensecomp, 2004). While the CMTS has not yet been implemented, Intensecomp proposes that the CMTS could entirely manage business processes such as cost quotation generations, order acceptance, testing task scheduling, billing generation and inventory tracking. The CMTS could also provide a common platform for information sharing by supplying remote access options to the information database. Access to the database will allow real-time tracking of materials and provide customers with the ability to login into the database in order to retrieve relevant material test reports: such as the results from steel bar tensile tests or concrete specimens compression tests. Finally, Intensecomp suggested that with the existing need for automated processes in material tracking business operations, CMTS has the capability of bringing complex tasks to a simple routine.

To integrate RFID technology with material tracking in the construction industry, BT Auto-ID Services launched a path-finding case study in 2006. The motivation for this case study was construction personnel who found a need for monitoring the location and condition of mobile construction assets that were being transported to construction sites and possibly exposed to intense conditions (Erabuild, 2006). With the need to track the location of mobile assets, BT developed a material tracking system utilizing GPS technology, for mobile (remote) communication, and active RFID tags, for asset identification and monitoring. BT successfully demonstrated the ability to increase asset visibility, reduce installation times, increase material deployment, and reduce operation costs (Erabuild, 2006).

In another case study conducted at the Red Hills Generating Facility, the receiving process for shipments of palletized pipe hangers and supports was found to be more efficient with RFID implementation. Before the implementation of RFID, workers carried out the "kick and count method," where they would manually unpack the pallets and check the items with a packing list. Packing list information was manually entered into a material tracking system and if an item was missing a special form was completed to record the anomaly. With the addition of RFID technology, workers could use an RFID reader to read/write to the tag instead of manually recording information and no longer needed to fill out the special forms. The data from the tags was then downloaded to the tracking system using the RFID reader. The results of the project showed that the time spent locating and tracking pipe supports and hangers was reduced by 30% (159 minutes per 100 hangers, Table 2.3) as a result of implementing the RFID pipeline tracking system (Jaselskis, et al., 2003).

**Table 2.3 - Estimated time required to process 100 pipe supports/hangers**

| Action | Manual (min) | Radio Frequency Identification (min) | Time Savings | Percent Time Savings (%) |
|---|---|---|---|---|
| Unload 100 hangers | 107 | 107 | 0 | 0 |
| Verify 100 hangers | 365 | 242 | 123 | 34 |
| Enter 100 hangers into material tracking system | 56 | 20 | 36 | 64 |
| Total time required | 528 | 369 | **159** | **30** |

#### 2.2.2.3 *Material Inventory*

As seen with the case studies shown in Section 2.2.1.1, industries have already been successfully employing barcode labels for item identification and material inventory. However, using RFID technology for inventory management of structural components goes beyond accurate inventory counts, and can also improve the organization of the construction process by making pertinent material information readily available at the site where all structural components are identified with RFID tags. Modern construction techniques allow for materials to be built offsite and then quickly assembled onsite. This concept is defined by FHWA as “Accelerated Construction.” Accelerated construction has many benefits, including the improvement of site constructability, the improvement in total project delivery time, the increase in material quality and product durability, and a safer work-zone for the travelling public and contractor personnel. The use of accelerated construction techniques with prefabricated elements and systems has become more common over the last 20 years in the United States (FHWA, et al., 2011). This rising acceptance and utilization in the construction industry has increased the demand for storage space in stockyards and the demand for inventory monitoring and material tracking: an RFID solution.

This implementation of RFID technology as a tool to manage material inventory was first demonstrated in 2005-2007 by Boeing Commercial Airplanes during their construction of the Boeing 787 Dreamliner. Each 787 Dreamliner is made up of approximately six million components, many which require frequent maintenance or replacement (Erabuild, 2006). Additionally, more than 80% of the construction of a 787 is dependent on external trading partners to design and manufacture major modules and control systems. With six million parts, it is evident that a large space is needed for assembly. In order to reduce inventory, track parts, avoid counterfeit parts, and improve the turnaround time in the airport, Boeing employed RFID tags on select discrete components. The RFID technology was utilized to trace the components during construction and to ensure the components arrived to the facility promptly. Once the airplane was built, workers could use an RFID reader to wirelessly monitor inventory and to locate specific parts for future preventative maintenance. This implementation of RFID tags creates a much more organized job site and reduces the possibility of using unapproved parts, such as components that may have been previously separated from their documentation (Erabuild, 2006).

The benefits taken from the Boeing example can be applied in the same way to construction yard management operations. On major construction sites, locating materials can be challenging due to a large number of components, numerous suppliers, a large inventory of materials, and the limited space. Furthermore, the visibility around large and congested construction yards, such as the one seen in Figure 2.3, has also been difficult to maintain; especially when the yards are covered with snow (Figure 2.4) or when written identification tags are illegible (Figure 2.5). The disorder could cause a significant increase of indirect work-hours, a loss or misplacement of components, redundant procurement, unplanned workarounds, and delays. However, the implementation of RFID with advanced software solutions can now offer significant opportunities to decrease the time to find specific materials, craft labor hours, and eliminate risk associated with lost, mismatched or misplaced components.

Figure 2.3 - An Aerial View of a Material Filled Construction Stockyard  (Atlas RFID, 2010)


Figure 2.4 - Stockyard covered with snow (Atlas RFID, 2010)

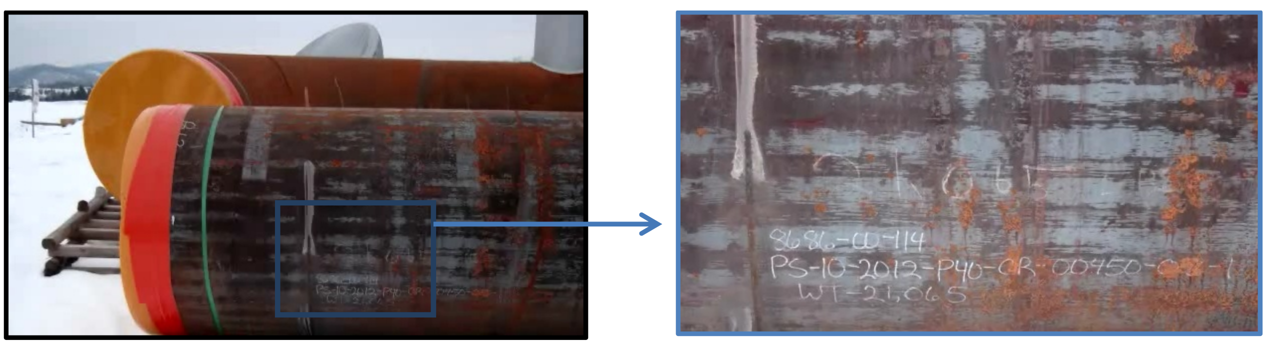



Figure 2.5 - Illegible identification number on weathered steel in a stockyard (Atlas RFID, 2010)

In 2007, Bechtel Corporation was contracted to the largest private construction job in Wisconsin history, involving the construction of two coal-fired steam turbine generating units at an estimated value of $2.15 billion dollars (Bechtel Briefs, 2007).  Due to the project size, stockyards were designed for the large abundance of prefabricated steel, piping, and other structural or functional materials.  In its initial project stages, (before RFID implementation) each material was delivered with a written ID code on the surface of the components.  The materials were accounted for manually and entered into a material management database system.  The materials were then placed in a specific grid system in accordance with their characteristics and material identification codes.  Once a material was ready for construction, workers visually located it in the stockyard, flagged it and turned it over to the construction crew.

Figure 2.6 - Layout of piping around the stockyard

Figure 2.7 - Layout of steel members around the stockyard

The "flagging" crew members found that individual piping pieces became very difficult to identify when they were closely stacked together (Figure 2.6 and Figure 2.7 (Atlas RFID, 2010)) and even more difficult when it snowed (Taylor, et al., 2009).  Due to the large volume of materials, visual location presented problems for the crew members, and even left the installation crew waiting for materials; a possible increase in craft labor hours of 16-18% (Torrent, et al.).

In order to efficiently track materials from fabricators to stockyards, Bechtel contracted Atlas RFID to develop an RFID/GPS solution to enhance the visibility of the status and location of prefabricated materials around the large stockyard.  The packaged solution was grounded by a uniform software system that operated with multiple data capture technologies, such as barcodes, passive RFID, active RFID, and GPS. The RFID tags, which also host the barcodes and GPS, can be attached to materials in the construction yard using Zip-Ties (Figure 2.8 and Figure 2.9 (Atlas RFID, 2010)).  The integration of GPS with active RFID tags provided the location and status of material components around the gridded stockyard, seen in Figure 2.10.

Figure 2.8 - An attached RFID tag with visible barcode

Figure 2.9 - RFID tags zip-tied to materials


**Figure 2.10 - Position of a material in a construction yard (Atlas RFID, 2010)**

The software displays aerial imagery of the material location, provides information on material availability, and offers users the option to search for specific materials. As seen in Figure 2.11, the visual representation illustrates exactly where a specific material is, regardless of the clutter of other materials around it. For compatibility, the software was also built to operate with Microsoft Excel spreadsheets, where material inventory data is imported and exported. Furthermore, RFID software can be integrated with engineering software platforms that a construction company may already be using.

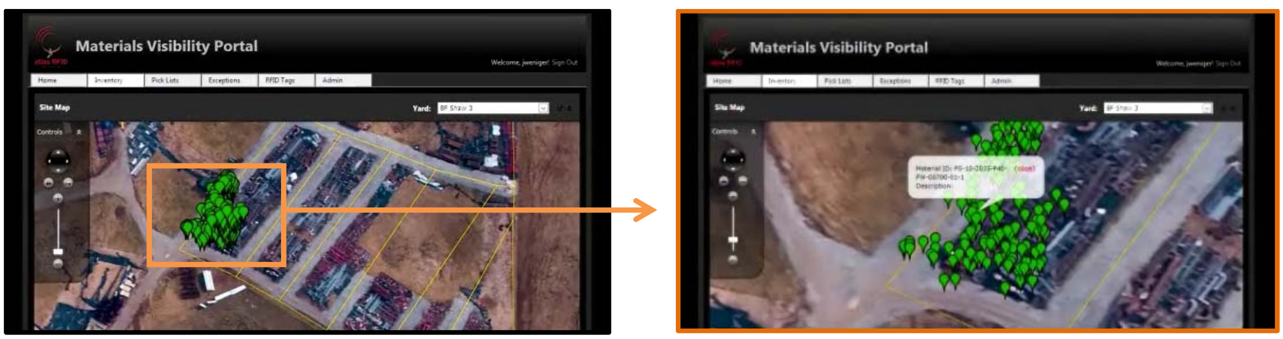



**Figure 2.11 - Material Visibility Portal provides aerial location of materials in construction yard**

The software functionality was also extended to the field through the use of rugged handheld computers (Figure 2.12) running comparable mobile software (Atlas RFID, 2010). In order to know the current location and status of construction materials, the handheld computers were composed of embedded RFID readers and with GPS receivers. Once the flagging crewmember was within close proximity of the material, the handheld computer would communicate with the RFID tag, and further visual and audible indicators would lead the individual to the right piece of material.

Figure 2.12 - Handheld computer (RFID Reader)

Figure 2.13 - Docked RFID/GPS Readers in Office

Atlas RFID Solutions and Bechtel Corporation found that the implementation of AIT had provided Bechtel the added benefit of reducing labor expenses, reducing material loss expenses, improving construction productivity, and providing better control and predictability/planning (Atlas RFID, 2010). The project compared the work hours required to locate 400 pieces of prefabricated structural shapes using the traditional manual/visual method to the total hours required to locate 400 pieces prefabricated shapes for another boiler using the RFID/GPS technology. As Table 2.4 illustrates, RFID/GPS technology helped to locate the steel components 8 times faster than the manual methods.

Table 2.4 - Time Comparison using automated methods and manual methods to find inventory

| | Search Rate | Total Time Spent |
|---|---|---|
| **Manual Method**<br>Visual Location | 36.8 minutes/part | 245 $^{1}/_{3}$ hours ⟶ 10.2 Days |
| **Automated Method**<br>RFID/ GPS Technology | 4.6 minutes/part | 30 $^{2}/_{3}$ hours ⟶ 1.3 Days |

Bechtel employees credited RFID/GPS with "eliminating a wasteful flagging step" in the process of finding materials. Furthermore, Rogers states, sending "…the loading crew straight to the material rather than having another pair of people go ahead to make sure they can find the material…optimizes the crew's time" (Taylor, et al., 2009). This result was also validated in a similar project, where RFID and GPS were used to locate 200 prefabricated spools. Similarly, the contractor on this project found he was able to reduce his crew size from 18 to 12 people; knowing that his search time for components would be significantly decreased (Stuart, 2010).

#### 2.2.2.4 *Material and Infrastructure Monitoring*

RFID tags can be attached or built into items of interest, such as guardrails, road signs, retaining walls, and can store information about the specific item. Throughout the item's life, maintenance information can be stored on the item, which would provide on-site inspectors with readily available updated information. With the integration of wireless networks, data stored on RFID tags and their corresponding database can also be accessed from remote locations.

In order to create a high-memory system to store maintenance information, Boeing Commercial Airplanes and Fujitsu developed *RFID Integrated Solutions*: an approach for integrating AITs and improving airlines overall maintenance efficiency and performance (Coop, 2012). By combining RFID and Contact Memory Button (CMB) technologies, Boeing found they could increase identification data storage capacity to 4 gigabytes, which created the opportunity to host a wide variety of information: material birth record, updated records (i.e. change in configuration, identity or characteristics), maintenance history, and a scratch pad or rewritable section for technicians to enter text or store photos and videos. The technology was used to "identify, track, and manage critical airplane parts" (Coop, 2012). Thus, the benefits of *RFID Integrated Solutions* are its capability to capture damage information on structural and component repairs, capture information on previous corrosion removal and material loss information at corrosion prone areas, and to store records of repairs and modifications. Overall, Boeing found they could significantly reduce an airline's operating costs by eliminating untimely, labor intensive maintenance and providing easy access to maintenance information and history (Coop, 2012).

Most recently RFID technologies have been employed for infrastructure monitoring. Specifically, the integration between RFID and other sensory technologies provide promise for structural health monitoring applications. When RFID tags are paired with sensors, they store the sensor-measured material property data and physical quantities, which can later be read with an RFID reader. Experimentation within the last decade has proven RFID-sensor integration to be a successful application. Wireless structural monitoring systems are becoming increasingly inexpensive to install, due to the innovations in RFID technology and lack of complex installation from minimal extensive wiring (Liu, et al., 2012). Some examples include determining concrete maturity, material properties of hot-mixed asphalt and concrete strain.

The traditional methods for evaluating concrete maturity can take days or several weeks. One of the more popular methods for testing concrete maturity is the compressive strength test. To perform the test, employees pour samples of concrete into test cylinders at the same time the concrete is poured on the construction site. During the curing process, an instrument measures the units of pressure per square inch of concrete required to crack or break the sample. However, the concrete on the construction site may cure more quickly than the test cylinders because the samples are not exposed to the same temperatures and environment as the poured slabs. Depending on the volume and temperature of the concrete, the poured concrete can cure at a faster rate, which could minimize the time spent waiting for concrete to cure and also put the project ahead of schedule. RFID also offers the capability of automating the mathematical step of determining the concrete's hardness.

In 2003, the Michigan Department of Transportation (DOT) implemented their first RFID-based concrete maturity testing package, assembled by WAKE Inc. (O'Connor, 2006). The purpose of the pilot implementation was to develop a wireless Concrete Maturity Monitoring System (CMMS) to test and estimate the strength gain of concrete, minimize traffic disruption, and provide real time data (DeFinis, 2004). The three main components of the CMMS are: an RFID tag, an interrogator to talk to the RFID tags, and developed software to pull data from the interrogator. In the pilot program, the RFID tags were randomly distributed into a concrete sample. During the concrete hardening process, information from the tags was read by the interrogator and the software was used to pull and store the data from the interrogator. The software package also had the capability of running on the Pocket PC Windows operating system as well as a laptop computer. To test the accuracy of the CMMS, the temperature and elapsed time data was put into a maturity model, which compared the temperature readings of the poured concrete with the results of concrete in test cylinders. The Michigan DOT found the RFID concrete maturity-testing package performed well (DeFinis, 2004). The CMMS also proved to be cost effective and best suited for projects with a short timeline, because it enabled laborers and paving crews to reopen the closed lanes faster, alleviating traffic backups and bringing normal traffic flow back to local business corridors (O'Connor, 2006). Additionally, the Michigan DOT found the CMMS could be used to monitor freeze-thaw cycles in concrete (DeFinis, 2004).

Similar to concrete, Hot-Mixed Asphalt (HMA) is another material that requires special attention from construction crews because it is a "high-value material" (Swedberg, 2011). In order to set properly and to alleviate cracking problems, HMA must be laid while still at a designated warm temperature. In the same context as embedding RFID tags in concrete, HMA can provide material property data of the asphalt, such as the temperature and physical parameters (i.e. the amount of asphalt delivered and the delivery time).

It has also been proposed that concrete structures will be more efficiently maintained if RFID tags with sensory functions are used to monitor environmental conditions and structural deterioration (Ogawa, et al., 2008). A considerable percentage of concrete and steel structures in North America are in a deficient state due to aging, aggressive environments, and various loading conditions (ASCE, 2009). The implementation of sensing technologies and analytic methods have the capability to instantly identify the point of onset structural damage in complex engineering structures using damage detecting algorithms. These systems have been used in practice to monitor the behavior of structures during extreme conditions such as earthquakes, winds, and live loading. Various employments of sensory technology paired with RFID have been found in aircrafts, ship, and civil structures.

It is considered that the assessment for structural maintenance can be more effectively answered if strain data is readily available (Ogawa, et al., 2008). In a preliminary study to use RFID tags with strain sensing, researchers at the Taiheiyo Cement Corporation attached an amplifier circuit to an RFID tag in order to measure strain in concrete column specimens without a battery source. The results of the experiment were promising for RFID solutions and showed that the voltage of the RFID tag increased linearly with the concrete strain. While this research was preliminary and more experimentation is needed, researchers at the Taiheiyo Cement Corporation concluded the implementation of RFID technologies would provide more efficient management in maintaining concrete structures (Ogawa, et al., 2008).

On a bridge structure, the deck is one of the most vulnerable components to corrosion due to chloride ingress from routine application of deicing salts, repeated freeze-thaw cycles and other deteriorating conditions, including environmental effects. Better methods for identifying the depth of chloride content and the resulting corrosion will help with the decision for routine repair or preventive maintenance. Accordingly, the Iowa DOT and researchers at Iowa State University are conducting research to embed RFID tags in concrete, which would act as wireless corrosion sensors. The researchers propose that if the RFID tags and sensors detect a problem early, then the structure may be repaired with a minimal amount of work (Iowa DOT, 2012).

# Chapter Three: Barcode Integrated Material Management System

## 3.1 Introduction

Barcodes are optical representations of data assembled in various geometric styles or patterns that have proven to be extremely beneficial in inventory control and logistical applications by improving the speed of data entry activities and minimizing error rates (Yu-Cheng Lin, 2010). Barcode technology has been integrated into such applications to provide automation by assigning a unique identifier to an item, then relating object specific information to it in a remote database. An automated barcode materials management system is comprised of the following: (1) barcode label, (2) digital reading device, (3) integrated data management software, (4) wireless infrastructure, and (5) network database. Figure 3.1 provides the typical architecture of a barcode material management system.

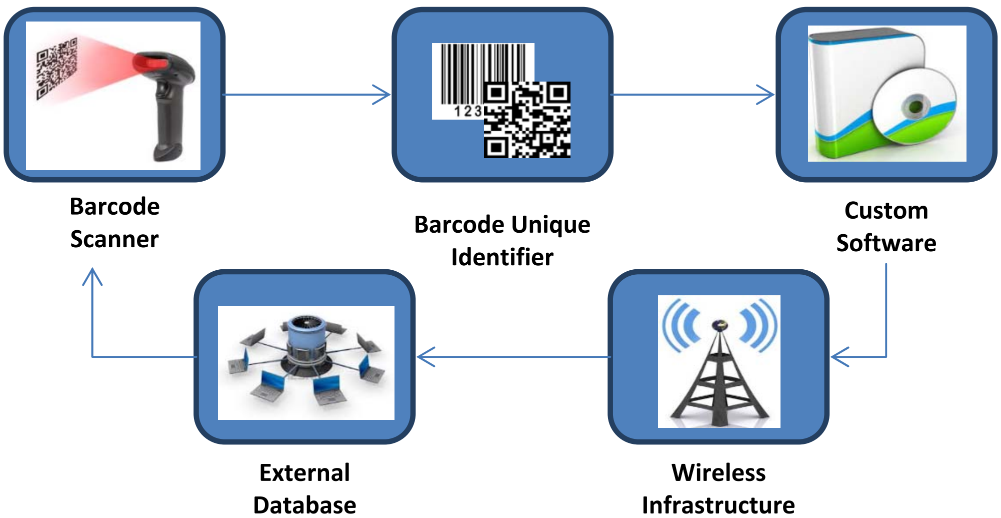



Figure 3.1 - Typical barcode material management system architecture

Before a business or an organization can implement a barcode system, it must obtain a GS1 Company Prefix from GS1, previously known as the Uniform Code Council (UCC). The Company Prefix is composed from the barcode's GS1 Prefix and Company number digits. After acquiring a company prefix, the business or organization can begin uniquely identifying items using Identification Keys. Identification Keys are used to name and distinguish objects or locations; specific Identification Keys applicable to the construction industry are Global Trade Item Number (GTIN), Global Location Number (GLN), and Serial Shipping Container Code (SSCC). Figure 3.2 displays the structure of the GTIN barcode, which can be used in a variety of applications to identify items. The item reference number is generated by the business entity in order to associate a different number to each item. Lastly, the check digit shown in Figure 3.2 is determined from the other digits to provide additional security and barcode reliability.


**Figure 3.2 - GTIN Barcode Structure for a one dimensional barcode**
**a) GS1 Prefix, b) Company Number, c) Item Reference Number, d) Check Digit (GS1, 2012).**

When barcode labels are initially printed, the label physically appears to be a random combination of parallel lines ranging in thickness or a pattern of dots, circles, square, hexagons, however these combinations and patterns are symbologies that encode the data within the barcode. The barcode reader/scanner, acts as a data acquisition unit. This component is either fixed (the reader is permanently hardwired into the system) or handheld to allow data to be collected wirelessly (best suited for use on construction job site). Depending on the type of software integrated in the system, the data stream "read" from the label can be manipulated to create a data request to reference and process specific information from the database. Then the result is sent to the remote computer or handheld device (if the barcode reader has the capability) for the front-end user. Barcode automated systems are a suitable choice for enhancing existing business processes because the system has the capability to automatically:

- Track real-time data of construction materials (i.e. arrival status on site, location)
- Record historical data of resources consumed during the duration of the project
- Transfer real-time data of materials to a network database via wireless networks

The three main benefits of barcode labels are the identifiers have the ability to withstand signal interference, are relatively durable in the construction environment, and have low acquisition or production costs. Unlike RFID technology, barcodes are not activated nor require radio signals to function, therefore barcodes are able to be read despite weak signals from the reader or signal interferences from objects with high to moderate metal or liquid contents. Also prevalent with fixed RFID readers, "ghost" tags (tags that do not actually exist) are read, which may cause minor confusion in inventory control systems. Conversely, when barcodes are scanned the label is instantly verified by a beep from the digital reader. In the case where the barcode is not being verified by the reader, the user has the capability to manually enter the information into the database. Also, since barcode labels are essentially optical representations of data, the labels can withstand water damage, static discharge or high powered magnetic surges. Barcodes have shown to provide the best return on investment in tracking applications when compared to RFID or Satellite/GPS tags because the identifier alleviates the level of manual data handling at a relatively low cost. However, if the objects require excessive handling or are in poor environmental conditions, RFID becomes a viable option in an automated tracking system (Ala-Risku, 2006). The main disadvantage of a barcode system is that the connection between the device and the external database is temporary and is only established when triggered by human intervention. The following sections will discuss the components required in the architecture of barcode automated material management system.

## 3.2 Barcode Classification

Barcodes can be classified into three categories: one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) barcodes. Each barcode type differs in its physical appearance, data storage capacity, and durability. When selecting a barcode label the main parameters that must be considered are the durability (in terms of readability), its attachment to an item both over extended periods of time and under adverse conditions, and data storage capacity. Based on the environmental conditions of the construction site, the business entity has a variety of barcode label types to choose from in order to improve durability and ensure longevity of the label's attachment; the following are the common barcode label types (Rasdorf, et al., 2003):

- Laser Imaged Labels – barcodes are printed on high-quality image paper. These are produced at resolutions of 200-600 dots per inch (dpi). They can come with removable or permanent adhesives and with or without protective laminate coatings (Patel, 2005).
- PolyII – Made from paper stock bonded with a protective polyester film. This use is recommended for warehousing and material handling operations because labels are primarily intended for dry, low impact environments.
- Plastic – Made from dense polystyrene or vinyl material protected, with a polymer coating. Generally recommended for areas not directly affected by harsh weathering.
- Photocomposed Paper – Produced in sheets or rolls with print resolution of over 1200 dpi and application specific adhesive on the back (Figure 3.4). The face of the label is protected with either a laminate or lacquer coating. These labels have the highest first-pass read rate of any barcode technology (Patel, 2005).
- Photocomposed Mylar/Polyester – Similar to photocomposed paper labels, made of durable plastic (Figure 3.5). These labels can stand up to abusive environments including water or caustic and solvent-type chemicals (Patel, 2005).
- Metal – Made from specially treated anodized aluminum (Figure 3.3) or stainless steel and intended for use in harsh/abusive conditions with intense heats, high humidity, dirt, containments, heavy impacts and even temperatures of over 1000°F.
- Fabric – Barcodes printed on fabric offers the ability for them to be used in the tracking industry; specifically clothing retailers or other textile products which pass through multiple cleanings. Labels can be sewn in and can last through 50 to 100 dry cleanings or washings (Patel, 2005).
- Thermal – Made from paper or polyester base stock, protected with a heat resistant laminate covering, also intended for use in relatively dry environments.


Figure 3.3 - One Dimensional Metal Tag (Patel, 2005)


Figure 3.4 - One Dimensional Photocomposed Paper Labels (Patel, 2005)


Figure 3.5 - One Dimensional Photocomposed Polyester Labels (Patel, 2005)

Table 3.1 provides a brief overview of the differences between 1D and 2D barcodes (3D barcodes are not shown because its features mirror 2D barcodes and only differ in level of durability).

Table 3.1 - Comparison of 1D barcodes and 2D barcodes features (Syscan, 2010)

| Barcode Type | Data Capacity | Data Type | Error Correction Function | Dependence on Database | Nature |
|---|---|---|---|---|---|
| **1D** | Small | Numeric, English | Yes | Must depend on database or wireless communication network | Object Label & Identification |
| **2D** | Large | Numeric, Languages, images, voice, and binary data | No | | Description of Object |

1D barcodes are typically composed of parallel lines ranging in thicknesses and encoded utilizing linear symbologies. This barcode type is typically used for storing product or serial numbers for logistical purposes. Most linear symbologies are also equipped with a self-checking algorithm that ensures the label will be read correctly, despite potential damage. To meet the limitations of 1D barcodes, 2D barcodes were developed to provide higher storage capacities and embedded data redundancy. Figure 3.6 presents an example of a typical two dimensional barcode.

Figure 3.6 - Example of a two dimensional Barcode (Gizmodo, 2013)

The 2D barcode features square and dot shapes modules arranged in matrix patterns that encodes data both vertically and horizontally (Adams, 2012). Although 3D barcodes have comparable data storage capacities to 2D barcodes, 3D barcodes are embossed on the manufactured object to improve durability.

### 3.2.1 Linear Barcodes (One Dimensional Barcodes)

Linear barcodes are encoded utilizing a series of varying bars and spaces; this symbology is continuous over the horizontal dimension of the label. In order to interpret 1D barcodes, the reading device must be integrated with scanning technology to allow the scanner to interpret the different light reflections, while the sensor within the reader translates the decoded data into an "identification number" for the specific object. Standard linear barcodes hold a limited amount of information (less than 40 characters) and represent a single piece of information such as a number or alpha-numeric code that will link back to a software application or database (Assetware Technology). Most linear barcodes act similar to "license plates" to identify an item. The numbers and/or letters stored in the barcode are unique identifiers that, when read, can be used by a computer to look up additional information related to the item. For instance, the description of a specific item is not stored within the barcode; instead data is read from the barcode and sent to a computer or handheld device. With the use of integrated application software, additional information associated to the item can be requested from the computer's database (Adams, 2012). Based on past automatic identification barcode system implementations, researchers recommend the use of one dimensional barcodes in construction related activities due to their adequate data storage capability, durability and cost effectiveness. Also, since 1D barcodes have been significantly integrated in the automotive and retail industries, it will be easier to adapt this type of system to additional activities within the construction industry (Moselhi, 2005).

### 3.2.2 Two Dimensional Barcodes

More recently, the ability to encode a portable database has made two dimensional symbologies attractive in applications where space is limited. A 2D barcode is composed of various geometrical shapes that have the capability of storing information along the height as well as the length of the symbol. Unlike linear barcodes, 2D barcodes can hold more data in the same amount of space as a linear barcode (up to 2000 characters) and are better at detecting and correcting errors due to damaged barcodes (Rasdorf, et al., 2003). Studies have shown that the amount of information stored on an entire 1D barcode is equivalent to the amount of data stored in a tenth of a 2D barcode. Industries have utilized 2D barcodes as direct mail business reply cards by storing information such as name, address, and demographic information (Adams, 2012). 2D symbologies cannot be "read" using a typical laser barcode reader; because the simple sweeping pattern cannot encompass and interpret the entire barcode. Instead, the labels must be read using an imager. Once the image is taken from the imager, it is digitized and translated into a readable message or data stream. Business applications such as facility maintenance or information management may have a need for 2D barcodes due to the higher data capacity. However, materials management or inventory control operations do not generally require this type of portable storage space.

### 3.2.3 Three Dimensional Barcodes

Similar to 2D, 3D barcodes also have capability to encode data both vertically and horizontally. However, unlike 2D, 3D barcodes do not need an adhesive to identity an item. Instead the barcode is embossed or applied to the item during the manufacturing process. By engraving the barcode onto the object, the barcode becomes nearly impossible to damage and invulnerable to obstructions. Unlike 1D barcodes, the engraved bars are not interpreted by variance in reflected light, but are determined by bar height variances utilizing a Direction Path Mark (DPM) barcode reader. The integrated sensor records the time the laser takes to bounce back from the barcode as a function of velocity in order to determine the bar element's height. The reader repeats this process until the entire barcode has been digitized then transmitted to the digital processing unit for interpretation (BarcodesInc, 2010). This type of identifier is recommended for manufacturing applications, such as the assembly lines or processes with extreme temperatures, and environmental conditions that may inhibit the use of adhesive labels.

## 3.3 Barcode Standards

Barcode standards are established by international organizations and industry groups. These standards provide insight for selecting the best hardware, software and equipment while minimizing the costs of system implementation, integration, and maintenance. Such standards are also used to define recommendations for representing data in optical and machine readable formats, barcode production, application of labels, and establishing parameters for assessing the label quality.

### 3.3.1 Production Standards

Barcodes are typically produced using direct printing technologies or imaging. Either technique can be done on-site or off-site. On site printing, also known as in-house barcode production, occurs at or near the point of use. In-house production is recommended for companies with available resources for printing and barcode quality tests. The on-site printing option requires the company to be responsible for purchasing printer hardware, label design software, and additional consumables (i.e. label material, toner, adhesives). Although the majority of barcode printers are equipped with programming languages that support all standard symbologies, there are symbologies that require separate software to support additional formatted text or graphics (AIM Inc., 2002). When selecting the in-house option, the user must consider the application of the barcode label. The five types of commonly used barcode printing methods are direct thermal, thermal transfer, dot matrix, ink jet, and laser. Barcodes can be printed onto documents, adhesive labels, tags, ID bracelets and other types of media. Table 3.2 summarizes the advantages and disadvantages of each printing method.

Direct thermal printing is a digital printing option originally designed for copier and fax machines that utilize chemically coated paper. The print head selectively heats bar elements onto a heat-sensitive label and the image is produced by a thermal chemical reaction. Advantages of direct thermal printing include: sharp quality barcodes that result in great scanability appropriate for applications with short life spans (i.e. shipping labels, receipts), is simple to operate, and requires low maintenance (does not require ink, toner, or ribbon to operate, and batch or single label printing is available) (Barcoding Incorporated, 2011). Thermal printers also tend to be more durably built than other printers, making them a good choice for the in-house printing option.

Thermal transfer printers are similar to direct thermal, except a chemically coated medium is not required and a heated intervening ribbon coated with ink is used to transfer the image from the ribbon to the label. Once the label cools, the ribbon can be peeled away producing a durable, high definition barcode label. Thermal transfer printers are available in large copy machine, desktop, or wireless configurations and typically optimize the readability and scanability of barcodes (AIM Inc., 2002). This technology can be used on a variety of label materials, to print a batch or single label, and requires low long term maintenance. Thermal transfer printers' supply costs tend to be greater when compared to direct thermal printing.

Dot Matrix printing is typically the method of choice for on-site barcode production. Using multi-pass technology the barcode image is created by multiple dots. This printing option is available in either large copy machine or desktop configurations and is also a less expensive method of printing because dot matrix printers are compatible with a variety of label mediums and the costs for ribbons and consumable materials are significantly reduced (Barcoding Incorporated, 2011). However, this printer type does not produce the clearest barcode and the labels may not be long-lasting.

Ink Jet printing uses a fixed print head with small orifices that projects ink onto the label material to produce the barcode symbology. This printing method is available in large copy machine configurations and is recommended for applications with a high demand for barcodes. Although this technology is favored due to its speed, system installation is costly and requires constant supervision to prevent paper jams and printing errors. Inkjet printers do not have the single printing capability and when printing on dark backgrounds, barcode readability is severely reduced.

Laser printers are similar to a photocopier; the barcode image is created on an electronically charged photo-conductive drum using a laser. Then the electronically charged image attracts toner particles and fuses the image onto the label material (AIM Inc., 2002). Laser printers produce high quality symbologies and can double as a typical office printer when not being used to print barcodes. This printer technology is not suited for harsh construction environments and requires label adhesive compatibility (Barcoding Incorporated, 2011).

Table 3.2 - Summary of available barcode printing technologies (Barcoding Incorporated, 2011).

| | Technology | Print Quality | Scanability | Initial Implementation Cost | Long Term Maintenance | Waste Material |
|---|---|---|---|---|---|---|
| *Limited Durability* | **Laser** | Moderate | Moderate | Moderate/High | Moderate/High | High |
| | **Dot Matrix** | Fair | Low | Low/Moderate | Moderate/High | High |
| | **Ink Jet** | Moderate | Low/Moderate | High | Moderate/High | High |
| *Durable* | **Direct Thermal** | Moderate/ Excellent | Moderate/ Excellent | Moderate/High | Low | Low |
| | **Thermal Transfer** | Excellent | Excellent | Moderate/High | Low | Low |

For small or newly automated businesses with limited resources, off-site printing is typically preferred because third party vendors provide their customers with full customer service guarantees such as maintaining the database of sequential numbers and ensuring barcode quality compliance. The disadvantages of selecting an off-site option are labels must be ordered ahead of time and vendors may have potentially slow lead times. Barcode vendors typically receive the data from the customer, print out the labels, and deliver the labels to the customer within 12 to 24 hours. However, for some businesses, this turnaround time may not meet their production rates or is not guaranteed, in which case on-site printing would be recommended.

### 3.3.2 Barcode Digital Reader

Barcode scanners, also known as digital readers, are electronic devices used for interpreting printed barcode symbologies. Similar to a flatbed scanner, barcode readers consists of a light source, lens and a light sensor that is used to translate optical signals into electrical signals (GS1 Canada, 2010). Barcode readers are available in two main configurations, handheld and fixed devices. Handheld devices are recommended in applications where objects are stationary (i.e. prefabricated yards, storage areas.) or the reader will be used to scan multiple items in different locations. Fixed readers are recommended in applications where objects are passed by the reader (i.e. by hand or conveyor belt) or to minimize the level of human involvement. The four types of barcode reading technologies that are currently available are contact wand, Charge-Coupled Device (CCD), laser, and imaging.

Table 3.3 compares these digital techniques in terms of the maximum length of barcode the reader can interpret, maximum read range, ability to read labels on irregular surfaces, and scanning reliability. Contact wand scanners were one of the first type scanners utilized in automated identification systems and are recommended for close contact applications (Assetware Technology). The pen shaped device is equipped with a lit tip used to decode barcode labels by drawing a line slowly across the length of the barcode. Due to the technological development of bar readers and the learning time required to properly use the device, contact wands are not typically seen in today's automated industry applications. Instead CCD scanners are often used in close contact applications. When reading a barcode, CCD digital readers utilize Light Emitting Diodes (LED) to reflect the symbology's image back to a series of photo-sensors (Moselhi, 2005). This technology is applicable in well-lit environments, to provide a quicker and more accurate read. Utilizing a laser beam and rapidly rotating mirror to create a cross hatched or starburst patterned laser beams, laser technology yields a great readability rating than CCD scanners. Despite the significantly greater cost, this technology is recommended in applications where barcodes must be read at a distance (i.e. warehouse management applications) and when barcode labels are applied on curved surfaces. The latest development in barcode readers is imaging technology. Primarily used to decode 2D barcodes, imaging readers use an integrated camera and digital software to capture the image of the barcode symbology and interpret the image. Although imaging technology is slower than the aforementioned barcode readers, it is beneficial for reading damaged or defected barcodes (Bell, et al., 1988).

**Table 3.3 - Comparison between barcode scanners (Moselhi, 2005).**

| Feature | Wand | CCD | Laser | Imaging |
|---|---|---|---|---|
| Maximum length of barcode | Unlimited | 4.2" | 12" | 12" |
| Maximum distance away from objects | 0.2" | 8.0" | 20" | 24" |
| Irregular surface reading capability | No | Yes | Yes | Yes |
| Scanning reliability | Low | High | High | High |

According to GS1-Canada's Bar Code Scanning Equipment Selection Criteria, when selecting a barcode reader the five common factors to consider are the front end users, scanning environment, use, scanning capabilities, and device specifications. For successful implementation, discussions with departments that will utilize the AIT will be required to gain support from the users. During such discussions, factors that would impact the users, productivity, and use of the reader such as ease of reader interface, connectivity, mobility, durability, and battery life can be considered (GS1 Canada, 2010). The environment also plays an essential role in the barcode reader selection process; therefore potential exposure to extreme temperatures or harsh chemicals must be addressed. Usability factors are subjective to the technology's application. For example, mobile scanning equipment integrated with Bluetooth or wireless technology to transmit data to remote databases are recommended for prefabricated yard logistics, field inspections, material testing and other construction applications. However, for simply verifying information stored on the barcode, such integration is not necessary. Also when selecting a manufacturer, the business or organization should consider the necessary software development, reading capabilities, power supply type (i.e. USB connection, cradle charger or power cord), and whether the manufacturer loans equipment and/or replaces defective devices (GS1 Canada, 2010). Table 3.4 displays currently available barcode readers and their significant features.

Table 3.4 - Currently available barcode reader and significant barcode features.

| | Low Frequency | | High Frequency | | | | | Ultra-High Frequency | | |
|---|---|---|---|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |  |  |  |  |
| **Product Name** | **Psion-Teklogix[1]** | **Bartec MC9090E X-K[2]** | **ChipherLab 9500[3]** | **Opticon H22[4]** | **CipherLab 9400[5]** | **Unitech PA690[6]** | **Unitech PA600[7]** | **Intermec CN70e[8]** | **Alien ALH-9000[9]** | **Intermec CK70[10]** |
| **Scanning Technology** | Imager | Laser | Imager | Imager | Imager | Imager | Imager | Imager | Imager | Imager |
| **Data Capture** | 1D/2D Barcodes | 1D Barcodes | 1D/2D Barcodes | 1D/2D Barcodes/RFID tags | 1D/2D Barcodes And RFID | 1D/2D Barcodes and RFID tags | 1D/2D Barcodes | 1D/2D Barcodes | 1-D/ 2-D Barcode | 1D/2D Barcodes |
| **Network Comm.** | USB/ Wireless | Wireless | Wireless/ Ethernet | USB/ Wireless | Wireless/ Ethernet | USB/ Wireless | USB/ Wireless | USB/ Wireless | USB / Wireless | USB/ Wireless |
| **Drop Rating** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 6 feet | N/A | 6 feet |
| **Read Range** | 0 - 3.15 inches | N/A | N/A | N/A | N/A | N/A | N/A | 13 inches | N/A | 13 inches |
| **Operating Sys.** | Windows CE NET 6.0 | Windows Mobile 2005 | Windows CE NET 5.0 | N/A | Window CE NET 6.0 | N/A | Microsoft Windows Embedded | Microsoft Windows Embedded | Windows CE NET 5.0 | Microsoft Windows Embedded |

[1] Psion Teklogix Inc. "7535 G2 Psion Teklogix - Handheld Computer." n.d. Psion Web site. July 2013
[2] Bartec. "MC 9090-K." n.d. Bartec Web site. July 2013 <www.bartec.de/>.
[3] Smarter Cipher Lab. "9500 series Industrial Mobile Computer." 2010. Motorola Solutions Web site. July 2013 <www.motorolasolutions.com>.
[4] Opticon Sensors. "H22 Barcode laser scanner & Color camera." n.d. Opticon Web site. July 2013 <www.opticon.com/H22.aspx>.
[5] CipherLab. "CipherLab Windows CE Mobile Computer 9400." 2011. Cipher Laboratory Web site. July 2013 <www.cipherlab.com>.
[6] Unitech Technology Corporation. "Unitech PA690 Mobile Computer." n.d. Unitech Web site. July 2013 <www.ute.com>.
[7] Unitech Technology Corporation. "Unitech PA600 Mobile Computer." n.d. Unitech Web site. July 2013 <www.ute.com>.
[8] Intermec Techology Corporation. "CN70/CN70e Ultra-rugged Mobile Computers Product Sheet." 2012. Intermech Smart Systems. July 2013
[9] Alien Technology. "ALH-900x Hand Held RFID Reader Datasheet." Morgan Hill: Alien, 2011.
[10] Intermec Techology Corporation. "CN70/CN70e Ultra-rugged Mobile Computers Product Sheet." 2012. Intermech Smart Systems. July 2013

### 3.3.3 Standard Barcode Symbologies

Barcode symbologies are patterns of geometrical shapes that map the relationship between the label and the encoded message. Two classifications of symbologies are discrete and continuous; Figure 3.7 and Figure 3.8 display the differences between the two symbology types. Within discrete symbologies each character is encoded and separated by an inter-character spacing. A character is a sequence of bar and space elements used to encode a specific value (Adams, 2012). This spacing is used to separate characters and does not hold any information. Unlike discrete symbologies, continuous symbologies cannot be interpreted individually because each character begins with a bar and ends with a space. Continuous symbologies are favorable because discrete symbologies typically require more space to print the same data as a continuous symbology type. However, discrete symbologies can be printed with less quality and still be readable. Commonly used barcode symbologies are shown in Table 3.5.

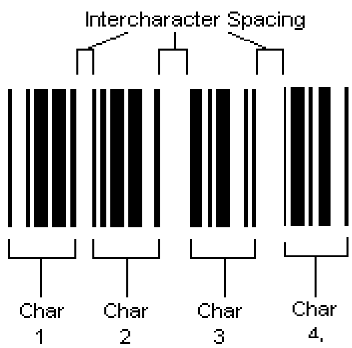



Figure 3.7 - Discrete barcode symbology (Adams, 2012)

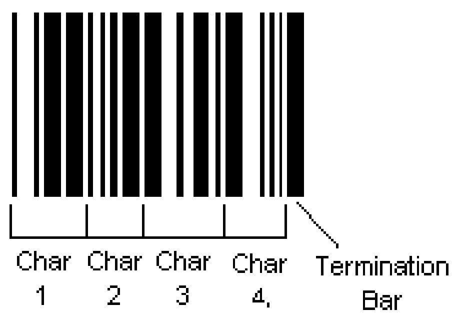



Figure 3.8 - Continuous barcode symbology (Adams, 2012)

The two types of barcode symbologies typically used in construction applications are Code128 and Code39. Code128 barcodes are high density, variable length symbologies that can carry a message of any length and encode a broad range of characters that allows a diversified level of information to be stored on the barcode. The prominent feature of this symbology type is it is designed to reduce the amount of space the barcode occupies by encoding two numbers into one "character width" (Honeywell, 2013). The symbology is also designed with self-checking geometric features to improve scanner read performance. Code128 symbologies are primarily used in logistical applications for ordering materials, material distribution and transportation. Code39 barcodes are also a variable length, self-checking symbology with high read accuracies, structural simplicity, and bi-directional reading capabilities. This barcode symbology is the most popular symbology implemented in a variety of industries. Although this symbology does not include a check digit, like other barcode symbologies, it is considered self-checking because printing or scanning errors do not cause the character to be incorrectly interpreted as another valid character (Stone, 2001). Therefore an incorrectly read bar element cannot generate a valid character when read. Dependent on the application and identification key used, barcodes are used to decode a variety of information.

Table 3.5 - Commonly used one and two dimensional barcode symbologies(Honeywell, 2013).

**One Dimensional Barcode Symbologies**

| **Symbology** | ***EAN-13 & EAN-8*** | ***UPC-A & UPC-E*** | ***Code 128*** | ***Code 39*** | ***IFT-14*** | ***Interleaved 2 of 5*** |
|---|---|---|---|---|---|---|
| **Applications** | Inventory Control & Returned Items | Inventory Control | Package Tracking & Inventory Control | Asset Tracking & Inventory Control (Implemented by the US DoD) | Asset Tracking | Inventory & Warehouse Control |
| **Symbol Format** | Multiwidth | Multiwidth | Multiwidth | Wide or Narrow | Wide or Narrow | Multiwidth |
| **Characters** | 10 Numeric | 10 Digit Numeric | Alphanumeric (letters, digits & special characters | Alphanumeric (letters, digits & special characters) | 10 Digit Number | 10 Digit Numeric |
| **Description** | International symbol used to encoded 13 (EAN-13) or 8 (EAN-8) digits. | Used to encode 12 digits, UPC-E encodes 6 digits and it best used for marking small packages. | Continuous symbology; Start/Stop code eliminates misread issues. | Meets the needs for many industry types. Encodes alphanumeric data in any length | Used to encode 14 digits; recommended in applications on corrugated cardboard | Partial scans typically occur with this symbology; bearer bars are used to minimize this issue |

**Two Dimensional Barcode Symbologies**

| **Symbology** | ***PDF417*** | ***Data Matrix*** | ***QR (Quick Response) Code*** |
|---|---|---|---|
| **Applications** | Inventory Management, Manufacture and Transportation Applications | Manufacturing Applications & Asset Tracking | Inventory Control & URLS for Mobile Phones |
| **Symbol Format** | Self-correcting | 28.5% - 62.5% self-correcting | Self –correcting |
| **Storage Capacity** | 2710 characters | Up to 2 kilobytes (2,335 alphanumeric characters) | 7089 Numeric; 4296 Alpha; 2953 Bytes |

The three selected two dimensional barcodes are known as self-checking barcodes. Self-checking barcodes are encoded with error correction codes to increase the semiology's strength. Therefore even if the barcode is partially damaged, it can still be read with ease (Bell, et al., 1988).

### 3.3.4 Barcode Print Quality Standards

In 1982, after barcode technology received accolades from the retail industries, a technical subcommittee of the American National Standard Institute (ANSI) began drafting print quality standards for barcodes to optimize their readability. In 1990 the subcommittee partnered with the Committee of European Normalization and the International Standard Organization (ISO) to develop the first version of the Barcode Print Quality Guidelines (AIM Inc., 2002). This document provides a methodology for quality assessment and automated interpretation of various symbologies. Although it is not realistic to conduct quality analyses on each printed barcode, it is beneficial to follow these guidelines on at least one barcode within a printed batch (AIM Inc., 2002). The primary test that is used to provide an overall understanding on the conformance of the barcode's quality is known as the edge determination test. This test is used to distinguish the bar and space elements by utilizing a scan reflectance profile**.** In a reflectance profile, each barcode edge (vertical line) is defined as the transition from a bar to a space element or vice-versa.

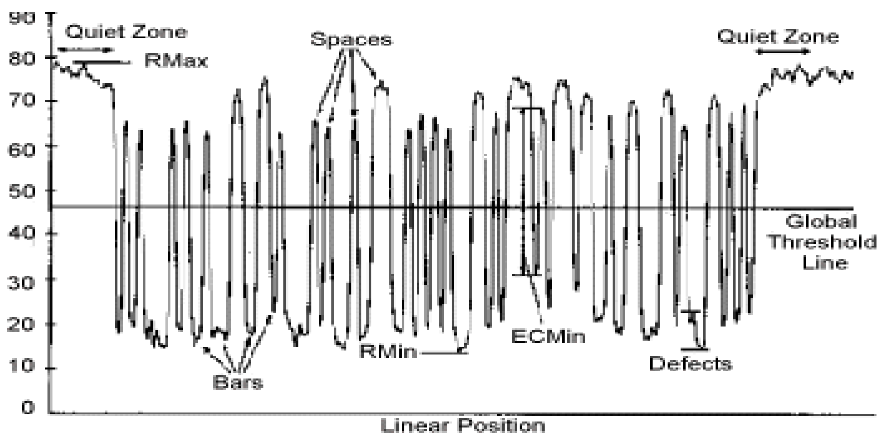



**Figure 3.9 - Sample Reflectance Profile of a Linear Barcode. The sample profile displays the values necessary for barcode quality assessment.**

As shown in Figure 3.9, the bar elements' reflectance values are below the global threshold limit because the element type absorbs light from the barcode reader. Conversely, the space elements' reflectance values are above the global threshold limit because the element reflects the light from the reader. Therefore quiet zones, located on either side of the barcode symbology, typically experience the highest reflectance value because it is the largest space element on the label. However in the case where the barcode does not meet the specifications of the symbology the six parameters listed in Table 3.6 must be assessed to identify problematic areas (AIM Inc., 2002).

**Table 3.6 - Overview of the ANSI, CEN, and ISO Printed Barcode Quality Standards indicating areas of improvements and standardized quality values (AIM Inc., 2002)**

| Quality Parameters | Standard | Areas of Improvement | Example |
|---|---|---|---|
| **Minimum Reflectance** | The reflectance value for at least one bar element must be equal to or less than half of the maximum reflectance values of a space element | N/A | If the maximum space reflectance value is equal to **70 percent**, the reflectance value of at least one bar in the reflectance profile must be **35 percent or less** |
| **Minimum Edge Contrast** | The edge contrast must be greater than 15 percent | Printing with darker ink, using Thermal Printing options and/or increasing the minimum element width | If the maximum space reflectance value is **70 percent** and the minimum bar reflectance value is **20 percent**, the minimum edge contrast is **50 percent** |
| **Symbol Contrast** | The symbol contrast is the variation between the maximum reflectance value (including quiet zones) and the minimum reflectance value. Value should be optimized. Value must be equal or greater than 70 percent. | Printing with darker ink and/or using non-laminate printing material (non-shiny paper) | (Same as above) |
| **Modulation** | Modulation refers to how the reader differentiates barcode elements by comparing the barcode's edge contrast minimum value and symbol contrast. Value must be equal or greater than 0.70. | Increasing widths of narrow spaces. Refer to **Minimum Edge Contrast** and **Symbol Contrast** parameters. | If the minimum edge contrast is **50 percent** and the symbol contrast value is **50 percent**, the minimum edge contrast is **1.00** |
| **Defects** | The defect grade is a comparison between the element reflectance non-uniformity value and the symbol contrast. The element reflectance non-uniformity is the difference between the maximum reflectance value and the minimum reflectance value of the barcode label. Defect grade is recommended to be less than 0.15. | Refer to **Symbol Contrast** parameter or re-consider printing options | If the element reflectance non-uniformity value is **10 percent** and the symbol contrast value is **50 percent**, the defect grade is 0.2. In this case the defect grade should be improved |
| **Decodability** | A measure of the accuracy of the printed barcode against the specific symbology's reference decoding algorithm* | Reassess software | N/A |

*Each symbology has a reference decoding algorithm that provides margins or tolerances for errors in the barcode printing or reading process.

Barcodes printed onto reflective laminate, polished metal or high gloss materials are typically not recommended to optimize their readability because such materials fail to diffuse light properly and therefore yield lower reflectance values. Defects are defined in the barcode's reflectance profiles, as voids located in bar elements or spots found in space elements, Figure 3.9 identifies a space in a bar element as a potential defect. The severity of the defect is measured by comparing the defect (also known as the element's reflectance non-uniformity value), and the symbol's contrast parameter.

### 3.3.5 Barcode Placement

Consistent label placement is critical to reducing learning curves and yielding successful automated identification business enterprises. For instance, when utilizing handheld devices for manual scanning, inconsistent label placement may make it difficult for the user to predict the location of the label therefore reducing the efficiency of the unique identifiers. In applications where a fixed reader is selected, label position must also be considered to effectively allow the object to pass through the reader's field of vision. GS1 has developed specifications for label placement to ensure smooth and efficient integrations of the AIT. To avoid reducing scanning performance by damaging or obscuring the barcode, the label should never be placed on an item with inadequate space or unsuitable surfaces (i.e. perforations, seams, ridges, edges, tight curves, folds, and rough textures). When using barcodes on documents, personnel must avoid stapling through the barcode or the label's quiet zone, and should never fold a label around a corner (GS1 Canada, 2010). To stay within GS1's edge constraints, the barcode label (including the quiet zone areas) should maintain a minimum distance of 0.3 inches away from the nearest edge of the item and a maximum of 4 inches.

To ensure the speed and efficiency of scanning operations, label placements must not only be consistent but follow natural hand movements during scanning operations. For the majority of package types (i.e. bags, bottles and jars, boxes, and documents) placing the label on the lower right quadrant of the back of the item while maintaining compliance with the barcode edge distance requirements, is recommended (GS1 Canada, 2010). However for unpackaged items, the barcode label should be placed on a flat surface on the item or on a hanging tag attached to the item. Large, heavy, bulky items require two barcodes for easier scanning: one barcode on the front of the item and one barcode on the back near the edge in the middle of the lower right quadrant. Although GS1 provides effective guidelines to make the transition from manual to automated operations as smooth as possible, the business entity must consider its users and the scanning environment when standardizing barcode placement (GS1 Canada, 2010).

## 3.4 Barcode Reader Technology Integrated in Mobile Phones

Smart phones are equipped with a variety of sensors (i.e. accelerometer, global positioning system, and camera) to interact with physical objects (Yu-Cheng Lin, 2010). The main advantage of smart phones is their ability to access the Internet or wireless infrastructure remotely. 1D and 2D barcodes can also be scanned using mobile application software, equipped with capabilities to access the phone's camera functionalities. When the camera on a smartphone takes a picture, it saves certain information about the photo such as when the photo was taken, image details, camera details, and even GPS coordinates (Figure 3.10) (Peterson, et al.). Since a smartphone uses its built in camera as the barcode reader, these same details can be saved when using a barcode scanner.

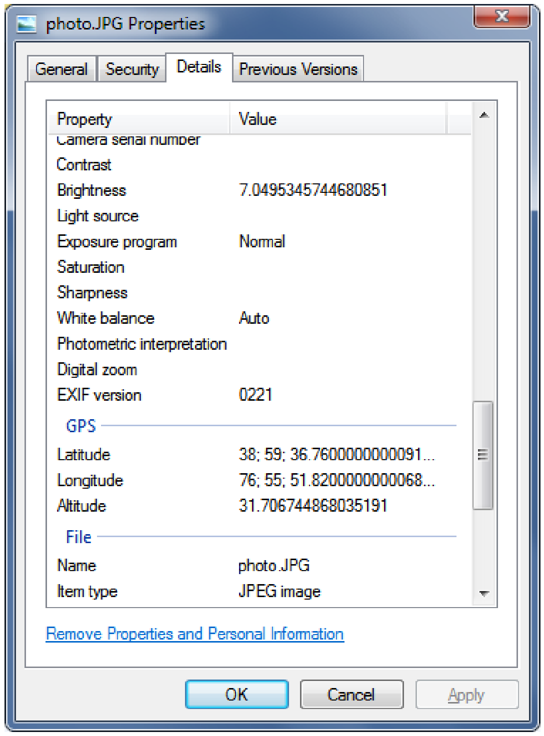



**Figure 3.10 - GPS coordinates saved to a photo, taken on a smartphone's camera**

Barcode scanning applications can be downloaded at no cost to the user or business entity. As shown in Figure 3.11, the application software is essentially used to manipulate the camera interface, Liquid Crystal Display (LCD) controller, Digital Signal Process (DSP) for image processing, and application host database for real-time visibility (Eisaku Ohbuchi, 2004). Using the application processor's selection menu, the barcode "reader" is activated. Once an image is captured using the camera interface, the image is sent to the DSP for image processing and the LCD controllers displays the image to the user. Using the DSP processer, the encoded data is detected and captured from the image and processed into a normalized size and digitized image (Yu-Cheng Lin, 2010). Using the application software, the digitized image is decoded and translated. The host application then displays the decoded results on the mobile device and any modification made to the item can be captured in the network database.

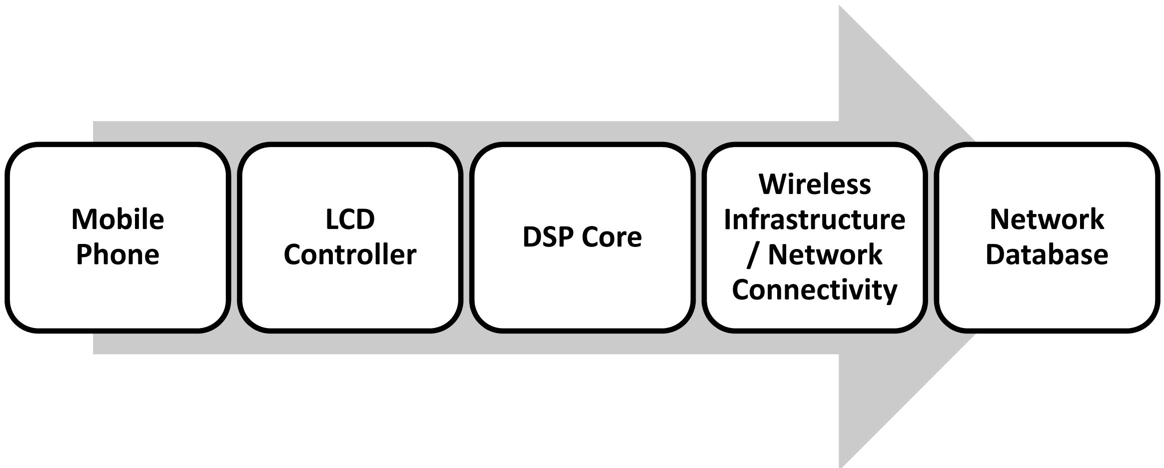



**Figure 3.11 - Typical mobile barcode scanning architecture**

Two main technologies used in designing a mobile management system include a software platform and a multiform barcode imaging processor. Software platforms provide an operating system and a variety of applications for mobile devices. The available mobile operating systems in the United States are listed below:

- Android
- Blackberry OS
- Firefox OS
- iOS
- Linux
- Windows Mobile
- Windows Phones

However, for material management purposes the mobile application requires an operating system that allows the material management system to interact with the mobile device's Internet access and camera interface. iOS, Android, and Windows operating systems are designed for mobile devices such as smartphones and tablets with such capabilities. However, iOS applications are developed for use on Apple products only. Android and Windows provides a low-cost customizable operating system with supported Software Development Kits (SDK). SDK provides the necessary tools and Application Program Interfaces (APIs) to develop applications (Yu-Cheng Lin, 2010). Zebra crossing, also known as ZXing is an open-source, multi-format 1D/2D barcode image processing technology used to provide APIs to decode barcodes captured by the mobile device. Although 1D barcodes can be read using mobile devices, the resolution of the phone's camera is inadequate in practical environments. QR Codem, VeriCode, DataMatrix, and Mcode are 2D barcodes that enhance the read robustness of data using error detection and correction algorithms. These types of barcodes are also able to be read without Internet network connectivity. Whereas VisualCode, ShotCode, and ColorCode 2D barcodes generate more reliable readings and also take into account the clarity limitations of current mobile devices (Yu-Cheng Lin, 2010).

Although there are various available software applications that are used to manipulate the camera of a mobile device, users typically find that the applications do not have the capability of keeping up with the volume of objects that must be scanned in the business enterprise. In such case, innovations have been made to transform a smartphone or tablet into a fully operational barcode scanner, matching the capabilities of any barcode reading device available on the market (Table 3.7). Socket developed a line of cordless scanners that can be paired with any iOS or Android device. Using this device, the scanners send data to the Internet capable devices via Bluetooth wireless technology and send the data stream into any specified software application (Barcodes Inc., 2012). Socket devices are also equipped with rugged housing in order to allow operations in harsh environments. There are two types of Socket scanners available on the market with limited warranties:

- Socket 7Ci – utilized to decode 1D barcodes and is ideal for inventory management and order entry implementations.
- Socket 7Xi – utilized to decode 2D and 1D barcodes. This scanner can read any type of barcode and is best for asset tracking and check-in implementations.

Opticon out-of-the-box barcode scanners provide a bit more flexibility, and can also be paired with Blackberry or Windows mobile devices. Data is transmitted to the mobile device using Bluetooth and Wireless technology and conveniently stores up to 20,000 scans during batch mode (Opticon, 2013). This handheld is often preferred because it is extremely lightweight; however this does not make it the best choice for applications in the construction industry. Like other traditional digital scanning devices, the Opticon handheld not only provides visual verification feedback but audible feedback as well. KoamTach's innovative design also provides users with an external power sources, and has been utilized in the transportation, warehouse management, and field services applications (KoamTac, 2013). Devices have been adapted to support Android, Blackberry, Windows and Apple (iPod, iPhone, and iPad) devices. Infinite Peripherals has developed a similar device with a sleeker design, made for Apple devices exclusively. In 2012, Infinite Peripheral introduced mobility into the transportation industry by supplying Amtrak with devices for ticket validation purposes (Infinite Peripherals Inc., 2012). Similar to the Opticon device, audible feedback from the scanner verifies the barcode has been read.

**Table 3.7 - Technologies used to transform mobile devices into fully operational barcode scanners**

| Attachment Technology | Read Range | Form | Operating System | Scanning Capability | Scanning Technology | Communication Type | Cost Range |
|---|---|---|---|---|---|---|---|
| **Socket**[1]  | Less than 33 feet | Wireless Handheld | iOS/ Android | 1D & 2D | Imager | Bluetooth | $250.00 – 500.00 |
| **Opticon**[2]  | Less than 33 feet | Wireless Handheld | iOS/ Android | 1D | Laser | Bluetooth & Batch | $250.00 – 300.00 |
| **KoamTac**[3]  | Close ranges | Wireless Handheld | iOS/ Android | 1D & 2D | Imager/ Laser | Bluetooth | $300.00 – 550.00 |
| **Infinite**[4] **Peripherals**  | Close ranges | Chargeable Battery Extender | iOS | 1D & 2D | Imager & Laser | Bluetooth & Batch | $500.00 and up |

[1]Barcodes Inc. Add Barcode Scanning to Your Apple iPad, iPhone, or iPod with Socket. 25 10 2012. <http://www.barcodesinc.com/news/?p=6732#more-6732>.

[2] Opticon. "OPN2005 Bluetooth Companion Scanner." Product Specifications. 01 May 2013.

[3] KoamTac. "KDC400 Barcode/MSR SLED for Smartphone." KDC400 Specifications. KoamTac, 2013.

[4] Infinite Perioherals Inc. "Linea-Pro 4." iPhone/iPod Touch 1D/2D Scanner. Infinite Perioherals Inc., 2012.

# Chapter Four: Radio Frequency Identification

Over the years RFID technology has been adopted in applications other than supply chain use because it has been proven to yield effective results. RFID allows for the unique identification of objects and transmits the identity of an item using radio waves. Key benefits of RFID systems over barcode systems are multiple tags can be interrogated within a wider range and assets can be located within a facility in seconds. These benefits are attractive advantages to organizations that seek to improve efficiency and minimize the effects of human errors. RFID automated systems are compiled into several components. These components consist of a RFID tag, an antenna or coil, a transceiver (aka a reader), a host computer system to store RFID readings, and transceiver software (Chung, et al., 2011).

## 4.1 RFID Tags

A RFID identifier is composed of a RFID chip, an antenna, and in some cases its own power source. All RFID tags must receive power in order to communicate its stored information. The range of operation for a RFID tag to function is dependent on the amount of power from the reader, the distance from the reader, the antenna size, the frequency, the antenna pattern and equipment sensitivity (The RFID Network, 2011). Tags are often classified into the following three different categories depending on how they are powered:

- Passive
- Active
- Semi-Passive

RFID tags that are classified as "passive" do not contain their own power source. To power the RFID tag, a RFID reader creates an electromagnetic signal to excite the RFID chip. A lack of power source in a passive RFID tag makes it simpler and less expensive than other options. Furthermore, the passive RFID tags have the potential for unlimited activity within its shelf life (Chung, et al., 2011). However, the downside of the passive RFID tags is their limited operating distance. Due to the lack of their own power source, the tags must be in closer proximity to the external power source, in order to transmit the information.

Active RFID tags contain their own onboard power source; usually in the form of a small battery. The battery powers both the RFID chip and the tag's attached antenna. Due to the additional power source, the range of operation of an active tag is far greater than the range of a passive tag. Active tags have the ability to transmit information over hundreds or even thousands of feet, whereas passive tags are only capable of transmitting up to a few feet in range (Chung, et al., 2011). Semi-active tags attempts to retain the advantages of both passive and RFID tags, while diminishing their disadvantages. "Semi-active tags typically use an internal battery to power circuitry that is internal to the tag itself" (Chung, et al., 2011). The circuitry built into the semi-active tags can act as sensors to capture and write data to the tag (Chung, et al., 2011). These sensor tags could be used to monitor physical parameters or environmental conditions, such as temperature and humidity. Furthermore, the sensors can also be used to detect vibration or movement, which could be used to monitor the possibility of damage or unauthorized movement during transport or storage. While semi-active tags utilize a battery, the battery is not used to power the antenna, as with active tags, and thus the battery power is conserved. Much like the communication in a passive RFID tag, the semi-active tag relies on the electromagnetic excitation from the reader (Chung, et al., 2011). Table 4.1 summarizes the differences in variables among the three major types of RFID tags: (Chung, et al., 2011)

**Table 4.1 - Radio Frequency Identification Tag Types**

| | Passive | Active | Semi-Passive |
|---|---|---|---|
| **Power Source** | External electromagnetic antenna field | Onboard Battery | Onboard battery for internal circuitry external electromagnetic field for transmission |
| **Range** | Measured in feet | Up to thousands of feet | Measured in feet |
| **Size** | Smaller | Larger | Large |
| **Data Storage** | Less | More | More |
| **Cost** | Less | More | More |

## 4.2 RFID Readers

A RFID reader is an external scanning device designed to emit radio waves at differing frequency levels to read RFID tags and also communicate with RFID middleware. RFID readers are often referred to as "interrogators," because they are said to "interrogate" nearby RFID tags. A RFID reader can be a handheld (Figure 4.1) or fixed unit (Figure 4.2). Readers are differentiated by their storage capacity, processing capability, and the frequency they can read. The frequency of the RFID tags dictates the range the reader will be able to detect the RFID tags. Once activated, a RFID reader is continuously transmitting radio frequency signals in search of nearby RFID tags. The moment the RFID tag is detected, the tag will transmit the signal to the reader in ASCII, Binary, or EPC coding. The code is a unique serial number related in a database that represents a product.

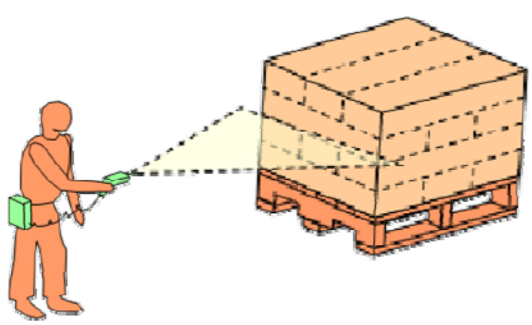


**Figure 4.1 - Handheld RFID Reader (Iyer, 2005)**

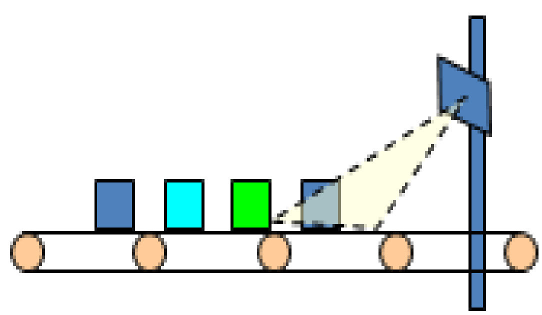


**Figure 4.2 - Fixed RFID Reader (Iyer, 2005)**

When selecting a RFID reader, the range is the primary parameter that should be considered. The range of the reader is determined by the radio frequency output, antenna type, environments, and interference waves. Readers typically operate at Low, High, or Ultra-High frequency levels as shown in Table 4.2. The frequency of the RFID tags dictates the range the reader will be able to detect the RFID tags. Once activated, a RFID reader is continuously transmitting radio frequency signals in search of nearby RFID tags. The moment the RFID tag is detected, the tag will transmit the signal to the reader in ASCII, Binary, or EPC coding. This code is a unique serial number related in a remote database that represents a product. Readers operating on low frequency bands provide the user with a shorter read range and slower read speed. The slower read speed makes the reader less sensitive to interference from moisture or metals compared to high and ultra-high frequency readers. The main drawback to a low frequency reader is it requires the user to get closer to the RFID tag to gather information from the tag. High and ultra-high frequency readers provide a greater frequency band that allows a high read range and even higher read speed. These reader types also have the ability to read and write at greater distances. However, the high and ultra-high frequency bands are more susceptible to interference from moisture and high metal contents. Along with low frequency readers, high frequency readers are also not recommended for construction applications because most electrical devices or sensitive equipment on or near the construction site operate on the same frequency band.

**Table 4.2 - Operational Frequencies of RFID technologies**

| | | Frequency Range | Read Range | Applications |
|---|---|---|---|---|
| Frequency Type | **Low** | ≤ 500 KHZ – 8.2 MHz | 1 – 12 inches | Access control, animal tracking, vehicle immobilizers, and point-of-sale applications |
| | **High** | 13.55 MHz – 500 MHz | 3 feet | Access control, Animal tracking, vehicle immobilizers, and point-of-sale applications |
| | **Ultra-High** | 900 MHz – 2.5 GHz* | 9.5 feet | Distribution and logistics applications, electronic toll collection systems, airline baggage, and parking lot access |

*In the North America regions the maximum frequency is 915 MHz as established by the FCC.

The readers' processing complexity dictates how the reader manipulates data. Reader classifications include smart readers equipped with business intelligence to process data and simple readers that are equipped with radio frequency intelligence. Depending on the application, either reader can be implemented for minimizing errors and streamlining productivity. Using a simple reader the received data is taken and filtered by a remote server or host, then manipulated for the desired result. This requires modifications to the backend system to accommodate the necessary RFID business processes. Whereas using a smart reader the tag data is filtered and managed at the reader level, therefore requiring little or no modification to the existing backend system. Although smart readers are initially costly when compared to simple readers, the existing business processes are not significantly disrupted and can be easily integrated into any system.

Handheld readers are predominantly used to perform air protocol operations such as reading information embedded in tags and writing information on tags. Modern readers also have the capability to act as gateways into network communication systems by supporting communication protocols such as Transmission Control Protocol/Internet Protocol (TCP/IP) and network technologies such as Dynamic Host Configurations (DHCP), User Diagram Protocol (UDP/IP) and Ethernet or 802.11x for wireless communication (Ward, et al., 2006). In order for reading devices to perform other air protocols that require the Internet to activate the signaling layer of the communication link between the reader and the end system the reader's connectivity must be considered. Handheld devices are typically connected to the internet via Bluetooth technology or a wireless network (hardwired network or cellular network). Whereas, fixed readers utilize a direct hardwired Ethernet connection to access the Internet.

### 4.2.1 Fixed RFID Readers

Fixed readers provide fully automated systems and are recommended for large scale deployments of materials or processing of large volumes. This type of reader must be permanently installed in defined locations, such as key entry and exit points of a facility to gather consistent readings. Depending on the specifications of the reader and the environmental conditions, protective enclosures may be necessary to ensure reliable readings despite environmental exposures and vibrations that occur on construction sites. The reader's active zone varies between 10 to 20 feet and is dependent on the antenna type. Readers using linear antennas are recommended when tag orientation is known and fixed, whereas circular antennas are designed to receive tags at various orientations. The drawback to this type of reader is that it requires a dedicated power source to continuously read tags. It is recommended for applications such as warehouse inventory control or assembly lines. Fixed RFID readers available on the market are displayed in Table 4.3.

### Table 4.3 Comparison of Fixed RFID Reader Hardware

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |  |  |  |
| **Product Name** | **Alien ALR-9900[1]** | **Alien ALR-9650[2]** | **SkyeReader SR70[3]** | **Unitech RS700[4]** | **Intermec IF61[5]** | **Intermec IF30[6]** | **Intermec IF30[7]** | **Motorola FX7400[8]** | **Motorola FX9500[9]** |
| **Type** | Smart | Smart | Smart | Smart | Smart | Smart | Simple | Simple | Simple |
| **Frequency** | 902.75 – 927.25 MHz | 902.75 – 927.25 MHz | 902 – 928 MHz | 860 – 960 MHz | 865 – 950 MHz | 865 – 915 MHz | 915 MHz | 902 – 928 MHz | 865 – 902 MHz |
| **Network Comm.** | Ethernet | Ethernet | USB | Ethernet / Wireless | Ethernet / Wireless | Ethernet | Ethernet | Ethernet | Ethernet |
| **Indicator** | LED | LED | N/A | LED | LED | N/A | N/A | Multicolor LED | Multicolor LED |
| **Coverage** | 4 Reading Points 50 Channels | 1 Reading Points 50 Channels | Linear Polarized | 4 Reading Points | 4 Reading Points | 4 Reading Points | 4 Reading Points | 4 Reading Points 2 Channels | 4 Reading Points 8 Channels |
| **Operating Sys.** | Linux | N/A | Microsoft Windows CE 5.0 | Linux | Linux | Linux | Linux | Microsoft Windows CE 5.0 | Linux |

[1] Alien Technology Corporation . "ALR-9900 - Enterprise RFID Reader." Morgan Hill: Alien, 2012.
[2] Alien Technology Corporation. "ALR-9650 Gen 2 RFID Reader with Integrated Antenna." Morgan Hill: Alien Technology, 2007.
[3] Skyetek Inc. "SkyeReader SR70 Datasheet." Colorado: SkyeTek , 2008.
[4] Unitech. "RS700 Smart RFID Fixed Reader." Los Angeles: Enitech Electronics Co., 2009.
[5] Intermec Technologies Corporation. "IF61 Enterprise Reader." Washington: Intermec, 2009.
[6] Intermec Technologies Corporation. "IF30 Fixer - User's Manual." Everett: Intermec, 2009.
[7] Intermec Technologies Corporation. "IF30 Fixer - User's Manual." Everett: Intermec, 2009.
[8] Motorola. "Motorola FX7400." Motorola Solutions, 2011.
[9] Motorola. "Motorola FX9500 Fixed RFID Reader." Motorola Solutions, 2011.

### 4.2.2 Handheld RFID

Handheld RFID readers offer a wide range of features, functions, and are ready for immediate deployment. They also provide an integrated power source, antenna, wireless local area network (WLAN) connectivity, and user friendly displays. Unlike fixed readers, the read zone of handheld devices is dictated by the scanning environment and tag type. In construction applications handheld devices are preferred not only because it provides the user with the flexibility to take the reader to the specific object but because it is designed to withstand dust, moisture, grease, and extreme temperatures. The durability of handheld readers is determined by the manufacturer's drop specification. In construction applications, the handheld device is expected to be dropped multiple times during its lifespan. Drop tests are conducted on all sides of the device to ensure reliable operations, regardless of how the device falls. In addition to reading RFID tags, select RFID readers have the capability of also decoding 1D and 2D barcodes. These multiple use readers can help reduce the cost of the overall system when multiple types of data capture systems are implemented within a business entity. They can also reduce the amount of time required to capture data from different types of unique identifiers and minimize learning curves. Handheld RFID readers available on the market are displayed in Table 4.4.

Table 4.4 - Comparison of Handheld RFID Reader Hardware

| | High Frequency | | | | Ultra-High Frequency | | | | |
|---|---|---|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |  |  |  |
| **Product Name** | **Motorola MC75**[1] | **Unitech PA690**[2] | **Barcode DualRunners**[3] | **CipherLab 9600**[4] | **Motorola MC9190-Z**[5] | **Honeywell Optimus 5900**[6] | **Motorola MC9090-G**[7] | **Motorola MC9090-Z**[8] | **Intermec IF30**[9] |
| **Scanning Technology** | Imager | Imager | Imager | Laser/ Imager | Laser | Imager | Laser | Laser | N/A |
| **Data Capture** | 1D/2D Barcodes and RFID | 1D/2D Barcodes and RFID | 1D/2D Barcodes and RFID | 1D/2D Barcodes and RFID | 1D/2D Barcodes and RFID | Gen 2 RFID | 1D/2D Barcodes and RFID | 1D/2D Barcodes and RFID | Gen 2 RFID |
| **Network Comm.** | Wireless, Ethernet & Bluetooth | Wireless & Bluetooth | Bluetooth | Wireless | Wireless | Wireless/ USB | Wireless | Wireless/ USB | Wireless/ USB |
| **Drop Rating** | 6 feet | 5 feet | N/A | 5 feet | 6 feet | 5 feet | 6 feet | 6 feet | 4 feet |
| **Read Range** | 2 inches | N/A | <10 inches | N/A | 30 feet | N/A | N/A | 20 feet | 15 feet |
| **Operating Sys.** | Microsoft Windows Embedded | Microsoft Windows Embedded | Windows 7 | Microsoft Windows CE | Windows Mobile 6.5 | Microsoft Window CE. NET | Microsoft Window CE. NET | Microsoft Windows Mobile 6.5 | N/A |

[1] Motorola. "MC75A Series Product Spec Sheet." Motorola Solutions, 2013.
[2] Unitech Technology Corporation. "Unitech 690 Mobile Computer." n.d. Unitech Web site. July 2013 <www.ute.com>.
[3] Baracoda. "Baracoda Traceability." DualRunners 2D. Baracoda, February 2010.
[4] Smarter Cipher Lab. "9600 Series Industrial Mobile Computer." Specification. 2013.
[5] Motorola.. "Motorola MC9190-Z Handheld RFID Reader Product Spec Sheet ." Motorola Solutions, n.d.
[6] Honeywell . "Optimus 5900 RFID Mobile Computer Data Sheet." Fort Mill: Honeywell , 2012.
[7] Motorola . "MC9090-G Product Spec Sheet." Motorola Solutions, 2010.
[8] Motorola.. "MOTOROLA MC3190-Z Business-Class Handheld RFID Reader Product Spec Sheet." Motorola Solutions, 2012.
[9] Intermec Technologies Corporation. "IF30 Fixer - User's Manual." Everett: Intermec, 2009.

**Ultra-High Frequency (continued)**

| |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| **Product Name** | **Intermec IF61**[1] | **Unitech RH767**[2] | **Alien ALH-900x**[3] | **Unitech RH767II**[4] | **Pidion BIP-6000**[5] | **CipherLab CP45**[6] | **Motorola MC3100**[7] | **Motorola DS9808-R**[8] | **Datalogic Falcon 5500**[9] |
| **Scanning Technology** | Laser | Laser | Imager | Laser | Imager | Laser/ Imager | Imager | Laser | Laser/ Imager |
| **Data Capture** | RFID | RFID | 1D/2D Barcodes and RFID | 1D/2D Barcodes and RFID | 1D/2D Barcodes and RFID | 1D/2D Barcodes And RFID | 1D/2D Barcodes and RFID | 1D/2D Barcodes And RFID | 1D/2D Barcodes and RFID |
| **Network Comm.** | Wireless | USB | Wireless/ USB | Wireless & Bluetooth | Wireless & Bluetooth | USB/ Wireless | Wireless & Bluetooth | USB | Wireless & Bluetooth |
| **Drop Rating** | 5 feet | 6 feet | 5 feet | 4 feet | 6 feet | 5 feet | 4 feet | 4 feet | 6 feet |
| **Read Range** | N/A | 30 inches | 25 feet | N/A | 4 feet | N/A | N/A | 15 inches | 5 feet |
| **Operating Sys.** | Windows Embedded Handheld 6.5 | Window CE NET 5.0 | Windows CE NET 5.0 | Microsoft CE 5.0 | Windows Mobile 6.1, 6.5 or Android | Windows Mobile 6.5 | Microsoft Windows CE 6.0 Pro | N/A | Window CE NET |

[1] Intermec Technologies Corporation. "IF61 Enterprise Reader." Washington: Intermec, 2009.
[2] Unitech. "RH767 RFID Handheld Reader User's Manual." Unitech Electronics Co., 2009.
[3] Alien Technology. "ALH-900x Hand Held RFID Reader Datasheet." Morgan Hill: Alien, 2011.
[4] Unitech. "RH767II Smart RFID Reader." RH767II Specifications. 2009.
[5] Bluebird Soft Inc. "Pidion BIP-6000 Series ." Rugged Handheld Computer. 2012.
[6] Smarter CipherLab. "CP40 series Industrial Mobile Computer." Taipei: Summit Data Communications, 2011.
[7] Motorola. "MOTOROLA MC3190-Z Business-Class Handheld RFID Reader Product Spec Sheet." Motorola Solutions, 2012
[8] Motorola. "Motorola DS9808-R Product Spec Sheet." Motorola Solutions, n.d.
[9] Barcodes Inc. "Falcon 5500 RFID Mobile Computer Data Sheet." Chicago: Barcodes, n.d.

### 4.2.3 Mobile Phones and AIT Readers

RFID readers can also be incorporated into handheld devices such as PDAs and mobile phones through the use of near field communication. Near Field Communication (NFC) is a combination of contactless identification and interconnection technologies that enables short-range communication between personal electronic devices. Smartphones can be supplemented with an NFC attachment, which turns the smartphone into a RFID reader/writer. RFID tag information can then be read and written with the smartphone and communicated in real-time to enterprise databases through the phone's Wi-Fi or 3G connections (Wireless Dynamics Inc., 2012).

In November 2009, the first RFID reader/writer was developed for Apple iPhones. The NFC attachment functions as an iPhone/iPod accessory and is attached to the bottom connector of the iPhone, as seen in Figure 4.3 and Figure 4.4. The read/write range of the attached reader varies from 1.5 to 2.5 inches, depending on RFID tag configuration, orientation and environment. Utilizing a RFID reader attachment within commercial applications allow users to have further accessibility to asset tracking, document tracking, security and access control (Wireless Dynamics Inc., 2013).


Figure 4.3 - Reader Attachment for iPhone/iPod Products (Wireless Dynamics Inc., 2013)


Figure 4.4 - Reader Attachment for iPhone5 (Wireless Dynamics Inc., 2013)

RFID readers can also be built in the form of a Secure Digital (SD) card, which is designed to be plugged into any PDA, Smartphone or other handheld device with an SD slot. The SD RFID readers also utilize NFC and have read/write capabilities. The variations of specifications between the different Secure Digital Identification (SDiD) products can be found in Table 4.5. The SD card can be sold with developmental kits (Figure 4.5) comprised of the SD card itself, tow RFID tags, and the SDK with full source code (Wireless Dynamics Inc., 2013).


Figure 4.5 - SDiD Development Kit

### Table 4.5 - Features and Specifications of the SDiD™ products (Wireless Dynamics Inc., 2013)

| | SDiD 1010™ 1010 NFC / RFID SD CARD | SDiD 1020™ 1020 RFID SD Card | SDiD 1212™ 1212 LF RFID SD Card with 2GB SD Memory | SDiD 1210™ 1210 LF RFID SD Card |
|---|---|---|---|---|
| **NFC** | NFCIP-1, ISO18092 compliant<br>Supports contactless payment<br>P2P communication<br>Data exchange speed up to 424 kbit/s | None | None | None |
| **RFID** | ISO 14443A compliant<br>Supports NXP MIFARE®<br>Supports NXP MIFARE DESFire®<br>Read, write and search RFID tags | ISO 15693 compliant<br>ISO 14443A compliant<br>Supports NXP I-CODE®<br>Supports NXP I-CODE® SLI<br>Supports NXP MIFARE®<br>Supports NXP MIFARE DESFire®<br>Supports Texas Instrument Tag-it™ HF-I<br>Read, write and search RFID tags | Low Frequency or LF RFID<br>ISO 11784, ISO 11785 for Animal ID<br>Supports both Half Duplex (HDX) and Full Duplex (FDX) LF RFID<br>Supports TI TIRIS LF, Sokymat Q5, NXP HITAG™ 1 and NXP HITAG™ S (no security)<br>Read, write and search 125 kHz and 134.2 kHz LF RFID tags | |
| **Secure Digital (SD) Card** | SDIO complaint, v 1.10<br>SD-1, SD-4, SPI mode<br>Extended SD form factor | SDIO complaint, v 1.10<br>SD-1, SD-4, SPI mode<br>Extended SD form factor | SD Combo Card Complaint<br>Embedded 2GB standard microSD<br>SDIO complaint, v 1.10<br>SD-1, SD-4, SPI mode<br>Extended SD form factor | SD Combo Card Complaint<br>SDIO complaint, v 1.10<br>SD-1, SD-4, SPI mode<br>Extended SD form factor |
| **Integrated Antenna** | Compact & Reliable Design | Compact & Reliable Design | Compact & Reliable Design | Compact & Reliable Design |
| **Frequency** | 13.56 MHz HF Band | 13.56 MHz HF Band | 134.2 kHz LF Band | 134.2 kHz LF Band |
| **PDAS / Smartphones** | Terminals with SDIO enabled SD Car slots<br>Microsoft Pocket PC 2002/2003 with SDIO*Now*! or Windows Mobile 2003 with SDIO*Now*! or Windows Mobile 5.0 or Windows Mobile 6.0<br>Palm OS® 4.1 & up | | Terminals with SDIO enabled SD Car slots that also support combo cards<br>Microsoft Pocket PC 2002/2003 with SDIO*Now*! or Windows Mobile 2003 with SDIO*Now*! or Windows Mobile 5.0 or Windows Mobile 6.0 | Terminals with SDIO enabled SD Car slots<br>Microsoft Pocket PC 2002/2003 with SDIO*Now*! or Windows Mobile 2003 with SDIO*Now*! or Windows Mobile 5.0 or Windows Mobile 6.0<br>Palm OS® 4.1 & up |
| **Read / Write Range** | Up to 2.0”<br>(depending on tag antenna config. & environment) | ISO 15693: Up to 3.2”<br>ISO 14443A: Up to 2.4”<br>(depending on tag antenna config. & environment) | HDX: Up to 5.0”<br>FDX: Up to 3.5”<br>(depending on tag antenna config. & environment) | HDX: Up to 5.0”<br>FDX: Up to 3.5”<br>(depending on tag antenna config. & environment) |
| **Low Power Consumption** (depending on host device) | 100 mA (typical) active<br>30 mA (typical) idle<br>10 mA (typical) standby<br>3.3V (typical) operation | 170 mA (typical) active<br>30 mA (typical) idle<br>10 mA (typical) standby<br>3.3V (typical) operation | 300 mA (typical) FDX active<br>120 mA (typical) HDX active<br>40 mA (typical) idle<br>32 mA (typical) standby<br>3.3V (typical) operation | 300 mA (typical) FDX active<br>120 mA (typical) HDX active<br>40 mA (typical) idle<br>32 mA (typical) standby<br>3.3V (typical) operation |
| **LED Indicator** | Indication for standby search and data communications | Indication for standby search and data communications | Bi-color (Red/Green)<br>Host Application controls activity | Bi-color (Red/Green)<br>Host Application controls activity |

## 4.3 System Operational Frequencies

RFID systems can operate on multiple radio frequency levels to transmit data to and from the RFID tags. Each frequency range has its own operation, power source requirements, and performance levels. The operational frequency determines how both the RFID tag and reader propagates signals. In practice, materials with high metal and/or liquid contents present a significant issue because these materials tend to reflect or absorb the propagated radio signals. Table 4.6 lists the standard frequencies regulated in the United States and their specifications. Operational frequencies also affect how tags interact with one another.

**Table 4.6 - Comparison of standard radio frequency bands of RFID tags and tag specifications.**

| **Frequency Ranges** | **Low Frequency 125KHz** | **High Frequency 13.56 MHz** | **Ultra-High Frequency 868-915 MHz** | **Microwave 2.45 GHz & 5.8 GHz** |
|---|---|---|---|---|
| **Typical Max Read Range (Passive Tags)** | Shortest 1”-12” | Short 2”-24” | Medium 1’-10’ | Longest 1’-15’ |
| **Tag Power Source** | Generally passive tags only, using inductive coupling | Generally passive tags only, using inductive or capacitive coupling | Active tags with integral battery or passive tags using capacitive storage, E-field coupling | Active tags with integral battery or passive tags using capacitive storage E-field coupling |
| **Data Rate** | Slower | Moderate | Fast | Faster |
| **Ability to read near metal or wet surfaces** | Better | Moderate | Poor | Worse |

Low frequency tags are foil inlay tags passively powered through inductive conductivity and therefore result in shorter read ranges. Foil inlay tags placed on top of one another may cause significant signal interference, which may result in unread or incorrectly read tags. This tag type is beneficial in rugged environments because of its ability to operate in close proximity to liquids and metals. However, low frequency tags have very low data read rates, compared to high and ultra-high frequency tags. High frequency tags are also packaged in foil inlays and are used in asset tracking applications. Although high frequency tags have a higher read rate and are less costly than low frequency tags, they do not operate as well near metals and liquids. In construction environments, high frequency tags are vulnerable to significant signal interference caused by tools used on site, because they both operate on the same frequency. Ultra-high frequency tags are made from a variety of materials and are commonly used for tracking applications due to their wider read range and low costs. Despite ultra-high frequency tag’s inability to perform in proximity to liquids or metals, materials have been developed to shield tags from liquid or metal-related interference. These types of materials are cost effective in implementations where tags will be reused or cost of failure is great; Figure 4.6 illustrates the different types of ultra-high frequency tags available and their applications. Microwave tags are also used in implementations where the cost of failure is great. Operating at super high frequencies, microwave tags offer higher read rates than ultra-high frequency tags. Despite this capability, microwave tags consume more energy than the previously discussed tag and may interfere with established wireless networks.

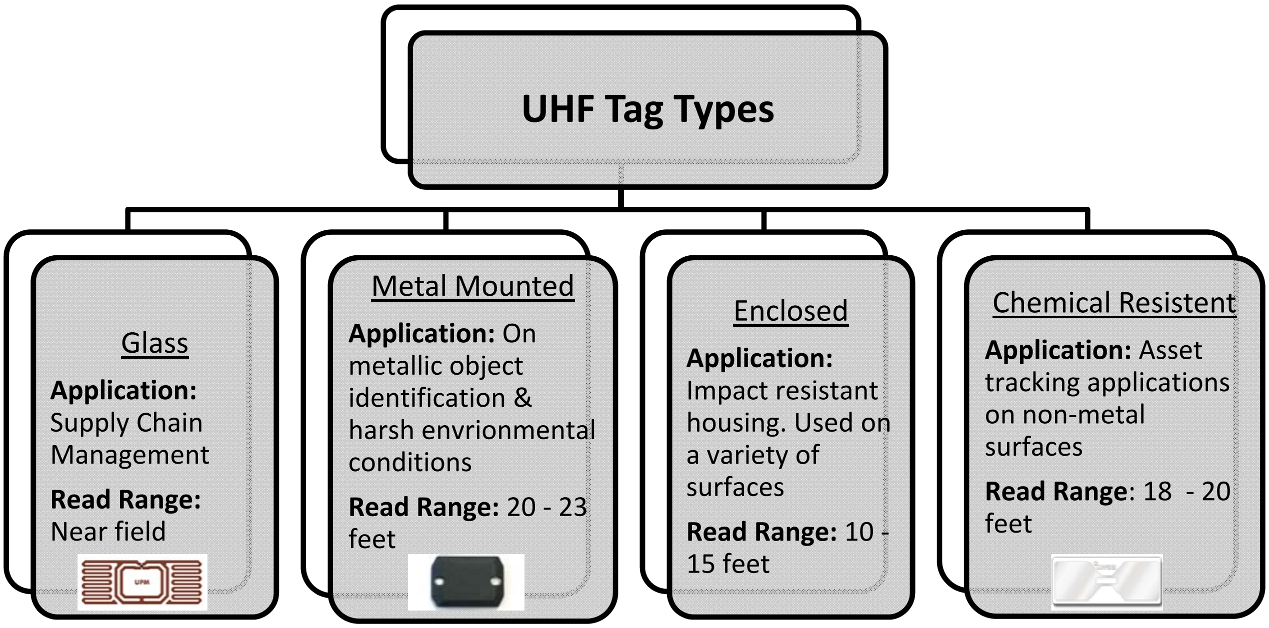



**Figure 4.6 - Innovative ultra-high frequency tag types for different application types and surfaces**

## 4.4 RFID Standards

The ISO is one of the key organizations in the world for standardizing equipment and operations. Since its establishment in 1947, ISO has been the international leader in producing guidelines, procedures, and policies on a wide range of issues and applications. ISO standards are accepted by organizations worldwide and provide business entities with implementation templates to produce items with international compatibility and consistency. It was ISO's standardization of the EPC that gave a huge boost to the rise and implementation of RFID technology.

The EPC has a similar function as the barcode affiliated UPC standard. The fundamental difference between the EPC and the UPC is EPC's capability to identify every single, individual product item. This EPC is the unique and universal code number embedded into the RFID chip. The EPC has become the global standard for Class 0 Gen 1, Class 1 Gen 1, and Gen 2 RFID tags (Chung, et al., 2011). The structure of the EPC is a 96-bit number with the following structure: (Ward, et al., 2006).

| **01.** | **0000A89.** | **00016F.** | **000247DC0** |
|---|---|---|---|
| Header<br>8 bits | EPC Manager<br>28 bits | Object Class<br>24 bits | Serial Number<br>36 bits |

The header bits define which of several coding schemes are in operation with the remaining bits providing the actual product code. It is the header that accommodates various existing global numbering systems, and integrates them all into the EPC. These number schemes include the Global Trade Identification Number, Serial Shipping Container Code, and the Global Location Number. The manager number identifies the manufacturer of the production item and the object class defines the product itself. The serial number is unique for the individual product. In its entirety, the 96-bit code provides unique identifiers for 268 million companies ($2^{28}$). Each manufacturer can have approximately 16 million ($2^{24}$) object classes and approximately 68 billion serial numbers ($2^{36}$) (Ward, et al., 2006).

## 4.5 RFID Network Architecture

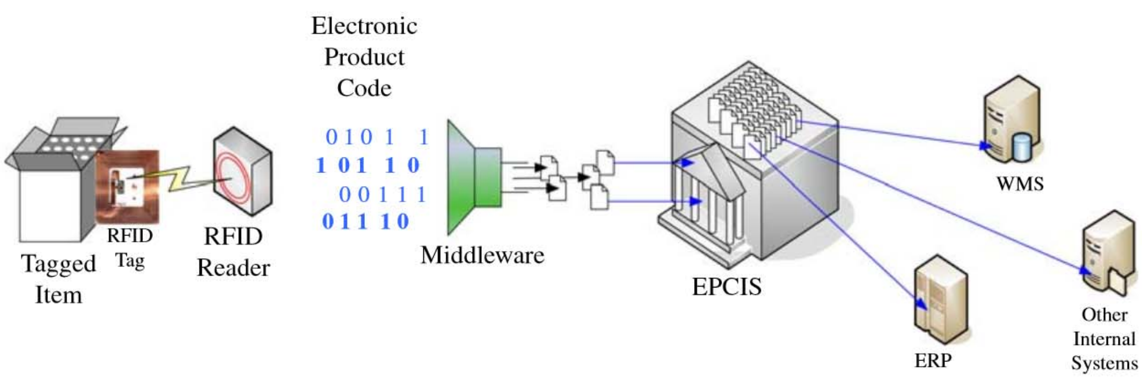



**Figure 4.7 - EPC Network Architecture (Chen, et al., 2007)**

An EPC Network, such as the one illustrated in Figure 4.7, provides the following main functionalities (Chen, et al., 2007):

- Physical objects with EPC tags can be linked together to work with one EPCIS;
- Various RFID tags within the same area can be automatically separated and evaluated;
- A large amount of information can be under management after the tags are read; and
- A standard data format for universal usage is provided in transferring information.

In the manufacturing industry, the model concept of a RFID tag is illustrated as a license plate for automobile registration. These "license plates" are used to access a remote database, which contains unlimited fields of information and details pertaining to the vehicle. Likewise, the EPC on the RFID tag is used to gain access to a network database and retrieve more details about the physical object. Because multiple RFID tags can be scanned at one time, RFID readers often handle a flood of data. In order to handle the data, a standardized RFID network architecture should be employed to process the aggregation of EPC codes. This also ensures the interoperability of RFID system components and its ability to provide network management. The Internet-based technologies and services behind this data management are known as the EPC Global network. The main components within the EPC Global network include RFID middleware, EPC information service, the Object Naming Service (ONS), and the physical markup language (Figure 4.8).

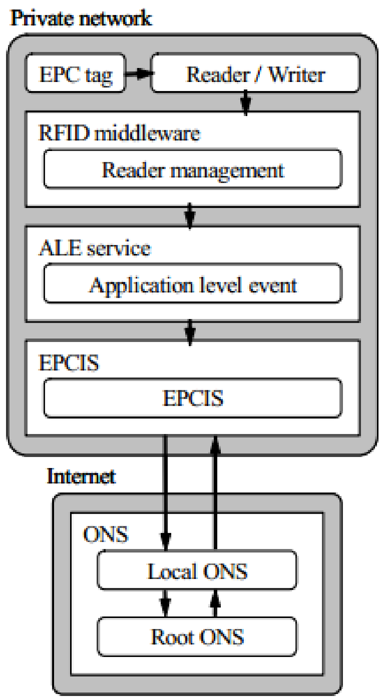



Figure 4.8 - EPC Network Conceptual Structure (Chen, et al., 2007)

The connection between the RFID reader and the information database(s) is facilitated using the RFID middleware and network infrastructure known as the EPC Information Service (EPCIS), as illustrated in Figure 4.7. The RFID middleware is used to handle the flow of data and pass on the useful information to the EPCIS. The EPCIS enables companies to store data associated with EPCs in secure databases on the Internet. The EPCIS can be built with external services or enterprise applications, e.g. Enterprise Resource Planning (ERP) and a Warehouse Management System (WMS). While some information with an EPC may be visible to everyone, the EPCIS also provides companies the ability to regulate different levels of access to different groups. EPCIS data is classified as static or dynamic written in a type of Extensive Makeup Language (XML) (Huifang Deng, 2010). For a structural component static data stored on the EPCIS may include the name of the producer, the date of production, dimensions, and/or quality. Dynamic data includes logistical information and installation status. An additional component to the EPCIS is the Object Naming Service (ONS). The function of the ONS is to locate the appropriate server that manages RFID information by converting the EPC to the URL of the EPCIS. The ONS can be compared to a "reverse phone directory," it looks at the unique EPCs and refers to the correct computers associated with the code. In order to access these computers, a standard and commercialized wireless network infrastructure is necessary. When an RFID reader interrogates an RFID tag, the EPC is transmitted to the middleware component. The middleware transmits the encoded data to an ONS on a localized network to obtain information related to the object. The middleware takes this stored data and forwards it to the reading device.

To use the ONS, the EPC must be converted into a Uniform Resource Identifier (URI). An RFID reader reads the RFID tag equipped object and records the EPC in binary code. Then data is decoded according to EPC standards. An example of a common Serialized Global Trade Identification Number (SGTIN) tag URI encoding format is shown below:

| **urn :** | **epc: id:** | **Sgtin :** | **1122334.** | **455667.** | **78899** |
|---|---|---|---|---|---|
| Tag Encoding Format | EPC Identifier | Tag Identifier | Company Prefix | Item Reference | Serial Number |

The tag encoding format (`urn`) indicates that the data is in the URN format standard. The tag identifier (`epc:id`) indicates the data is in the EPC format standard. The first three digits of the company prefix identify the country that the company is in, and the last four digits identify the company in the EOC network. When taken to the ONS, the URI is rewritten as,

**455667.1122334.sgtin.id.onsepc.com**

The ONS ignores the serial number because it stops at the item level, systems and the domain onspec.com is added to the ONS root service to locate information related to the item (Sandoche Balakrichenan, 2011).

### 4.5.1 Middleware

RFID middleware is essential to the system and it is often known to vendors as, "the central nervous system of an RFID platform." This component of the RFID system architecture refers to the software that resides on a server to connect the readers and data collected, to the enterprise applications. The purpose of the middleware is to ensure optimal operations between RFID hardware, such as readers and information database servers. RFID middleware also contributes to the handling and filtering of large quantities of data that is gathered when scanning multiple RFID tags. This process can be illustrated with the subway tree example (Figure 4.9); when multiple RFID tags are read, the information is sorted by the unique EPC code and only relevant information is sent to the host system. The middleware component is composed of two interfaces; the application interface and the reader interface. The application interface communicates with enterprise applications while the reader interfaces communicates with the RFID readers (Chen, et al., 2007). As illustrated in

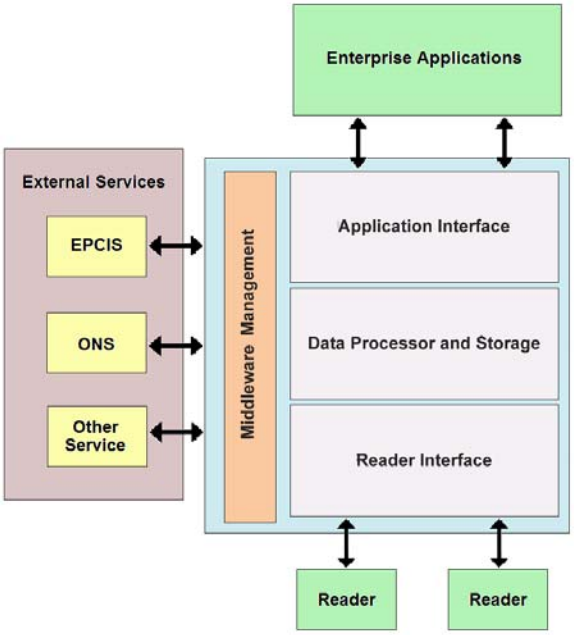


Figure 4.10, the communications by the interfaces allow for external services to interact (El Khaddar, et al., 2011).

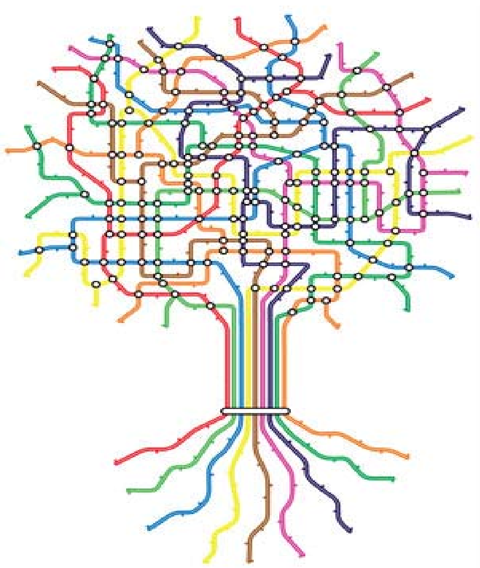


**Figure 4.9 - Subway Tree Illustration of Middleware Dispersing EPC Codes(O'Connor, 2010)**
**(Figurative representation for illustrative purposes only)**

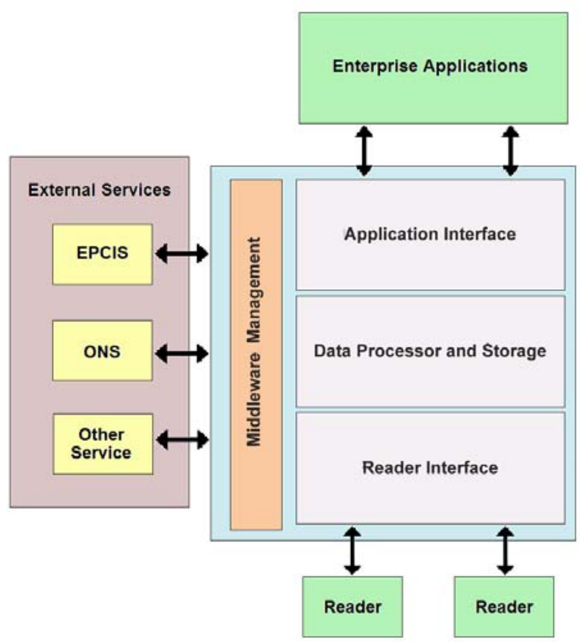



**Figure 4.10 - Organization of Middleware Components**

RFID middleware can be implemented on dedicated computers where RFID readers are employed, on individual readers, or on each networking appliance where the technology is used. Middleware has more recently gained the capability of working on the edge of a network and is sometimes referred to as edgeware. Edgeware has the added benefit of extracting, filtering, and counting data right from the RFID reader. Middleware can also be used within a Wide Area Network (WAN) to communicate with readers over the network (O'Connor, 2010).

Many RFID vendors develop middleware products to filter data from RFID readers. Most of these products are based on savants: standardized software developed by the Auto-ID Center to provide smooth data and to find information related to EPCs. However, due to the quick evolution and improvements of middleware technology, many RFID vendors don’t refer to the term “savants” on their websites. Instead, vendors typically advertise the benefits of custom built middleware and offer particular middleware architecture for specific AIT applications (O'Connor, 2010).

## 4.6 High Memory RFID Tags

The amount of data a RFID tag holds is in the region of a few bytes to a few kilobytes (sometimes referred to as n-bit). However, some tags only operate using 1 bit. When using this tag type, the reader can only tell if a tag is there or not, and nothing else. This is useful in applications such as shop security (Electronic Article Surveillance (EAS)) where you want an alarm to sound if a tag passes through the door regardless of what the tagged item is (WP3, 2007).

In other applications, high memory RFID tags that store data beyond an identification number may be needed. Recent publications show that high memory RFID tags are being developed with extended memory blocks, which holds more information and act beyond the role of “license plates.” High memory tags are typically classified as tags which can hold 1KB to 4KB (Xerafy, 2013). The largest commercially available high memory RFID tag is known as the TegoTag, developed by Tego™. TegoTag is a UHF EPC Gen 2, passive RFID tag, with the ability to host 32 kilobytes of memory. As the company reports, the extra memory offers companies the ability to encode information directly to the tag, while using a standard EPC Gen 2 interrogator (Bacheldor, 2009). Operation and compatibility with the interrogator is a requirement when selecting RFID tags; because some readers are not equipped with the required software systems and cannot read beyond the EPC number (Xerafy, 2013).

High memory RFID tags are used in the airline industry, where they provide easy and inexpensive solutions for automated tracking and traceability of aircraft parts and aircraft part shipments. Industry guidelines and standard formats for Automatic Identification and Data Capture (AIDC) with RFID can be found in *Spec2000,* created by the Air Transport Association of America (ATA, 2011-2012). These specifications determine what steps and data are necessary to allow “cradle-to-grave parts traceability” and to monitor the life-cycle status of aircraft parts. ATA found that implementing AIDC on aircraft parts and part shipments can improve the reliability and the organization of maintenance information exchanged between airlines and part manufacturers (ATA, 2011-2012).

High memory RFID tags offer maintenance engineers the added benefit of storing inspection records, maintenance records, repair records, and equipment status directly on the RFID tag and available for point of use (Xerafy, 2013). Moreover, Xerafy™ has cited multiple advantages of high memory RFID:

- Increased utilization and time in service for parts;
- Reduced costs for managing audit paperwork and reduced regulatory fines;
- More efficient labor with reduction in searching for tools and parts;
- Reduction in overall maintenance and repair costs with improved predictive maintenance and servicing by tracking parts;
- Faster turnaround time for maintenance, auditors, and logistics with access to critical data without requiring;
- Fewer spare components required with automatic parts allocation;
- Automated audit trail of maintenance and inspection activities simplifies compliance;
- Increased process control and safety; and
- Increased safety due to automatic checks for tool and equipment to reduce risk of Foreign Object Debris (FOD) damage.

# Chapter Five: Wireless Network Infrastructure

## 5.1 Introduction

Wireless networks are used to connect handheld devices to end systems. Wireless capabilities have been proven to improve productivity, mobility, and efficiency within various types of industries. In barcode and RFID auto-ID systems, information is stored in centralized computers or databases. Wireless networks allow personnel to access this remotely stored information in order to expedite their existing work processes. However the wireless network will need to be designed to not only allow users to access the Internet and internal data systems but also to accommodate a large number of users simultaneously. The primary components of a wireless infrastructure are (1) access points, (2) base stations, and (3) application connectivity software.

When initially designing or making modifications to an existing wireless infrastructure, the number of access points and their locations should be determined to create an efficient network with optimal coverage. Access points are devices used to interface the wireless communication signals to the wired network, which allows the user to access network services (i.e. database applications, the Internet, etc…) (Geier, 2004). These devices are strategically located n a facility to transmit and receive wireless data from servers to users. In instances where modifications to the existing infrastructure are necessary to improve the strength and area coverage, the number of existing access points should be increased. When determining the location of the access points the following parameters must be considered:

- Number of expected users;
- Type of data that will be transmitted;
- The space of the facility;
- Existing access points; and
- Environment (indoor/outdoor).

Multiple access points are managed by base stations from a centralized location to customize security measures and ensure efficient use of bandwidth. A gateway or firewall is a type of base station that regulates access to databases or websites by authenticating users based on log-in information. Routers are advanced forms of base stations, or gateways that allow multiple devices to operate on one broadband connection. Application connectivity software is a combination of customized protocols used to handle the interface between the handheld device and the end system hosting application. In automatic identification implementations, "smart" handheld devices are equipped with development kits that allow application software to be modified to interface and establish communication links with network services. Three types of commonly used connectivity software are direct database connectivity, wireless middleware, and terminal emulation. Direct database connectivity software allows applications to be designed that interface directly with databases located on central servers. This approach allows maximum flexibility when accessing network services and utilizes the Transmission Control Protocol/Internet Protocol (TCP/IP) to connect computing devices to the Internet (Parziale, et al., 2006). This is done by providing a communication service at an intermediate level between the devices' application program and the IP address as shown in Figure 5.1. Using File Transfer Protocols (FTP), data connections are established to transmit data between the database and the mobile device. FTPs can operate in active or passive modes. In active modes (i.e. Ethernet connections), the established TCP/IP connection accesses the FTP client in order to interface with the Internet and access the necessary network service. In passive modes, the FTP client is behind a firewall and is not able to receive TCP connections. In which case, a command is sent to the FTP server, along with a server IP address and server port number. The FTP client then opens a data connection from the client port to the server IP address and the received server port. Similar to TCP/IP, in data capture systems wireless middleware provides intermediate communication links between handheld devices and the database. (Parziale, et al., 2006). A hardwired distribution system is used to tie together the access points, wireless switches and end systems using physical wiring. The wireless network's distribution system is usually an Ethernet connection or Wireless Local Area Network (WLAN) that is hardwired remotely.

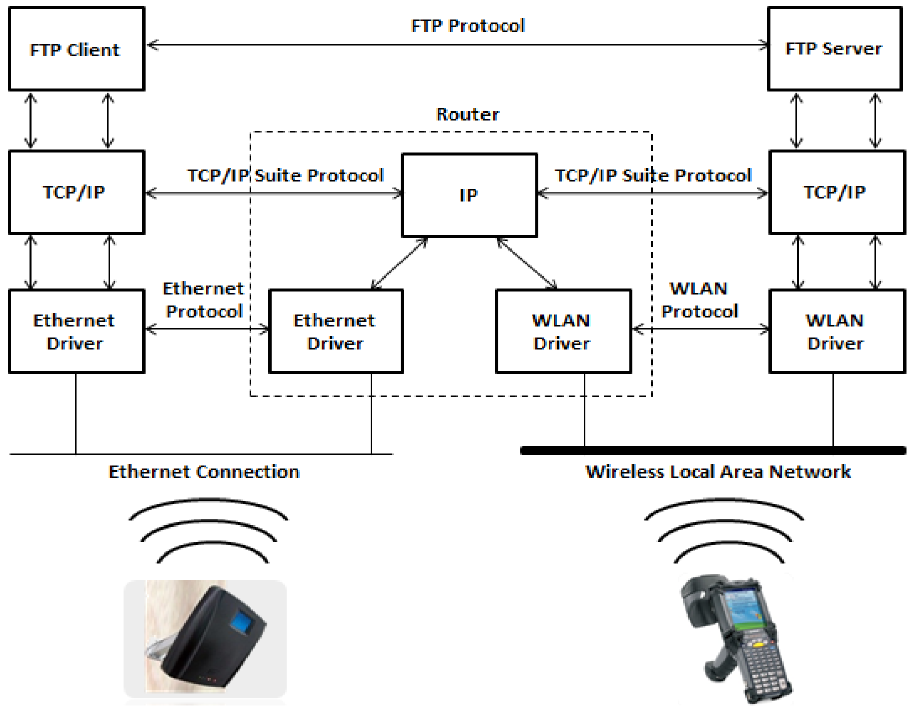



**Figure 5.1 - General architecture of wireless infrastructures to transfer data via the Internet utilizing either a hardwired Ethernet connection or Wireless Local Area Network (WLAN).**

Similar to the previously discussed aspects of the auto-ID system's components, the wireless provider ensures the business entity's needs are achieved over the life of the system such as security, support, and maintenance. To avoid compromising or damaging the database or network, security policies must be enforced to impede the propagation of wireless signals to unknown persons. Support is also necessary to provide common solutions, such as connectivity resolutions, to users. In cases where user issues are not resolved maintenance may be necessary to repair or reconfigure the wireless infrastructure such as replacing an antenna, setting channels on access points, and re-evaluating radio signal propagation (Geier, 2004).

## 5.2 Wireless Networking Standards

Available wireless network standards significantly differ in frequency, data rate, and range coverage. When selecting a wireless standard to integrate in an automated identification system, the business entity should consider the number and type of users, required data rates, overall network capacity, and necessary security measures (Geier, 2004). Commonly used standards are compared in Table 5.1. Wideband Code Division Multiple Access, or WCDMA, is an air interface standard in 3G mobile telecommunication networks and is commonly used by cellular phone companies to enable communication between devices. Cellular networks also utilize Worldwide Interoperability for Microwave Access (WiMAX) as an alternative for increasing network capacity. This technology can be used to provide mobile connectivity across cities or countries for devices (National Instruments, 2013). Unlike CDMA or WiMAX, Bluetooth technology utilizes short range radio signals to simplify communications and allow data synchronization among handheld devices and end systems. Wireless Fidelity (Wi-Fi) increases this coverage by providing a wireless network that allows electronic devices such as cell phones, tablets, computers and computer devices to access the Internet.

**Table 5.1 - Comparison of Wireless Networking Standards(National Instruments, 2013).**

| **Wireless Standards** | **Frequency** | **Max Data Rate** | **Range** |
|---|---|---|---|
| **Wi-Fi** | | | |
| *802.11 a* | 5.25, 5.6, and 5.8 GHz | Up to 54Mbps | Up to 65 feet |
| *802.11 b* | 2.4 – 2.4835 GHz | Up to 11Mbps | Up to 100 feet |
| *802.11 g* | 2.4 – 2.4835 GHz | Up to 54Mbps | Up to 100 feet |
| *802.11 n* | 2.4 – 2.4835 GHz & 5.15 – 5.35 GHz | 108+ Mbps | Up to 100 feet |
| **Bluetooth** | 2.4 GHz | 2.1Mbps | Class 1: 330 feet<br>Class 2: 33 feet<br>Class 3: 3 feet |
| **WiMAX** | 2.3 GHz | Up to 75Mbps | 30 miles |
| **WCDMA** | 850 and 1900 MHz | 9.6kbps | - |

The user must be considered when selecting a wireless standard because the user directly initiates and terminates the use of the wireless network. Users are either portable or stationary. Portable users are in a specific location using the wireless network for a finite amount of time; whereas stationary users operate in a specific location using the wireless network for an indefinite amount of time (Geier, 2004). In order to execute mobile operations, users utilize handheld devices to access databases, the Internet, or any remote end system required to complete work operations. Handheld devices used in automated identification applications are normally integrated with Bluetooth or Wi-Fi compatible technology to provide the enterprise application with real-time access to the data. Such devices are equipped with operating systems such as Windows, LINUS, Android, or MAC OS to run software, applications and recognize available wireless networks. For instance, Windows XP based handheld devices automatically recognize WLANs.

Wi-Fi networks are highly recommended in automatic identification technology used in construction applications to avoid unplanned downtimes due to incorrect component selections or the use of non-compliant materials (ETA-Melco Elevator Co. LLC, 2005). Handheld devices with wireless capabilities are integrated with wireless technology that translates data into radio signals and transmits the radio signal to a centralized router. Then, the router decodes the data and sends it to the remote database, using the Internet via a hard wired Ethernet connection. Information can also be sent from the database to the handheld device via the Wi-Fi connection (Geier, 2004).

### 5.2.1 Mobile Telecommunication Wireless Networks

Although Wi-Fi networks are more reliable, wireless areas are smaller than those of mobile telecommunication technologies. Cellular networks provide a wider service area, whereas WLAN networks offer high speed rates and easy compatibility of wired Internet over small areas. Most barcode digital scanners, RFID readers or enabled smartphones and tablets are equipped with configurable Global System for Mobile Communication (GSM) protocols and WCDMA channels to allow business entities to select any cellular network to provide the best coverage for field and laboratory personnel (Geier, 2004). Figure 5.2 displays a basic structure of cellular wireless networks. The mobile terminal processes authentication protocols (EAPs) from the wireless infrastructure. Mobile terminals are devices with wireless capability such as mobile, tablet and handheld devices. The access point is the authenticator in the EAP, to transmit data between wired and wireless networks that are managed in the WLAN network. The WLAN Authentication Server is the back-end authentication server in the WLAN network, and the Cellular Network Authentication Server is the subscriber's cellular network, where credentials are stored to verify authorization information.

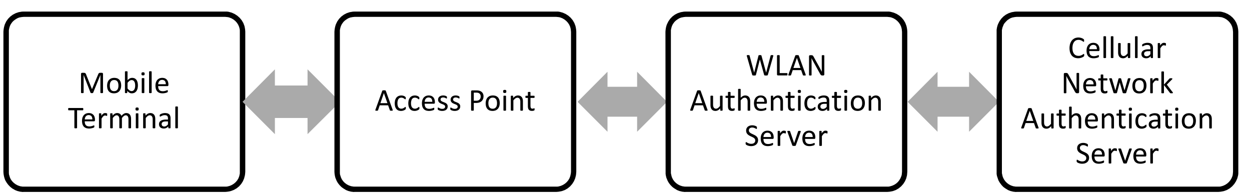



Figure 5.2 - The network architectural model

Data services such as third generation (3G) or Long Term Evolution (LTE) mobile communication networks function as gateways to provide connections to the middleware platform using IP network connections and allowing mobility across a larger area. 3G systems provide mobile broadband Internet access to laptop computers (network USB), tablets, smartphones, and other mobile devices (National Instruments, 2013). This wireless network operates on the 850, 900, and 1900 MHz frequency bands and provide data rate ranges between 1 Gigabits per second (Gbits/s) to 100 Megabits per second (Mbits/s). LTE is also a standard for wireless data communication technology, designed to increase the capacity and speed of a wireless data network using Digital Signal Processing (DSP) techniques. In the United States, LTE operates on a range of frequency bands (700, 800, 900, 1700, 2100, and 2600 MHz).

# Chapter Six: Survey Discussion

A survey was sent to Iowa, Alaska, and Michigan to inquire about the use of AITs on DOT projects. The University of Maryland research team was particularly interested in applications related to concrete, construction materials, structures, and construction projects. A sample survey and the three DOT responses can be found in the Appendix A.1.

Michigan DOT uses RFID and barcode technologies on a project by project basis. They use RFID tags to uniquely identify and communicate with temperature sensors. These sensors are embedded in concrete, aggregate, and HMA (after the first roller passes), as well as used to monitor ambient temperatures. The collected data is used to determine maturity calculations, warping and curling research, and determining specification compliance. The use of RFID has proven to be beneficial because it provided an automated electronic system for maturity testing and facilitated earlier "open-to-traffic" times. Warping and curling research helps analyze pavement performance and provides information about the causes of pavement cracking. The use of RFID on Michigan projects also helped the DOT determine the effectiveness of construction methods. For example, the effectiveness of flooding an HMA separator layer with water prior to paving an unbounded concrete overlay can be easily determined using an RFID system (Stallard, et al., 2012)**.**

The Alaska DOT is investigating how RFID technology may be used to track the delivery of asphalt materials. Currently, the tracking of asphalt for paving in Alaska uses a paper based system. Paper tickets are printed at the asphalt plant then handed off to the truck driver and then to a DOT inspector at the paving site. Information about load size, location, and how much area each load covers are recorded on the ticket. Furthermore, after the tickets have been passed off several times and written on, the tickets go back to the office and are used for payment items. The tickets have to be stored for 3 years after the job. The purpose of Alaska's investigation into the use of RFID was to ascertain if the technology would result in more efficient methods to weigh, track and measure unit price items weighed on certified scales. At the time of publication of this report, Alaska's report, *T2-08-09 Feasibility Study of RFID Technology for Construction Load Tracking,* was pending final edits (Sweeney, 2012)**.**

The Iowa DOT currently uses barcodes to keep an accurate count of raw materials (e.g. sign blanks, wood, and scothlite) and finished signs. They use barcode/stock number stickers throughout the shop to designate the location for all raw material and finished products. In accordance with Iowa DOT officials, specific radios are used to find where certain raw materials are kept. The radios also provide information about the amount of signs/raw material in each location which is useful for restocking these materials. According to the Iowa DOT, auto-ID implementation provides a "very fast and efficient method for keeping track of all raw material and finished signs" (Anderson, et al., 2012).

# Chapter Seven: Recommendations for Integrating Auto-ID Technologies into SHA/OMT Operations

## 7.1 Introduction

The Maryland State Highway Administration's (SHA) Office of Materials Technology (OMT) ensures construction materials used on active projects are designed, produced, and installed to meet safety and environmental standards. The Asphalt, Concrete, and Soils and Aggregate Technology Divisions and Structural Materials and Pavement Marking Division of OMT, are directly responsible for quality assurance, quality control, clearance and approval of materials used on SHA projects. In the materials clearance process the materials undergo a series of required tests and quality assessments to ensure that they are in compliance with American Association of State Highway Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), and SHA specifications. Materials are currently transported from the field to the OMT laboratories with written identification numbers, General Materials Sample Form (SHA73.0-88), and in some cases production or fabricator documentations. As the sample manually travels through the different OMT laboratories, its general form is updated with new information related to the tests conducted on the sample. The actual testing information is printed to a hard copy (which is later stored in filing cabinets), filled into the Materials Sample Forms, and then manually entered into a computer database, known as the Materials Management System (MMS).

The MMS is an Oracle produced database system which OMT uses to track, record, evaluate, analyze, and review the quality of materials used on SHA construction projects. OMT uses the MMS as a central repository to host the data from materials testing and clearance activities, including materials tested in central and field laboratories, consultant laboratories, manufacturing sites, and project sites as needed (Dye Management Group, 2008). Although currently under development to extend its capabilities, the overall goal of the MMS is to provide tools to more effectively and efficiently manage the entire materials clearance process using digital file storage, task tracking, and correspondence sharing. Once the nine phase upgrade is completed, the MMS will also be capable of sharing data with SHA enterprise databases and other management systems such as AASHTO Trns•port®, the Maryland Construction Management System (MCMS), the Financial Management Information System (FMIS), the Pavement Management System (PMS), and the Bridge Management System (BMS) among others (Dye Management Group, 2008). The organization of the completed MMS is illustrated in Figure 7.1. As appropriately illustrated in the figure, the Laboratory Information Management System (LIMS) is the largest component of the MMS.

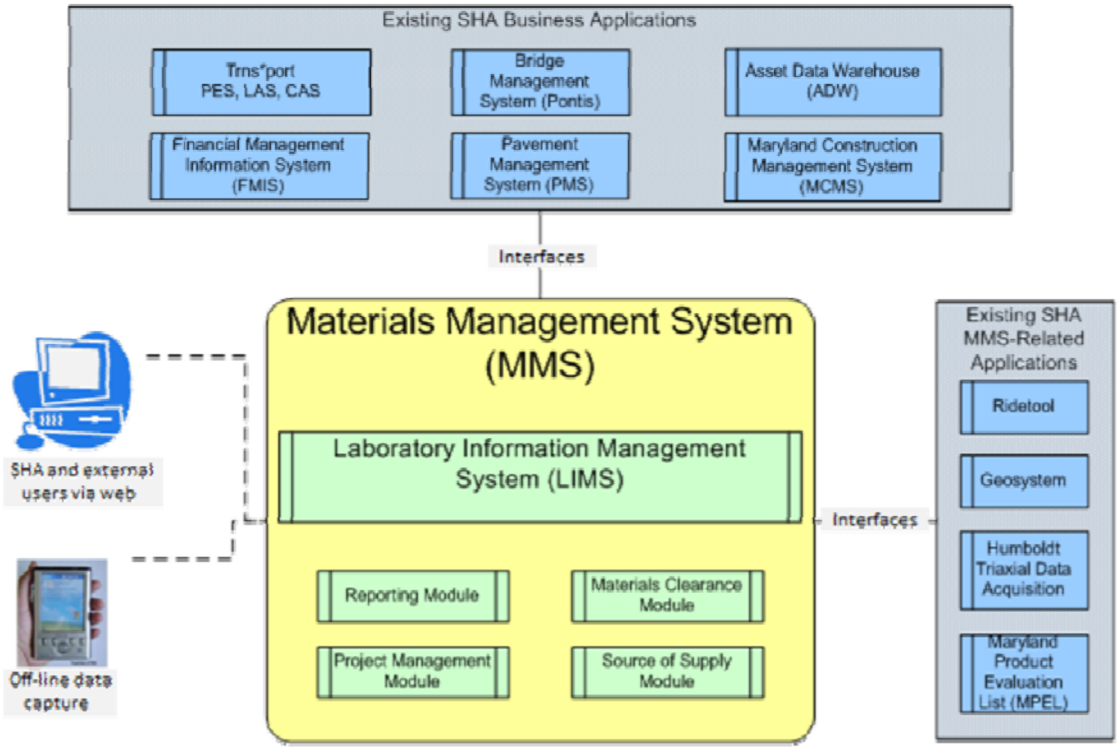



**Figure 7.1 - Conceptual Overview of the proposed MMS (Dye Management Group, 2008)**

It has been SHA's experience that field technicians who collect material samples may be unfamiliar with the details and information that must be recorded on the materials sample forms or may have illegible writing, which may result in transcription errors at the SHA laboratory. As a result of this issue SHA recognizes the need for AITs to improve the efficiency of the current materials clearance process and expand the functionalities of the MMS. Table 7.1 details the potential improvements that AITs may have in SHA personnel's (Project Engineer, Contractor, and OMT Technical Representative) daily operations. The use of unique identifiers on material samples will further reduce the amount of paperwork involved and the time necessary to transmit information between OMT laboratories and construction projects sites. Use of this technology will improve the efficiency of inter-laboratory processes including material testing, acceptance, and compliance to allow SHA personnel to better manage the materials clearance process. These improvements will increase SHA's ability to more efficiently and effectively perform design, construction, rehabilitation, and maintenance on state highways (Dye Management Group, 2008).

**Table 7.1 - Potential improvements auto-ID technologies may provide the SHA (Samuel Y.L. Yin, 2009)**

| Member | Potential Improvements provided by AIT |
|---|---|
| ***Project Engineer*** | 1. To know the detailed issues surrounding soil, concrete, asphalt, cement, or structural components materials and conditions.<br>2. To have an automated database for removing the non-conforming. construction materials that are discovered upon completion of material testing.<br>3. Have real time test data for decision making. |
| ***Contractor*** | 1. Address the lack of instant feedback caused by low traceability and visibility of field samples.<br>2. Address the difficulties of inspecting the quality of the components and materials along with the incapability of instantly checking the data remotely.<br>3. Address the difficulty of recording and checking data while in the field.<br>4. Avoid progress delays while having real time test data. |
| ***OMT Technical Representative*** | 1. Address the difficulty of storing and transferring data taken from the field to centralized databases.<br>2. Address the difficulty of storing and carrying information on paper.<br>3. Address the waste of time and human resources on searching for information caused by low traceability and visibility of field samples.<br>4. Improve the current operation processes that involve repetitive data entry and potential incidence of errors. |

This chapter discusses how current material specifications, clearance and quality assessment operations will be modified and enhanced with the implementation of AITs and provide data capture hardware and software recommendations. In order to illustrate how the existing processes will be modified, current business processes within OMT will be discussed as well as the recommended AIT, hardware, software development, database modifications, and overall system architecture.

## 7.2 Flow of Materials

The following list is a general description of the flow of materials, from when they are first sampled in the field and as they move throughout the OMT laboratories.

1) Materials are sampled in the field
    - General data/information is manually recorded (hand written) on a Materials Sample form e.g. date sampled, project sample number, type of material, type of construction

2) Materials are delivered to OMT laboratories
    - The field data/information is logged into the OMT database and the sample is often transcribed with a new ID number for tracking around the laboratory

3) Prepare specimen for testing; Determine tests to be performed
    - Complete relevant information on general materials sample form, e.g. date of test, completed test date, person in charge of test
    - Input testing information into OMT database

4) Materials are tested
    - Evaluate whether or not material characteristics comply with design criteria

5) Test results are compiled
    - A recording of the results are transcribed to the general materials sample form
    - Results are recorded in the OMT database

6) Prepare sample report

An official flowchart of OMT's process is included in Appendix A.4. A flowchart outlining the major operations a material is subjected to once it enters the OMT laboratory is illustrated in Figure 7.2. This flowchart is modified in Figure 7.3 to illustrate how the process changes with the integration of AITs.

# SHA/OMT: Material Flow Summary – No Auto-ID

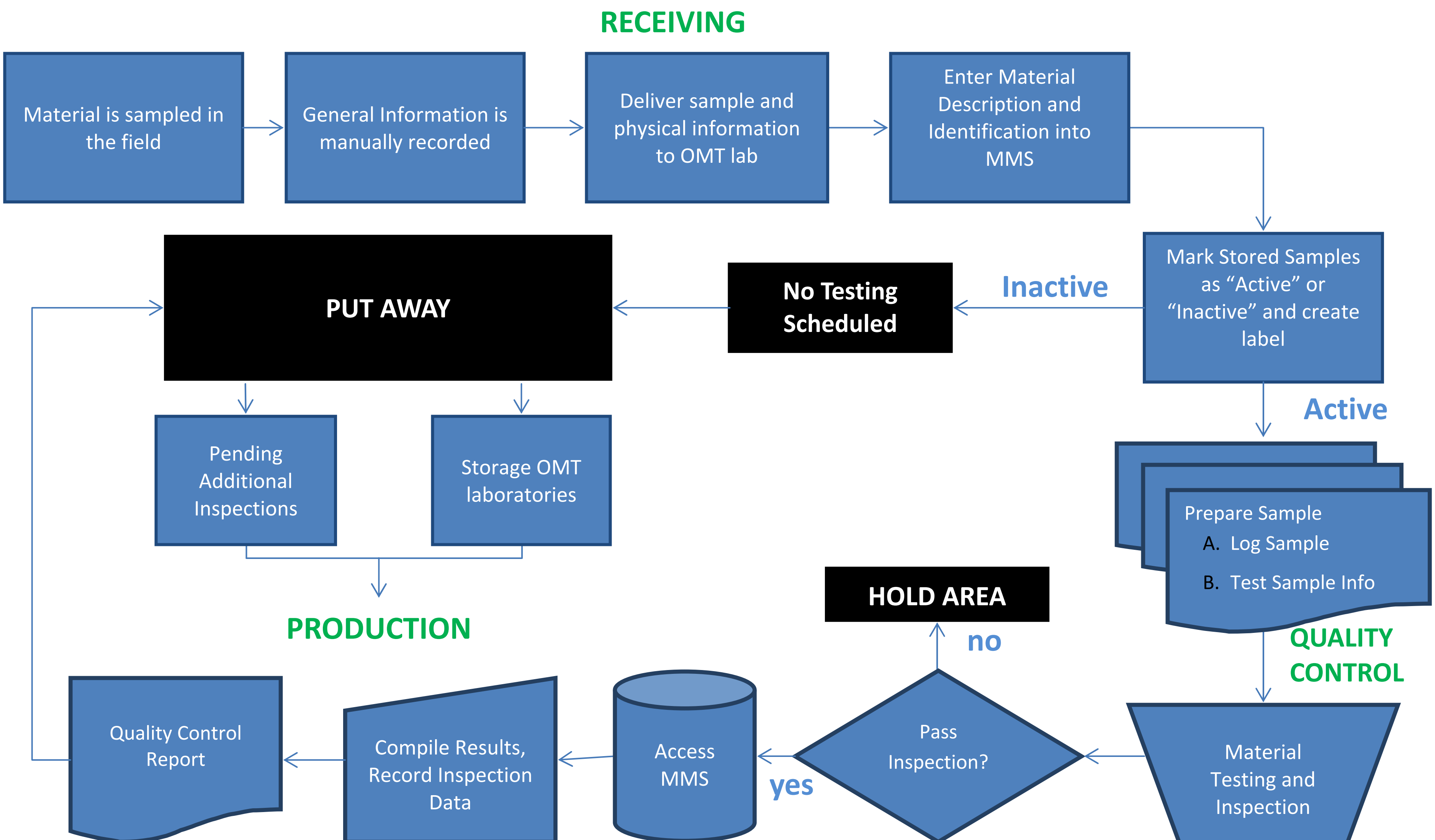



Figure 7.2 - Flowchart to Illustrate the Material Flow when Passing Through Material Testing and Inspection within SHA Laboratories

## Flow of Materials With Auto-ID

The following list is a general description of the flow of materials enhanced with auto-ID, from when they are first sampled in the field and as they move through OMT's laboratories.

1) Materials are sampled in the field
    - Current - General data/information is manually recorded (hand written) on a Materials Sample Form e.g. date sampled, project sample number, type of material, type of construction.
    - Enhanced - An auto-ID tag is attached to the sample. The tag is activated with a reader or scanner and the general data/information is entered into MMS.
2) Materials are delivered to OMT laboratories
    - Current - The field data/information is logged into the OMT database and the sample is often transcribed with a new ID number for tracking around the laboratory.
    - Enhanced - The material is tagged with an auto-ID tag in the field. Once scanned with a laboratory reader or scanner, material specific information is uploaded to MMS and available for status inquiries.
3) Prepare specimen for testing; Determine tests to be performed
    - Current - Complete relevant information on the general materials sample form, e.g. date of test, completed test date, person in charge of test.
    - Enhanced - Input testing information in the OMT database (if not already automated).
4) Materials are tested
    - Evaluate whether or not material characteristics comply with design criteria.
5) Test results are compiled
    - Current - A recording of the results are transcribed to the general materials sample form.
    - Results are recorded in the OMT database.
6) Prepare sample report
    - Results are available for distribution and/or viewing in the database.

# SHA/OMT: Material Flow Summary – Auto-ID Included

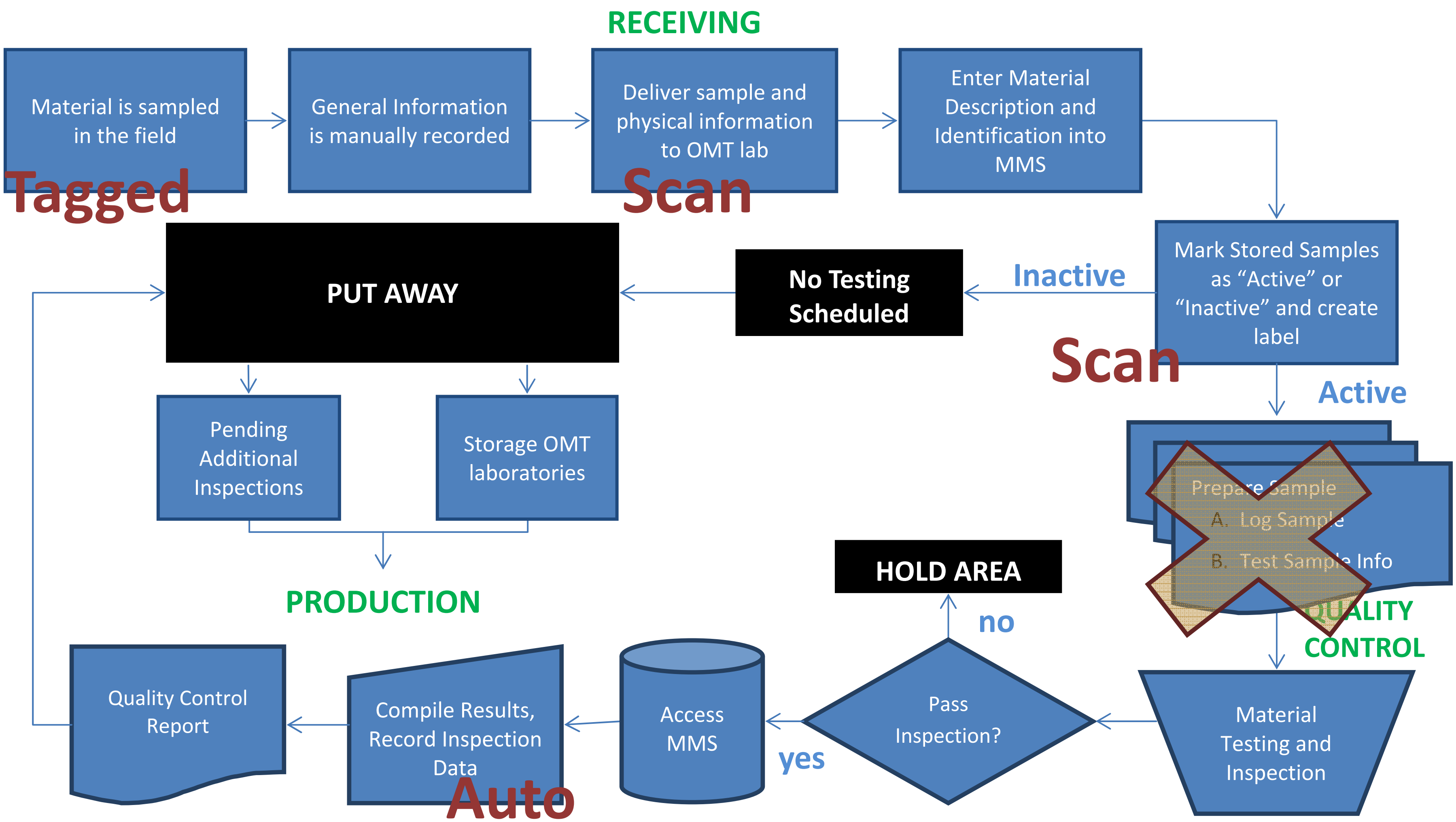



Figure 7.3 - Flowchart to Illustrate the Addition of Auto-ID Technology in the Material Flow Process

## 7.3 OMT Laboratory Material Management Operations Integrated with Auto-ID Technologies

As previously discussed, OMT is responsible for the materials clearance, specification and quality assessment programs for preliminary engineering and active construction projects. The materials undergo both on-site field and laboratory testing or a product certification process. The SHA is interested in implementing AIT to enhance its laboratory material clearance operations, eliminate redundant data entry processes, further streamline business operations, and allow remote real time or near to real time access to test data.

HTML5 servers have a password encryption feature to ensure security. Authorized individuals are able to track and update the sample testing status, quality control inspections and additional information. Real-time or like real-time access, will minimize the large volume of requests for sample status information because Project Engineers, contractors, and suppliers will be able to access it online. AIT is capable of minimizing repetitive data entry of sample and project data (once in the field and again in the laboratory). Once the sample is taken, the unique identifier is attached to the sample in the field and logged into the MMS. The sample is then transferred to the necessary OMT laboratory for testing. Upon arrival, the laboratory technician can use a handheld device to retrieve the sample's production or field testing information. AIT will also provide the laboratory technician with advanced delivery notification which will result in improved laboratory production and laboratory activity scheduling.

Based on the sample type, certain tests and other properties will be assigned once the sample is logged into MMS. This will make it easier for technicians to know the work associated with each sample and prioritize their work load (Dye Management Group, 2008). As the sample undergoes tests, results and additional commentary may be accessed online in real time or near-real time using an HTML5 server. Integrating an automated data capture within OMT laboratories can improve productivity and efficiency. However, before SHA can implement this type of system it must consider (1) the type of unique identifier that will best meet SHA's needs, (2) the type of reading device best suited for field and laboratory personnel, (3) necessary modifications to the current MMS and wireless network, and (4) required software development to allow the device to communicate with the unique identifier.

### 7.3.1 Enhanced Materials Clearance Process

Beyond the utilization of real-time data, AIT can improve the productivity and efficiency of the materials clearance process by:

- Reducing the number of incomplete General Sample Information forms;
- Reducing the high volume of sample status requests from the field;
- Removing the process of sample information re-entries;
- Minimizing the potential of human errors; and
- Providing remote sample visibility.

AIT has the ability to transform workflows inflicted with tedious paperwork, frequent phone calls and challenging coordination into an automated process with accountability and significant time savings.

Table 7.2 illustrates how AIT could enhance the materials clearance process. These time savings are the result of faster processes, the removal of steps, and smoother information flow (Vela Systems, 2009). The following sections will detail how the implementation of AITs could improve the technology divisions within OMT.

**Table 7.2 - Displays the current material clearance processes that will be enhanced using AIT**

| Process | Current Method | Proposed Method |
|---|---|---|
| **Associate general and field data to the sample in MMS before the sample is delivered to the OMT laboratory** | Field personnel generates and fills out a General Information Sample Form | Field personnel will activate a unique identifier to associate information to the unique identifier using the handheld device or computer |
| **Reference field data in the OMT laboratory** | Information from the General Information Sample form is entered into the responsible laboratory's database | Laboratory personnel reads the unique identifier using the handheld device |
| **Assign laboratory number to sample** | Manually generated and assigned to the sample by laboratory personnel | Automatically generated by software once sample is accepted into the laboratory |
| **Review relevant project sample history information** | Refer to physical files or contact responsible laboratories | Query database using the handheld device |
| **Update sample assessment information** | Manually update physical forms | Using the handheld application, field and laboratory personnel will be able to update sample information through the materials clearance process |

### *7.3.1.1 Soils and Aggregate Technology Division*

The Soils and Aggregate Technology Division (SATD) is responsible for the quality control and quality assurance of a large variety of aggregate types used on SHA's active construction projects. The SATD's process begins with a request to the field team after a Source of Supply (SOS) entry is made in MMS. As detailed in the sample request, the field team collects the necessary aggregate samples (i.e. as coarse base, backfill, high friction materials, as well as fine concrete sand, mortar sand and No. 10 dust). After acquiring the sample, the field team member attaches a unique identifier to the sample. Figure 7.4 displays the recommended placement of unique identifiers for commonly used sample containers in the soils and aggregate laboratory. Using a handheld computing device, the field team member records general field data (i.e. sample location, producer, material specification, item number, the contract number, contact information, and tests required for the sample) to MMS via the HTML5 materials management server. Section 7.6.1 summarizes SATD's current materials management process and how AIT can be used to enhance it.

**Figure 7.4 - Commonly used sample containers in the Soils and Aggregate laboratory with attached unique identifiers, as recommended by EPCGlobal (from left to right: bagged sample of fine aggregate and embankment samples, sample testing containers, and coarse aggregate sample).**

After the requested samples are collected and identified, they are delivered to the soils and aggregate laboratory by the project Inspectors for further testing. Once the sample is accepted, the laboratory team can update the sample's status, automatically assign a laboratory number to the sample, and reference data that has been previously recorded in MMS. Based on the sample type and project, the sample will be required to undergo specific tests. After conducting the tests, the results are entered into Geosystem (used to analyze and store the data using the laboratory log number) and auto-populated into MMS to provide visibility to the Project Engineers and eliminate the need for OMT's Soil Test Report. To ensure that the material is in compliance, the sample's results are compared to AASHTO, ASTM, and SHA Standards. If it is found to meet the Standards, the laboratory team member can dispose of the sample and update the status of the sample to 'Completed,' indicating to the Project Engineer that the material has been accepted by the OMT. However, if the sample does not meet the Standards, the status will be updated to 'Not Approved' and the field team will be automatically notified by the database to collect a new field sample for reassessment.

#### *7.3.1.2 Asphalt Technology Division*

The Asphalt Technology Division (ATD) is responsible for ensuring that the liquid asphalt binder, asphalt mix, asphalt emulsion, and asphalt core samples meet all applicable specifications for design, verification, and quality control/assurance in accordance with SHA's standard specifications for Construction and Materials. The ATD's material clearance process begins with the Field Quality Assurance or Project Representative receiving a request for asphalt design verification. As detailed in the request, the Representative collects an asphalt mix, asphalt core, asphalt emulsion, or liquid asphalt sample from the project or plant manufacturer and attaches a unique identifier to it. Figure 7.5 displays the recommended placement of unique identifiers for commonly used sample containers in the asphalt mix laboratory. Using a handheld device, the Representative records data that is accompanied with the sample and/or data acquired from tests conducted in the field (i.e. date sampled, project number, type of material, quantity, contract number, sample location, required tests…etc.) to the MMS via the HTML5 material management server. Section 7.6.2 summarizes ATD's current process and how AIT can be used to enhance it.

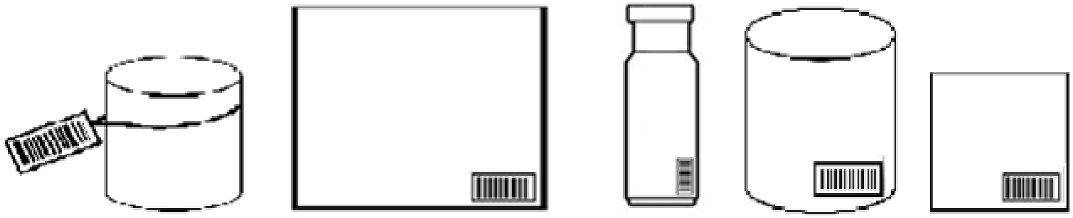



**Figure 7.5 - Above are the commonly used sample containers in the Asphalt laboratories with attached unique identifiers, as recommended by EPCGlobal (from left to right: asphalt core sample with hanging tag, boxed asphalt core, asphalt emulsion, liquid asphalt binder, and hot mix asphalt box sample containers).**

After the samples are collected and identified, the Project Representative directly delivers them to the responsible OMT laboratory, nearest drop-box location, or a second party testing consultant agency. Once the sample is delivered the status can be updated to either verify that it has reached its destination or to notify the courier service for a pickup. Once the sample is accepted by the Asphalt laboratory, the laboratory team can update the sample's status, automatically assign a laboratory number to it, and reference data previously recorded in MMS. Based on the sample type and project it will be required to undergo specific tests. Asphalt core samples are evaluated for thickness and percent density. Asphalt mix samples are evaluated for asphalt content, gradation, and volumetrics. Emulsion samples are evaluated for asphalt content, viscosity and consistency by sieve test. Asphalt binder samples are evaluated for high and low temperature performance characteristics. The use of the AIT will eliminate the need of the Hanover Complex's Intra-Laboratory Test Coordination Form. After conducting the required tests on the samples, the results are entered into MMS to provide visibility to the Project Representative and Contractors. All test results compiled by the ATD are compared to the applicable specification for compliance.

#### *7.3.1.3 Concrete Technology Division*

The Concrete Technology Division (CTD) is responsible for the acceptance and compliance of the cement, concrete, and chemical materials used in active SHA projects. Implementation of AIT can be utilized to improve the efficiency and automate several processes required in each of the respective laboratories.

The Cement Laboratory is responsible for the clearance of cement used in Portland cement concrete, and must determine if it complies with the SHA and ASTM Standard Specifications. Section The Ready Mix field team collects the cement sample from the Production Plants (i.e. cement, slag, fly ash, chemical admixtures, and mortar cubes) and attaches a unique identifier to it. Figure 7.6 displays the recommended placement of unique identifiers for commonly used sample containers in cement laboratory. Using a handheld device, the field team member records data that is accompanied with the sample and/or data acquired from tests conducted in the field (i.e. date sampled, project number, type of material, quantity, contract number, sample location, required tests…etc.) to MMS via the HTML5 material management server. 7.6.3 summarizes the Cement Laboratory's current process and how AIT can be used to enhance it.

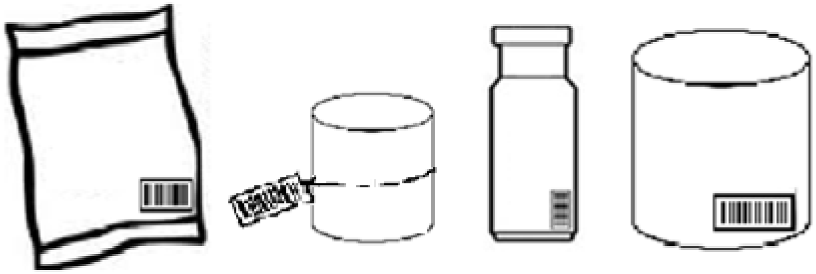


**Figure 7.6 - Above are the commonly used sample containers in the Cement laboratory with attached unique identifiers, as recommended by EPCGlobal (from left to right: cement, slag, and/or fly ash bagged samples, sample cores, chemical admixtures, and plastic jugs for mortar cubes).**

After the samples are collected and identified, the field team delivers them to the Cement Laboratory for further testing. Once the sample is accepted, the laboratory team can update the sample's status, automatically assign a laboratory number to it, and reference data that has been previously recorded in MMS. Based on the sample type and project, the sample will be required to undergo specific tests. Masonry samples will undergo Compression Cube, Autoclaved, and Non-Destructive testing. Cement and grout samples are assessed similarly and must also undergo Vicat testing. Fly Ash samples are sent to the Chemical Laboratory for additional testing (when the sample is accepted by the Chemical Laboratory, the sample's status should be updated accordingly). After conducting the tests on the samples, the results are compared to AASHTO, ASTM, and SHA Standards for compliance and entered into MMS to provide visibility to the field team. If the sample is found to meet the Standards, the laboratory team member can dispose of it and update its status to 'Completed,' indicating to the Project Engineer that the material has been accepted by OMT. However, if the sample does not meet the Standards, the status will be updated to 'Not Approved' and the field team will be automatically notified by MMS to collect a new field sample for reassessment.

The Concrete Laboratory is responsible for the assessment of concrete mixes that may be used to assess the Producer's proposed design or to determine the amount of cement required to produce concrete of a specified strength. The Concrete field team receives a request to collect a sample in the field. After acquiring the sample, the team member attaches a unique identifier to the sample. Figure 7.7 displays the recommended placement of unique identifiers for containers in the concrete laboratory. Using a handheld computing device, the field team member adds general field and test data (i.e. Concrete number, placement date, mix design number, producer, quantity, slump, and air content) to MMS via the HTML5 materials management server. Section 7.6.4 summarizes the Concrete Laboratory's current process and how AIT can be used to enhance it.

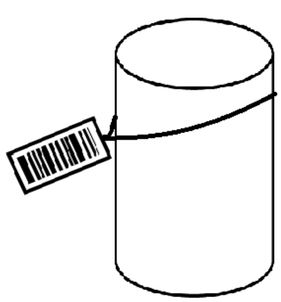


**Figure 7.7 - Concrete cylinder sample containers with unique identifier, as recommended by EPCGlobal**

Before the samples are sent to the specific laboratory, plastic concrete samples (while still wet) are taken and tested for acceptance in the field. The Project Engineer then compares the results to the list of approved mixes for the project. If the mix does not comply with SHA requirements, the database will automatically update the sample status as rejected and concrete cylinders will not be made. If the mix complies, concrete cylinders will be made, undergo an initial curing process at the jobsite, and the Contractor will transport the sample to the Concrete Laboratory; 28 day concrete cylinders are delivered to the nearest SHA drop-box location. Once the sample is accepted the laboratory team can update the sample's status, automatically assign a laboratory number to it, and reference data that has been previously recorded in MMS. Concrete cylinders will undergo a final curing period of 28 days in the moisture room and compression testing. Patchwork cylinders are cured with the project structure and the Contractor delivers samples directly to the Concrete laboratory for testing. These samples are removed from the curing after approximately 24 hours (± 15 minutes).

The laboratory team will receive an alert from their handheld computing device when it's time to remove the concrete sample from the moisture room. Concrete mix samples are removed after 28 days. After conducting the tests on the samples, the strength requirements are compared to the contractual values and the values attained in the field. Results are then entered into MMS to provide visibility to the Project Engineer and Contractors. If the sample meets the strength requirements, the laboratory team member can update the sample's status to 'Completed' and give the Contractors the approval to set the concrete for a minimum of two days and strip the framework as specified in the contract. However, if the sample does not meet the Standards, the sample's status will be updated to 'Not Approved' and the Project Engineer and Contractors will automatically be notified by MMS.

The Chemical Laboratory is responsible for offering a wide range of services and for verifying quality assurance tests on construction materials such as adhesives, structural steel coatings, epoxies and joint seals. The field team receives a request to collect a sample by specified Production Plants. After acquiring the sample, the team member attaches a unique identifier to it. Using a handheld computing device, the field team member enters general data (i.e. sample description, production specifications, quantity, priority status, and requested tests) into MMS via the HTML5 materials management server. Section 7.6.5 summarizes the Chemical Laboratory's current materials management process and how AIT can be used to enhance it.

After material samples are collected and identified, the field team delivers them to the Chemical Laboratory for testing. Once the sample is accepted, the laboratory team can update the sample's status and reference data previously recorded in MMS. The Chemical Laboratory also accepts samples from the Soils and Aggregate, Asphalt, Cement and Structural Materials Laboratories. AIT can eliminate the need of the Chemical Intra-Laboratory Test Coordination Forms. Based on the sample type and project, the sample will be required to undergo specific tests. The laboratory team will also automatically assign a laboratory number, material code (i.e. SSL for Topsoil, GCA for chemical admixtures, CNC for slag, CC1 for Cement Type 1 etc.), and sequence number to it. After conducting the tests on the samples, the results are compared to the AASHTO, ASTM, and SHA Standards for compliance and logged into MMS to provide visibility to those in the field. Samples that meet the required specifications get approval and the status is updated to 'Completed,' indicating to the Project Engineer that the material has been accepted by OMT. A sample that does not meet required specifications does not get approval and the field team is notified by MMS to collect another sample. The new sample is brought to the Chemical Laboratory and the materials clearance process starts over.

#### *7.3.1.4 Structural Materials and Pavement Markings Division*

The OMT maintains a listing of qualified liquid coatings and fusion bonded powder manufactures to apply to metal items intended for use on SHA construction projects as well as galvanized facilities. The Structural Materials and Pavement Markings Division (SMPMD) conducts the quality control and assurance testing procedures to ensure the liquid coatings and fusion bonded powders utilized in the field meets ASTM, AASHTO, and SHA specifications. The materials clearance process begins with structural materials (i.e. fencing, signage, rebar, brick, structural beams, panels etc.) being collected in the field as detailed in the quality control request. The field team collects the material, coating, or adhesive sample from the field or material manufacturer and after acquiring the sample, the field personnel attaches a unique identifier to it. Using a handheld computing device, the field team member enters data that is accompanied with the sample and/or data acquired from tests conducted in the field into MMS via the HTML5 material management server. Section 7.6.6 summarizes the SMPMD's current materials management process and how AIT can be used to enhance it.

After material samples are collected and identified, the field team delivers them to the Structural Materials Laboratory for quality control and assessment. The Laboratory also accepts samples from equipment manufacturers, suppliers, fabricators, and inspectors. Once the sample is accepted, the laboratory team can update the sample's status, automatically assign a laboratory number to it, and reference data previously recorded in MMS. Based on the sample type, the sample will be required to undergo specific tests. Coating samples, such as paint coatings and galvanizing are sent to the Chemical Lab for testing. Adhesive samples, such as epoxy, sealants, and constructive joints undergo tensile yield testing. While structural materials (i.e. rubber, steel poles, rebar, wire mesh, anchor bolts etc…) undergo tensile yield, compressive strength, and bending testing. The sample results are compared to the project's contractual specifications to assess the compliance of the material and entered into MMS, to provide visibility to the parties in the field. If the material does not comply, the database will automatically alert the field team of the issue, and the sample's status will be updated to 'Not Approved.' The Contractors, equipment manufacturers, suppliers, fabricators, and inspectors will be immediately notified of the discrepancy. If the sample meets the contractual specifications, the laboratory team member can update the sample's status to 'Completed' and give the necessary parties approval of the material.

## 7.4 Automatic Identification Technology System Component Recommendations

Integration of an automated identification system into the technology divisions of OMT has the capability of providing MMS with wireless data collection, automatic data processing and remote data storage. Although AIT can be applied in a wide variety of applications, it is impossible to create a single all-purpose AIT system integration strategy. Despite the challenges that come along with AIT integration, it is possible to design an MMS application that can mesh seamlessly with current applications. To guarantee operability the hardware options, equipment, application software development, and communication components must be considered. This ensures that the system is capable of being integrated into the existing materials management database and of transferring data between tags, readers, and the material management software. While discussing the system component recommendations, this section also outlines the requirements of a system that utilizes both barcode and RFID data capture technologies. The SHA has expressed interest in barcode identification systems because the unique identifier can be applied onto any surface type, can withstand signal interferences, is instantly verified, and has low production costs in comparison to RFID unique identifiers. Although barcode identification systems are applicable to each of the technology divisions within OMT, RFID unique identifiers may also be implemented in several laboratories to extend the abilities of the laboratory personnel and to further improve operations beyond the capabilities of barcode data capture technology.

### 7.4.1 Unique Identifier Recommendations

A successful AIT implementation is dependent on the data capture technology used to identify the sample material wirelessly. Unique identifiers should be able to be removed from the sample when necessary and readable when scanned. Due to the large volume of samples coming into OMT laboratories, it would be reasonable for SHA to set up an in-house production operation. However, this option would require a greater initial investment, and also make OMT responsible for acquiring label design software, printing consumables and regulations of print quality. Therefore it is recommended that SHA initially contract with a data capture vendor to generate unique identifiers instead of establishing an in-house production operation. This option is preferred for newly automated businesses because it provides a quicker and easier integration, does not require additional labor, ensures reliable identifiers, and decreases the overall investment costs. The vendor must have the ability to generate general purpose labels and special purpose labels with a special adhesive for use in rugged environments (AMIS, 2013). The majority of the sample containers in OMT laboratories are made from smooth surfaces (aluminum, glass, and plastics), therefore thinly layered adhesives are recommended. However for applications on rough or textured surfaces (i.e. cast iron, checkered plate and precast structural components) thick adhesives are suggested (Rasdorf, et al., 2003). Labels should be printed on paper stock media, bonded with a protective polyester film which is suggested for warehouse and material handling operations and is primarily intended for dry, low impact environments. For application on rough surfaces or harsh environments, plastic media with a polymer coating is recommended. Direct thermal or thermal transfer printing methods are recommended because both methods guarantee sharp quality labels that result in optimum resolution for scanning and are ideal for short life span applications.

#### 7.4.1.1 *Barcode Unique Identifier Recommendations*

Barcode unique identifiers are highly recommended for implementation in all four technology divisions within OMT. Depending on the barcode printing software, a wide range of 1D and 2D barcode symbologies are available to SHA. However Code128 and Code39 linear symbologies are preferred for construction applications because they are readily available by the most basic printing software and are equipped to withstand rugged environments. Code 128 is a continuous symbology with a faster read rate than Code39. It also allows flexibility (full ASCII character set) in developing a coded message and supports interfaces to standard software, such as spreadsheets (Rasdorf, et al., 2003). Although Code128 is a high density symbology that includes a checksum for digit verification and has been implemented in a wide range of applications, Code39 is recommended for implementation in OMT's laboratory because it incorporates a self-checking algorithm for character comparison, reduces the detrimental effects of poor label printing, and provides the same amount of flexibility as the Code128 symbology. Despite the longer read rate, Code39 barcodes are easier and cheaper to produce, do not create a physical space issue, and have been recommended by the Construction Industry Institute for use in construction applications due to their high performance in the manufacturing and automotive industries. Figure 7.8 displays the proposed layout of the general purpose barcode label, using a Code39 symbology. The barcode label indicates the sample's contract number, barcode symbology and decoded identifier underneath the code in cases where the symbology is damaged or unreadable.


**Figure 7.8 - Proposed layout of the general purpose barcode label**

An XML format is recommended to encode the barcode because it provides a generic method of representing information and can be easily implemented using the standard XML schema. This format provides the advantage of being a standardized convention that is easy to understand and learn in comparison to other text formats. The barcode will not be capable of storing data or documentation on the tag; however using the XML format, the unique identifier encoded in the barcode will be used to access the data from MMS remotely, once scanned by the handheld device.

### *7.4.1.2 RFID Unique Identifier Recommendations*

Although barcode automated systems can be seamlessly implemented into all OMT laboratories, several laboratories could benefit from the advantages provided by RFID technology such as contactless identification over a wide range and simultaneous interrogation of multiple samples and durability. Implementation of RFID systems are recommended for laboratories that have a large amount of sample materials, involve various parties internally and externally, require dynamic processing of material assessment and verification, and exhibit limited visibility of the samples. RFID labels are available in a wide variety of sizes, shapes, and mediums designed for specific applications. Selection is dependent on the type of items being tagged. For instance, if the tag must be mounted on a metallic, glass, or item containing liquids, it must be customized for direct application or reapplied as a hanging tag. Also, the various types of materials distributed throughout OMT's laboratories pose the challenge of finding a single type of RFID tag that meets the demands from each laboratory. For instance, the Asphalt Laboratory currently stores emulsion samples in metallic containers, while the concrete specimens in the Concrete Laboratory are handled with written identification codes placed on the cylinder itself. Despite the options to overcome signal interference, RFID is rarely the recommended solution for tagging such items because they do not work well and are not cost effective. However, the Soils and Aggregate Technology Division (SATD) and Concrete Laboratories can benefit from this technology because both have a large inflow of samples. Passive GEN2 96-bit Ultra-High Frequency (902 – 928 MHz) RFID inlay labels are recommended in the SATD and Concrete Laboratories, to optimize the sample's visibility and improve the Laboratories organization. To ensure each label is compliant with EPCGlobal Standard specifications, they must be generated and encoded using GS1 approved software. Figure 7.9 displays a proposed passive GEN2 96-bit UHF inlay label utilizing the same format as the barcode label to allow interoperability of the two unique identifiers.

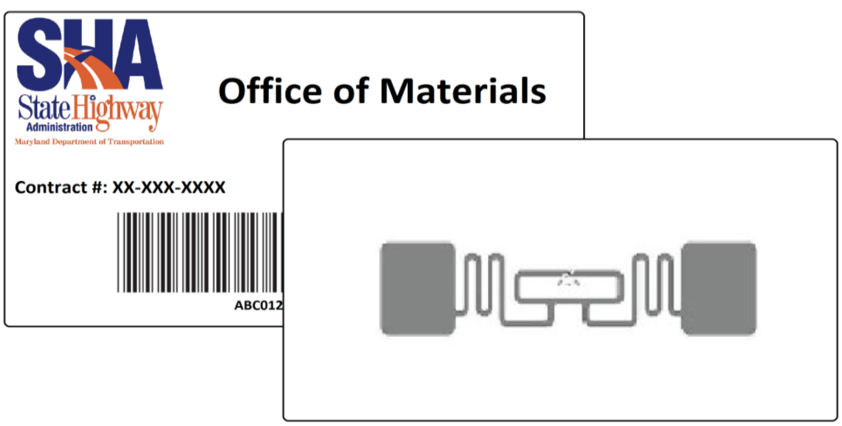



**Figure 7.9 - Proposed passive GEN2 96-bit UHF RFID inlay label utilizing the same format as the barcode label.**

The use of the barcode label allows it to still be read in the case where the radio frequency signals are blocked or cancelled out. Gen2 UHF RFID tags allows the storage of more redundancies to withstand metallic or liquid interferences, eliminates duplicate reads while reading multiple tags, and can be read up to 32 feet. These features extend the capabilities of a barcode data capture system, eliminate the line-of-sight requirements, and increase the automation of the entire identification system.

### 7.4.2 Automatic Identification Technology Reading Device Recommendations

For integration into the materials clearance process a combination of handheld, mobile, and tablet devices from regional vendors (vendors may be able to supply unique identifiers, reading devices, and software) are recommended. Devices must have the capability of decoding both barcode and RFID data capture technologies for implementation in the OMT laboratories. In each of the four OMT technology divisions, one to two handheld devices are recommended to transmit data back to MMS and supply pertinent sample related information to Contractors, Quality Inspectors, and Project Engineers. Handheld readers also allow the laboratory personnel to take the reader to the specific sample and provide a wide range of features such as integrated power sources, WLAN connectivity, and user friendly displays (as shown in Figure 7.10).

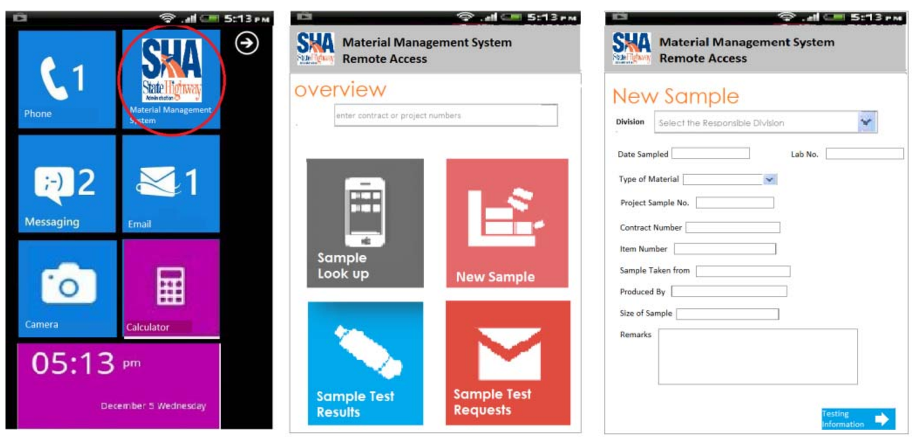



**Figure 7.10 - Proposed handheld or mobile device interface of material management application**
**The third screen displays a proposed interface for logging a new sample in MMS.**

The Motorola MC3100 is recommended because it has 1D, 2D and RFID reading capabilities, wireless and Bluetooth connectivity, imaging technology, Microsoft Windows operating system, and is designed to operate in a rugged environment. For use in the field, ruggedly designed mobile devices and/or tablets are recommended to allow easier communications with laboratory personnel and device-to-device connectivity. Figure 7.11 exhibits the interface of a mobile or tablet device used to either search (via contract or project number) or scan unique identifiers. The application interface requires a button or activator to trigger the integrated scanning capability. Devices recommended for this integration must be equipped with a touch screen interface (consider semi-transparent and flexible dust covers for the screens), integral barcode imager, wireless data communications to transmit XML files to the HTML5


Figure 7.11 - Proposed interface for smartphones & tablets to either look up the unique identifier

materials management server, and must operate using a Microsoft Windows operating system. The devices must also be equipped with rechargeable batteries, battery charger and tethered stylus.

The anticipated application of AIT is not limited to harsh construction, large open warehouses, production facilities (with or without an established wireless infrastructure), or laboratory environments. During the lifespan of the device, it is expected to be dropped multiple times; therefore the selected reading devices must be industrially hardened, designed, fabricated, and tested to ensure reliable, continuous performance in all working environments (AMIS, 2013). Drop tests are conducted on all sides of the device to confirm consistent operations regardless of how the device falls. Smart handheld devices are also preferred because they are equipped with software development kits (SDK) that can be used with standard application development tools (Basic, .NET, and C/C++ compliers) to produce executable coding for the materials management application. The majority of handheld devices have slightly smaller read ranges compared to fixed readers. Although handheld readers are applicable to OMT's four technology divisions, RFID fixed readers are applicable to the SATD and Concrete Laboratory. This reader type is recommended in these areas to further automate their materials clearance and effectively handle the large volume of materials coming in and out. The proposed placement of this system in SATD is shown in Figure 7.12.

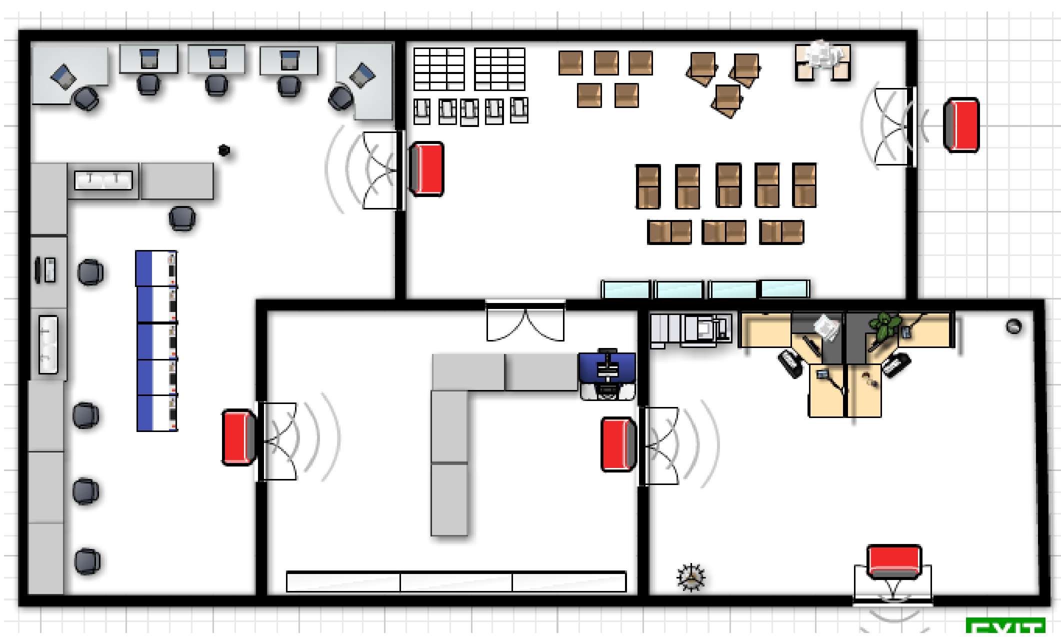


Figure 7.12 - Proposed fixed reader placement in the Soils and Aggregate Technology Division.

This placement plan proposes that the fixed readers be installed in the entry and exit points of each laboratory to gather consistent readings. This allows the samples' status to be automatically updated as the sample moves through the different testing phases providing field personnel with near-real time visibility. At least one handheld device would be necessary to provide flexibility. Similarly Figure 7.13 displays the proposed placement in the Concrete Laboratory. The figure proposes placement at the entry and exit points of the laboratory and the moisture room. Should SHA decide to utilize RFID in these areas a wireless fixed reader with an enclosure is recommended for an easier and cleaner installation.

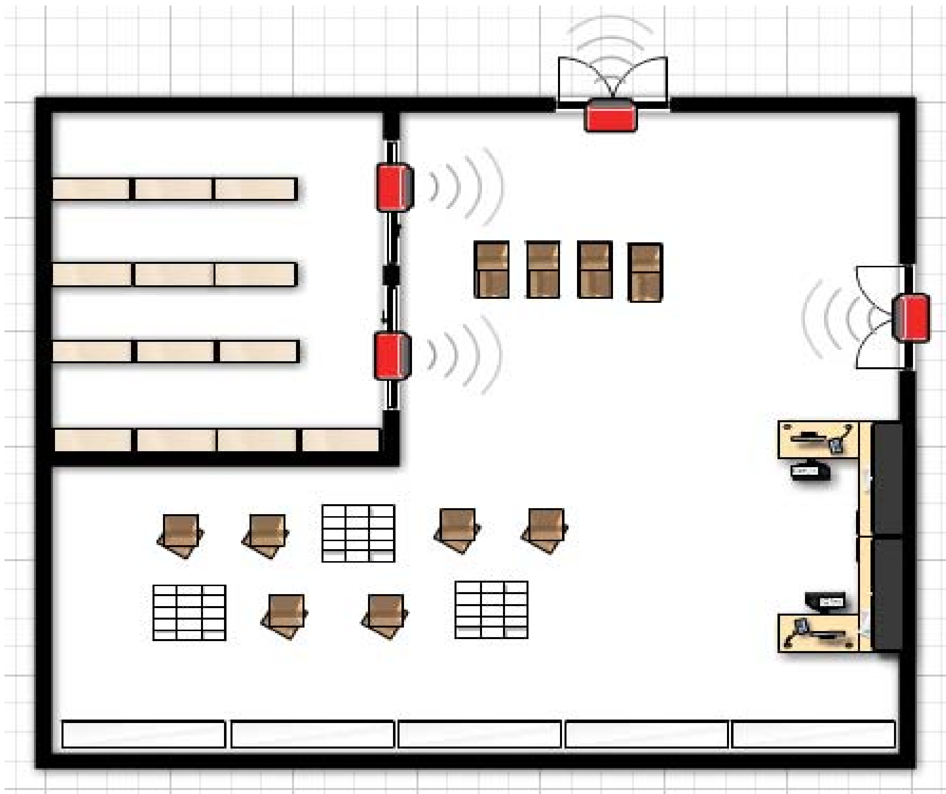


**Figure 7.13 - Proposed fixed reader placement in the Concrete laboratory.**

The recommended fixed readers for the SATD and Concrete Laboratories are the SkyeReader SR70 and Motorola FX7400. Both models support a Microsoft Windows operating system, however, they do not have wireless connection options such as the Unitech RS700 and Intermec IF61 fixed readers.

Table 7.3 displays the auto-ID vendors in the metropolitan area. A much more detailed list of vendors across the country that may be of use to the SHA is in Appendix A.2. That list is composed of local, national, and global auto-ID vendors that market in the Maryland area. The list below is limited to vendors headquartered in the Washington DC metropolitan area and auto-ID providers to the Maryland area. This list is presented to illustrate how services differ by company.

**Table 7.3 - Source of Supply List of Auto-ID Vendors in the Washington DC Area**

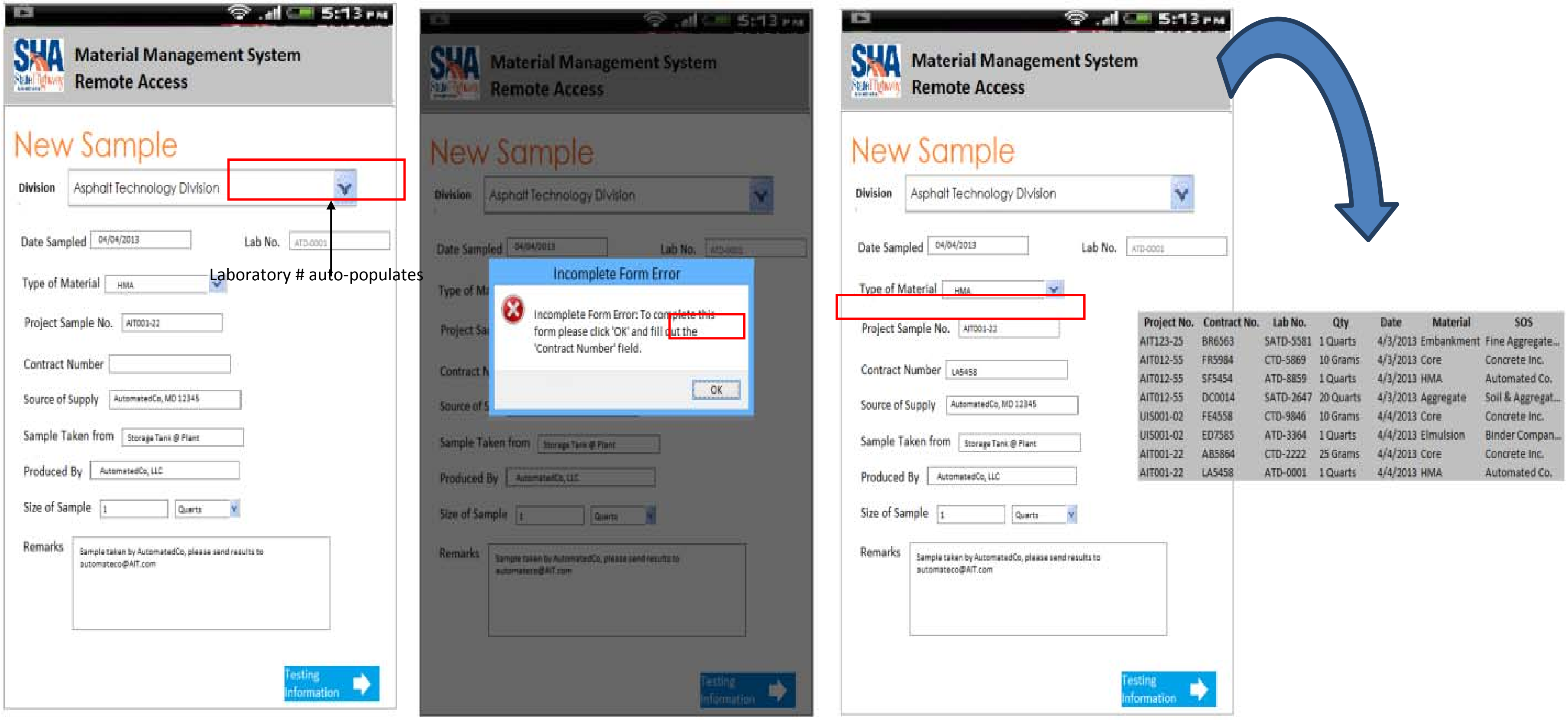
| Source of Supply (SOS) Lists | | | Business/Strategic Consulting | Distribution of RFID Hardware/ Software | Finished RFID Labels | Labeling Making Equipment Materials/Services | Middleware | Networking Hardware/Software | Readers/Interrogators (fixed) | Readers/Interrogators (mobile) | RFID Chips | RFID Manufacturing Applications | RFID Enabled Supply Chain Applications | RFID Enabled Warehouse Management Applications | RFID Enabled Enterprise Applications (other) | RFID Label Printers/Applicators | Systems Integration | Technology Consulting | Wireless Sensors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Company** | **Headquarters City** | **State** | | | | | | | | | | | | | | | | | |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| **Gentag, Inc.** | Washington | DC | | X | X | | X | | | X | | | X | | | | | | X |
| **McKenna Long & Aldridge LLP** | Washington | DC | X | | | | | | | | | | | | | | | X | |
| **Avalon Integration** | Baltimore | MD | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| **IntelliTrack Inc.** | Hunt Valley | MD | | | | | | | | | | X | X | X | X | | X | X | |
| **Multispectral Solutions, Inc.** | Germantown | MD | | | | | | | X | X | X | X | X | X | X | | X | | |
| **PEAK Technologies** | Columbia | MD | X | X | X | | X | | | | | | | | | | X | X | |
| **RFID –Pros** | Owings Mills | MD | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| **RFID Global Solution** | Mount Airy | MD | X | X | | | X | | | | | X | X | X | X | | X | X | X |
| **RFID Revolution** | Silver Spring | MD | X | | | | | | | | | | | | | | | | |
| **BearingPoint** | McLean | VA | X | | | | X | | | | | X | X | X | X | | X | X | |
| **Bent Systems** | Fairfax | VA | X | X | | | X | | | | | X | X | X | X | | X | X | |
| **CODE Plus, Inc.** | Fairfax | VA | | | | | X | | | | | X | X | X | X | | X | X | |
| **Ekahau, Inc.** | Reston | VA | | | | | | | | | | X | X | X | X | | | | X |
| **epcSolutions** | Great Falls | VA | | | | | X | | | | | | | | X | | | | |

### 7.4.3 Software Development and Database Modifications

Without the proper software the reading device will be useless. As a result, it is recommended that the vendor selected by SHA is a total solutions provider with the ability to offer both hardware options and software solutions. The vendor must be able to develop a fully customizable materials management server application that interfaces with MMS and enables the use of AIT for front-end processes (i.e. data acquisition, data collection, wireless communication, and sample material visibility). The sever must be designed to address the challenges with MMS and gain visibility over sample materials for improved decision making, operational efficiency, and sample control. The designed server application should also be capable of initiating password protection at the device level and will be presented to the user as a sign-in screen on the device to prevent an unauthorized user from accessing specific data on MMS via the materials management server. The software developed for OMT to collect data and track sample material should be able to:

- ✓ Read either RFID or barcode identifiers or both;
- ✓ Integrate with the existing MMS;
- ✓ Offer an easy-to-use and intuitive graphical user interface (GUI);
- ✓ Create new sample records and update MMS;
- ✓ Record testing data and interface with the existing test programs;
- ✓ Display active requests based on interface log-in information;
- ✓ View productions and manufacture reports;
- ✓ Import and export with Microsoft Excel;
- ✓ Generate material quality reports;
- ✓ Search or query past and active samples;
- ✓ Push-to-talk;
- ✓ Automatically log-out idle users; and
- ✓ Auto-alert users of incorrectly filled forms.

These features ensure that the system will be easily integrated in the existing MMS, minimize the necessary training time due to easy-to-use and intuitive GUIs, and increase productivity by allowing personnel to use their existing wireless data collection devices to communicate directly with one another at the push of a button. For a smooth integration into MMS it is recommended that SHA contract with a vendor to design an HTML5 server application and data request processer, to allow simultaneous access (level of access will be determined by log-in information) to sample information without disturbing the existing network firewall. Utilizing a request processor, the software will be designed to “listen” for requests from the reading device. Once a request is heard, the processor sets up an HTTP connection to the HTML5 materials management server. Once the processor receives the requested data, it connects to MMS and generates a query according to the information encoded by the barcode and RFID unique identifiers. After it queries the database, the reading device receives the desired data from MMS and generates an XML response file by auto-populating the data in an output file and sends this response to the client (Sirkanungo, 2009). The server, or online database, can be updated by all authorized users and necessary parties will be notified immediately regarding any non-compliant materials. Figure 7.14 is an illustration of the proposed application interface when a user is logging a new sample into MMS using a handheld device. The laboratory number field is greyed out because it auto-populates once the sample is accepted by the responsible laboratory. If the form is not complete, field personnel will receive an alert from the handheld device detailing which field was not filled out properly. The information entered on the form will be auto-populated in the MMS Oracle database. This capability ensures that laboratory personnel will have all the necessary information from field personnel to complete their tests in a timely manner. In the case where the field team does not have all the information at hand to complete the form, the sample's status will not be updated but saved to allow the field team to add the information at a later time. Once the form is properly filled out, the sample can continue through the materials management process.




| Project No. | Contract No. | Lab No. | Qty | Date | Material | SOS |
|---|---|---|---|---|---|---|
| AIT123-25 | BR6563 | SATD-5581 | 1 Quarts | 4/3/2013 | Embankment | Fine Aggregate... |
| AIT012-55 | FR5984 | CTD-5869 | 10 Grams | 4/3/2013 | Core | Concrete Inc. |
| AIT012-55 | SF5454 | ATD-8859 | 1 Quarts | 4/3/2013 | HMA | Automated Co. |
| AIT012-55 | DC0014 | SATD-2647 | 20 Quarts | 4/3/2013 | Aggregate | Soil & Aggregat... |
| UIS001-02 | FE4558 | CTD-9846 | 10 Grams | 4/4/2013 | Core | Concrete Inc. |
| UIS001-02 | ED7585 | ATD-3364 | 1 Quarts | 4/4/2013 | Elmulsion | Binder Compan... |
| AIT001-22 | AB5864 | CTD-2222 | 25 Grams | 4/4/2013 | Core | Concrete Inc. |
| AIT001-22 | LA5458 | ATD-0001 | 1 Quarts | 4/4/2013 | HMA | Automated Co. |

**Figure 7.14 - Proposed application interface for handheld, mobile or tablet device**

Although the server application will be designed to communicate with MMS, integration also requires modifications to the existing materials management database so that MMS can communicate with the developed server. Table 7.4 displays the requirements for the database, server, and handheld software to ensure a smooth AIT implementation process. The proposed AIT may need to interface with the Geosystem, Humboldt Triaxial Data Acquisition, and existing Pavement Management systems identified for potential future integrations with barcode or RFID technology. Geosystem is a unidirectional system used to calculate and classify raw data, while maintaining database by contract number. This system is typically used on preliminary engineering and active construction projects. The Humboldt Triaxial Data Acquisition is also a unidirectional system used to record and calculate raw data, and provide final analysis of Triaxial and Consolidation testing for preliminary and active construction projects.

**Table 7.4 - Requirements of the database, server, and handheld software to ensure a smooth AIT implementation process**

| Requirement | Descriptions | Classification |
|---|---|---|
| **Access** | Reading device must be able to remotely access the MMS or material management server and manually record test results on materials. | *Database Modification and Server Design* |
| | Authorized field and laboratory personnel should be able to access specific project information recorded on the database via the handheld or mobile device to view the status and results of testing. | *Database Modification, Software Development and Server Design* |
| **Security** | Access should be restricted based on the rights provided to the individual user. | *Software Development and Server Design* |
| **Notification System** | Email functionality to allow notifications to be sent via e-mail (i.e. if a sample is rejected in the laboratory, the field team will need to be contacted instantly to collect a resample). | *Software Development and Server Design* |
| **Accurate Recordings** | Provide warnings for missing fields and error messages in the sample's general information form (i.e. if the field team member accidently does not record the sample's contract number, the system will alert the user with a pop-up indicating the field was not filled out) | *Software Development* |
| **Automatic Assessment** | Provide warnings for non-compliant test results (i.e. if the lab technician inserts a test result that is not compliant with AASHTO standards, the system will alert the user with a pop-up indicating the sample is non-compliant). | *Software Development* |
| **Test Assignment** | Capability to associate required test forms for specific sample and present the available forms in a selectable menu (i.e. when a soil sample comes through the OMT laboratory, once the label/tag is scanned the available forms should be "General Specifications", "Direct Residual Shear", "Consolidation Test", "Grain Size Analysis", and "Atterberg Limits Test" in a selectable or drop-down menu format). | *Software Development* |
| **Data Batch Capability** | Capability to process data batches from handheld devices (i.e. a user may conduct several tests on multiple samples using the handheld or mobile device. Instead of waiting for each result to be updated to the server, test results can be batched and sent the server once the user is complete). | *Database Modification, Software Development and Server Design* |

### 7.4.4 Wireless Infrastructure Recommendations

Wireless networks are essential to the enhanced materials clearance process because it provides both field and laboratory personnel with the necessary data and tools to improve their productivity and expand their capabilities. For this AIT integration it is recommended that SHA contracts with a contractor or complete solutions vendor to design an Institute of Electrical and Electronics Engineers (IEEE) Standard 802.11 WLAN (Wi-Fi) to support multiple wireless users simultaneously to store, process, and transmit data from MMS to the computing device. Although wireless capabilities are currently available within each of the OMT technology divisions, it is recommended that the vendor also supplies a Radio Frequency Technician to conduct a complete site survey of OMT laboratory facilities and assess whether the existing wireless coverage can provide the recommended data rate and support the automated sample identification system. The Technician will also assess the hardwired connections of OMT's existing access points, hubs, switches, and routers. Proper site surveys provide a full understanding of the radio waves within a facility before installing any wireless devices. Integrations that do not utilize a site survey typically exhibit interruption in connectivity, dead spots, lack of communications between reading devices, and redundancies (Honeywell, 2012). Based on the site survey, the vendor can begin to install access points and antennas to improve the wireless signals prorogated within the OMT facility. During the installation phase, access points and antennas are mounted, enclosures are installed (on a case-by-case basis), connections are established (antennas to access points, LAN to access points, and power supply to access points) and coverage is verified (Barcoding Inc., 2011).

Although Wi-Fi is a suitable option for the OMT facility, construction sites and production facilities typically use cellular network hot spots or Bluetooth technology. Therefore, it is recommended that field personnel utilize mobile or tablet devices that are connected to a cellular network or have the batch processing capability. Batch processing is recommended to allow personnel to collect data via handheld devices that are not physically connected to LANs or through a wireless connection. The collected data is stored in the device's memory until the user automatically connects to the nearest verified WLAN and synchronizes the device to the server or directly connects the device via USB or Ethernet connections. The disadvantages of this type of data processing are (Honeywell, 2012):

- Time must be allotted during the beginning and end of the field personnel's shift to download and synchronize data onto the reading device;
- Synching and data processing issues may occur during the synchronization process; and
- If the reading device is damaged for any reason, data cannot be recovered.

In cases where the OMT requires real-time processing in the field, to enable instantaneous movement of samples from the point of capture to the OMT divisions, wireless networks are recommended to access the server and populate the database in real-time.

## 7.5 Initial Impacts of Barcode/RFID System Implementation

Implementation of AIT provides OMT with an automated approach to identifying materials, which will improve the accuracy and efficiency of daily operations. The people who will be immediately impacted by this implementation include SHA field operators and personnel at the OMT laboratories.

**SHA Field Personnel**

In order to ensure the validity of field samples sampling is typically done under the oversight of an SHA employee. In its current form material field samples are matched with material sample forms, such as the ones listed in Appendix A.3. With the AIT implementation these forms are no longer necessary. Instead, a pre-dumb unique auto-ID tag would be attached to the material sample in the field. By using an application on a device (such as a smartphone or reader), SHA personnel would activate the tag and upload the data to a secure webpage that talks to SHA's Materials Management System.

**SHA Lab Personnel**

With the addition of the auto-ID tag to the field sample, samples will no longer be accompanied with the material sample forms. Once the material arrives in the lab, SHA employees will no longer need to manually enter the field information into the database, nor would it be necessary to apply a new identification number. Personnel in SHA laboratories only need to scan the sample to access all the field information. Furthermore, upon the completion of the Materials Management System Project, it is expected that the output of laboratory test data will automatically be integrated into MMS (Dye Management Group, 2008); illustrated in Figure 7.1. With this data accessible in MMS, it can easily be linked with the sample identification number. Although the data will automatically be uploaded, users will be able to generate reports and testing data on specific samples when necessary.

### 7.5.1 Costs/Return on Investment

The cost of a fully functional auto-ID system is dependent on the application, the size of the installation, the type of system and additional related factors. The largest cost of any auto-ID system is incurred by the initial implementation. Software development and integration typically consume a large portion of the implementation costs. In order to get auto-ID hardware to work with enterprise management systems, custom wireless network infrastructure is required. It is difficult to assess the costs of individual auto-ID systems and is recommended that SHA get an estimate from individual contractors in order to have a more accurate valuation. The following section outlines the costs of the components in RFID and Barcode systems. Cost estimation includes the initial costs and some expected long term and occasional maintenance costs.

**RFID Costs**

Because there are so many variables involved in the sale price of RFID tags and readers, prices are rarely quoted per unit for system implementation. The majority of the costs vary with the volume of tags that are desired (Indrajaya, 2010). On average, a passive RFID silicon-based 96-bit EPC inlay tag (chip and antenna mounted on a substrate) costs from 7 to 15 U.S. cents. However, as RFID technology becomes a more popular, the tags will become cheaper (RFID Journal, 2012).

There is a wide variation in costs of an RFID reader, depending on the type of reader that is needed. UHF readers generally cost from $500 to $2000 (Indrajaya, 2010). As with RFID tags, the cost of a RFID readers is also decreasing as additional companies adopt RFID systems. A low-frequency reader model (a circuit board that can be put into another device) can be under $100, while a fully functional standalone reader can be $750 (RFID Journal, 2012).

Along with the purchase of the RFID tags and readers, the installation and power source also contributes to the cost of the system. Additionally, companies might need to purchase middleware to filter RFID data readings from tags. The Enterprise Application Software (EAS) that is currently in place will need to be upgraded to be compatible with the innovative RFID technology, which would require temporary employment or hiring a systems integrator. Networks within the laboratories may also need to be upgraded for compatibility reasons. In short, the application and environment of the RFID system significantly influence the cost of the system. It is suggested that businesses start with a small RFID project for testing because expansion of applications is always possible. At a total cost of $25,000 it is typical for RFID system implementers to provide some kind of express ROI assessment. This cost includes kicking off the project with one or two readers, tags, installation, and support (Inc. Staff, 2010).

**Barcode Costs**

As with an RFID system, the cost of a barcode system is highly dependent on the size of the project. Barcodes are a less expensive option when compared to RFID. Barcode labels can either be pre-printed or a barcode printer can be purchased so that they can be printed in-hosue. As with RFID, the price of barcode labels decreases as the number of barcodes purchased increases (Table 7.5).

**Table 7.5 - Costs of Barcode Labels (Crew-Noble, 2011)**

| Number of Labels | Costs of Regular/Pre-printed Labels |
|---|---|
| 2,000 minimum | 5.0 cents |
| 10,000 | 4.5 |
| 20,000 | 4.0 |
| 30,000 | 3.6 |
| 40,000 | 3.3 |
| 50,000 + | 2.9 |

Barcode readers can vary in costs from a couple hundred dollars to a thousand dollars; ranging from the most basic barcode reader to readers with superior options, e.g. longer read distances, programmable features, ruggedness, etc. Table 7.6 illustrates typical costs associated with various types of barcode readers. The readers are described in greater detail in section 3.3.2.

**Table 7.6 - Costs of Barcode Readers (Crew-Noble, 2011)**

| | | | |
|---|---|---|---|
|  | **Laser Gun** | Laser gun-type bar code reader. Attaches to computer via USB cable or as keyboard wedge (choose one.) Reads labels up to 10" away.<br><br>Other models are available which can read from greater distances and/or are more rugged. | **$199**<br><br>(Other models are $299 and up) |
|  | **2D Digital Barcode Scanner** | Two-dimensional bar code scanner. Reads 2D bar codes such as PDF417, MaxiCode, and more, as well as standard 1D bar codes (such as UPC/EAN, Code 39, Standard 2 of 5, and more.) Can be used with any PC running Windows 7, Vista, XP, or 2000. USB interface only; includes USB cable. | **$ 599** |
|  | **Handheld Reader with Integrated Scanner** | Handheld bar code reader with built-in laser scanner.<br><br>Connects to computer via USB, keyboard wedge, or serial interface (choose one.)<br><br>Programmable. Reads labels up to 15" away. | **$699 - $799** |

Due to the required customized components of individual projects, it is difficult to develop a precise cost estimate for SHA. Nonetheless, a barcode system is composed of critical components that are necessary regardless of the project's uniqueness. Table 7.7 illustrates the approximate costs of typical barcode implementation (Patel, 2005).

**Table 7.7 - Implementation costs of barcode technologies**

| **Barcode Costs** | **(United States)** |
|---|---|
| Barcode Printer | $1,400 |
| 2 Keyboards Wedge Scanners | $500 |
| 3 PDAs | $3,300 |
| Consumables<br>(Labels & Resin Ribbons) | $4,400 |
| Software Development | $2,700 |
| Integration with back Office | $2,700 |
| **Total Investment** | **$15000** |

The estimated recurring costs are attributed to a percentage of the consumables and the ongoing integration with the back office.

**Table 7.8 - Recurring costs of barcode technologies**

| **Barcode Costs** | | **(United States)** |
|---|---|---|
| Consumables | 25% of Original Cost | $1,000 |
| Integration with back office | 25% of Original Cost | $700 |
| **Total Recurring Costs** | | **$1,700** |

**Return on Investment**

A breakdown of the costs of implementation, recurring costs, and a comparison of old work vs. new work is a useful analysis to assess the return on investment (ROI). In the majority of cases, the ROI of an auto-ID system depends on the amount of mobile workers you have, the hardware you purchase, the software used, and the services you need (Barcoding inc, 2011). Specific to SHA, the greatest benefit of AIT is the induced efficiency to daily operations. An auto-ID system increases SHA's organization, while decreasing labor hours by eliminating problems of illegible handwriting, blank or missing forms, and eliminating manual entry of data. With an auto-ID system in place, these saved hours will accumulate and will ostensibly generate a large ROI.

In material tracking studies with objectives similar to SHA, implementation of barcode technology reported results in a time savings of 50% and 80% for operational tasks. These tasks include the manual update of status upon receiving materials and manual entry of information into data reports. These time savings were credited to the 20% improvement of work productivity (Vela Systems, 2009).

In an intricate case analysis by the Department of Defense (DoD), best and worst case scenarios were examined for ROI assessments of RFID implementation. In the worst case scenario, the DoD would break even in 3 years, and then save another $60-$70 million dollars only 2 years later. In the best case scenario the DoD would break even almost immediately upon installation (DOD, 2006).

**Training/Learning Curves**

Learning to use handheld readers, scanners, or smartphone applications requires little training. The interface on these systems can be designed to be no different than webpages or basic online forms and the hardware itself is mostly intuitive.

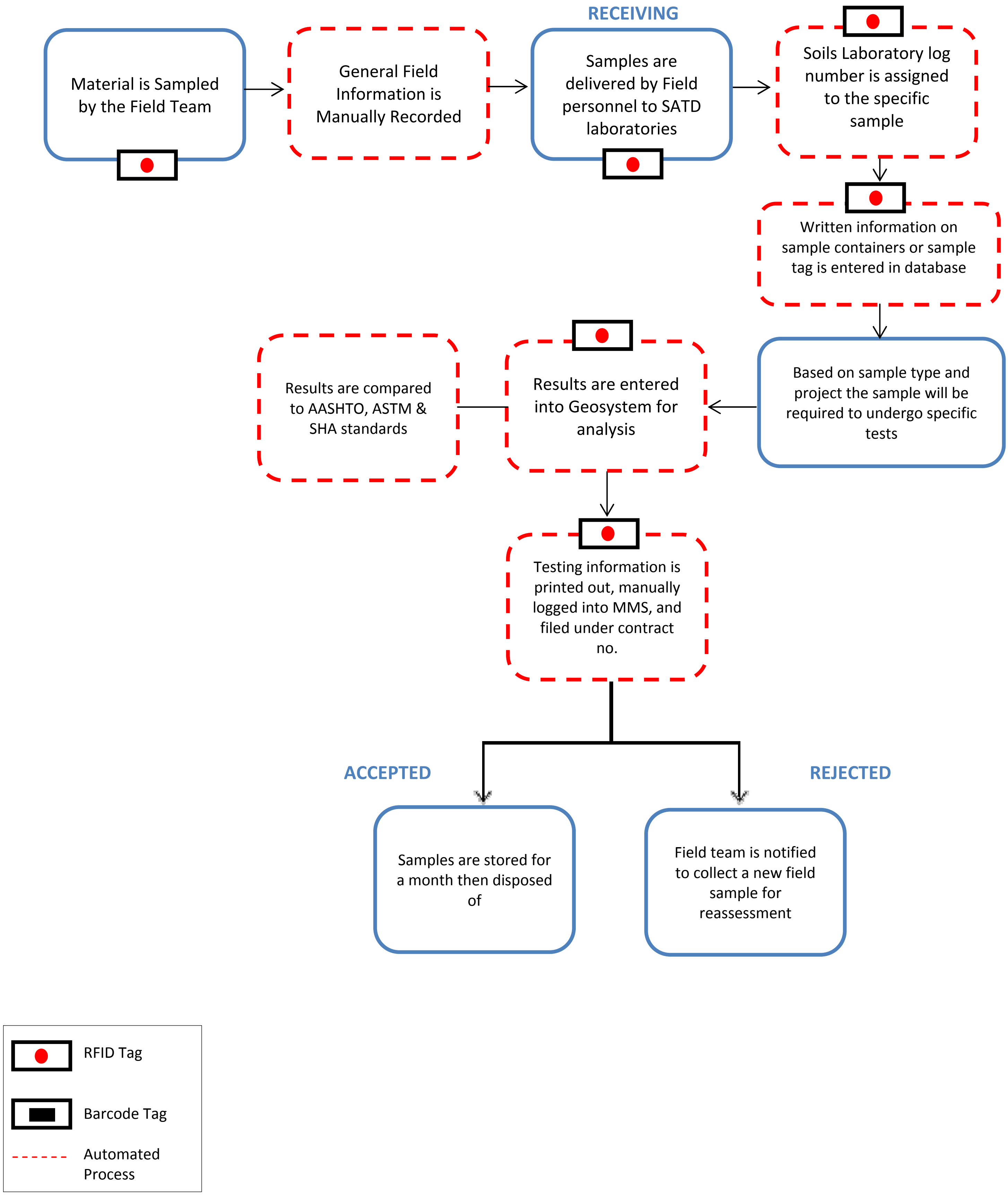
### 7.5.2 Impacts on Contractors

In many cases, there will be no impact on contractors as the majority of samples in the field are taken with SHA personnel present. However, through the expansion of the auto-ID system implementation, there may be situations where a contractor is expected to have the same role as SHA field personnel; e.g. if there are no SHA personnel on site. In those cases, the contractor would attach the auto-ID tag, activate the pre-dumb tag, and would be responsible for the field information. If a smartphone is used as the reader, then it could be validated that the specimen was actually taken on-site by the GPS coordinates from when the tag was activated, as illustrated in Section 3.4.

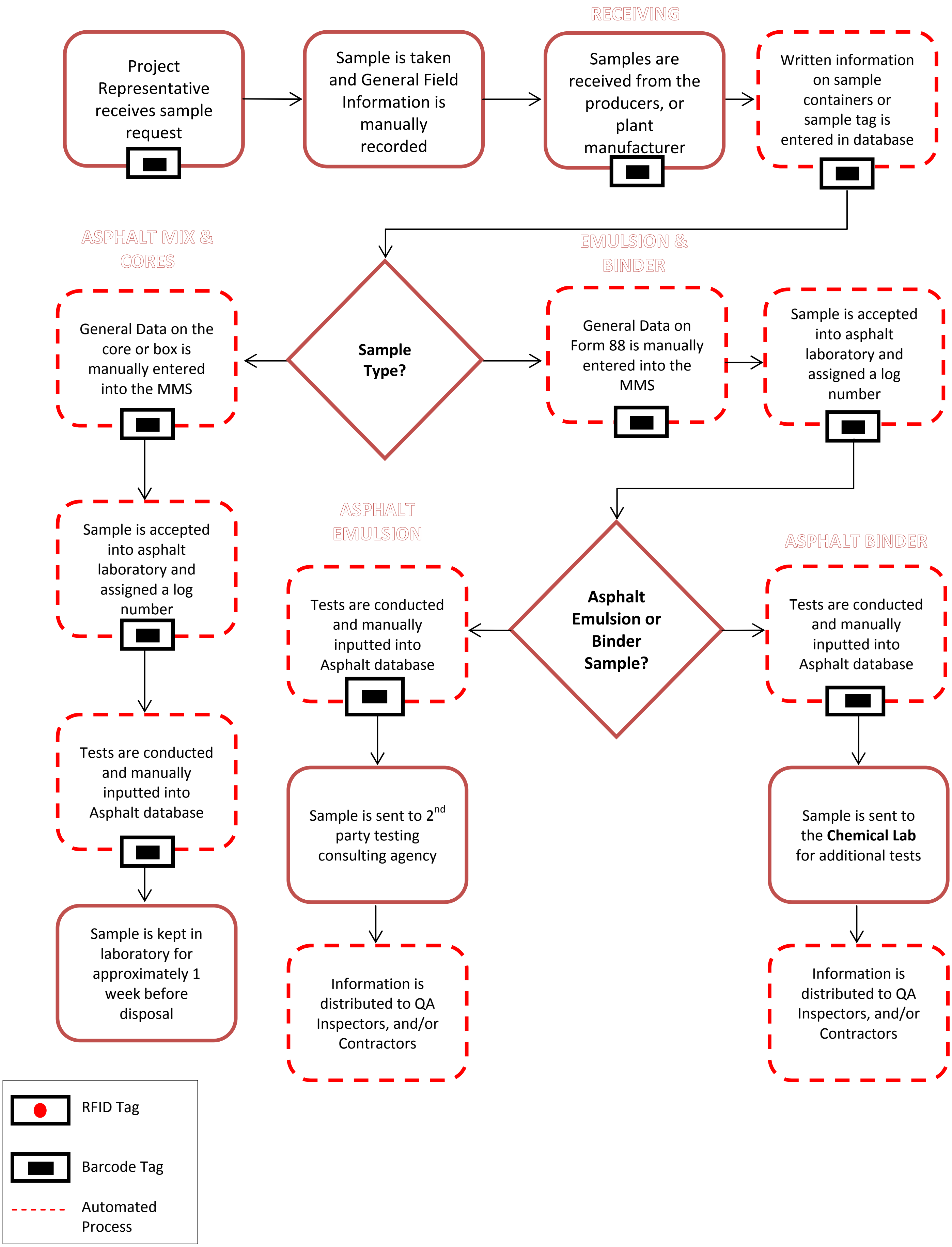
Eventually, contractors would need to have auto-ID tags and readers available. Currently SHA is in charge of distributing the Material clearance forms. Similar to the forms, SHA would also be responsible for distributing the auto-ID tags to the contractors. In the case where SHA personnel are not involved in the initiating stages of the materials management process, SHA must contractually specify that the contractor is responsible for tagging the sample material or it will not be accepted into OMT facilities. It would also be necessary for these contractors to have RFID readers to activate the tags and upload the field information to MMS.

## 7.6 Enhanced Laboratory Procedures

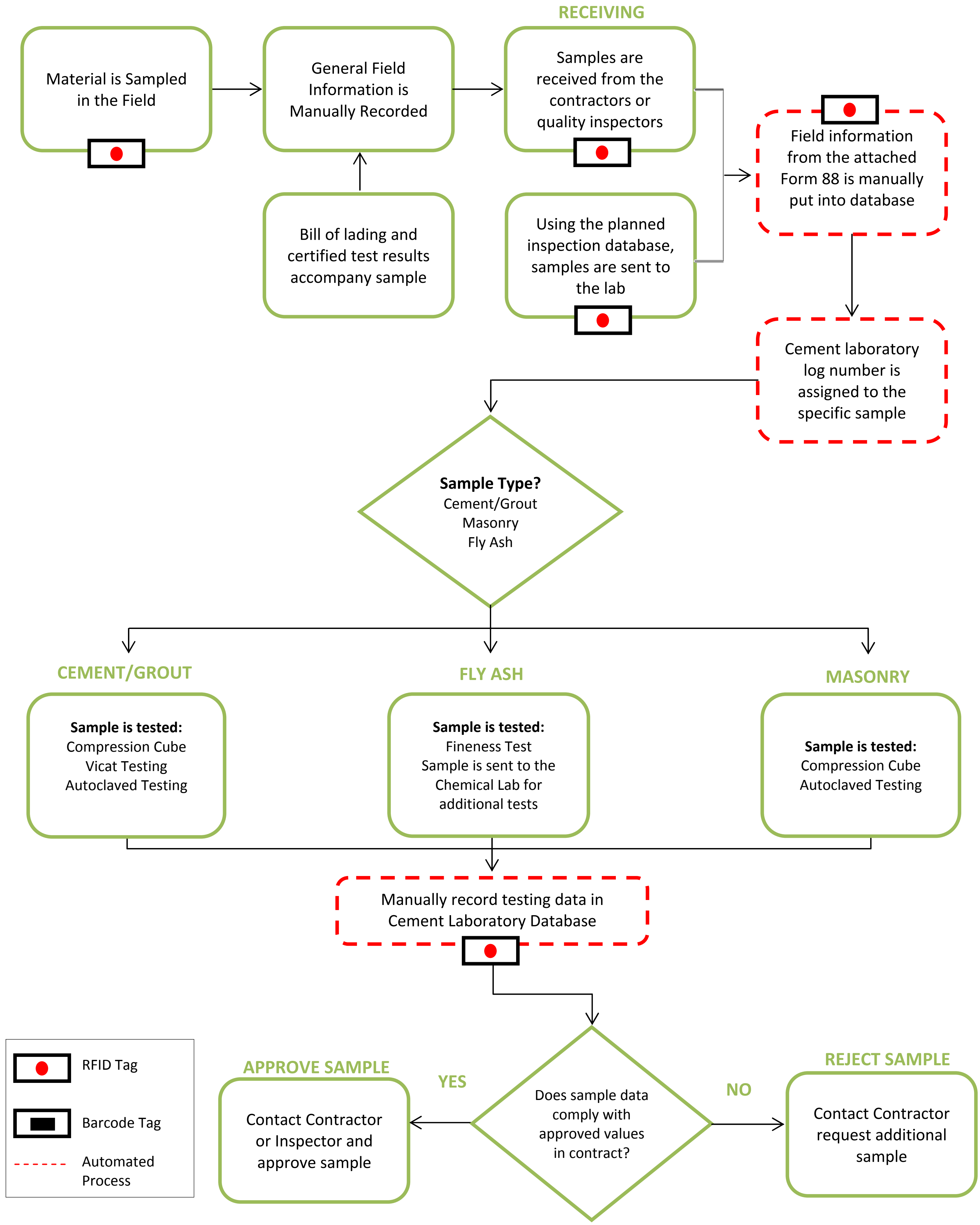
### 7.6.1 Soils and Aggregate Lab Procedures



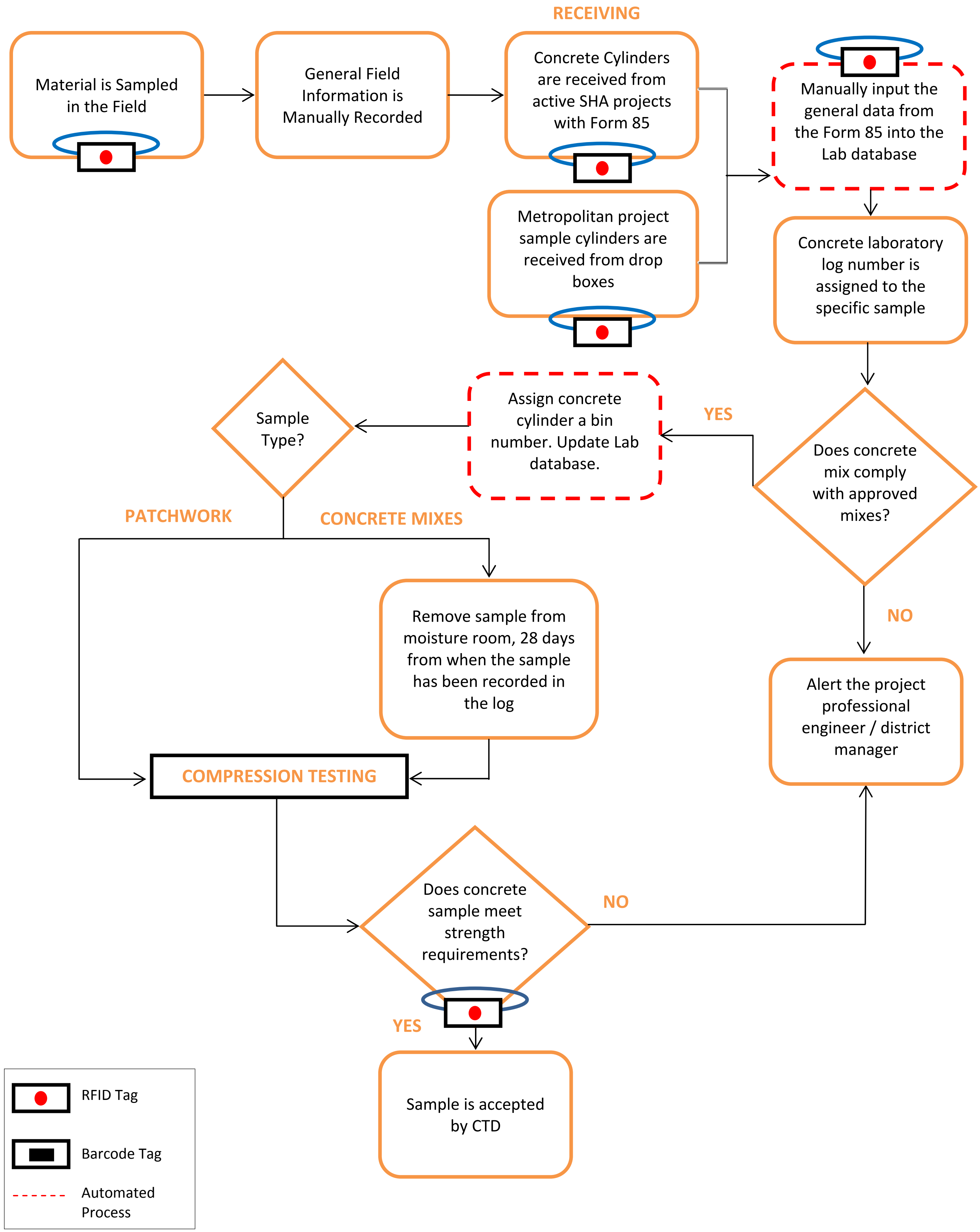
### 7.6.2 Asphalt Lab Procedures



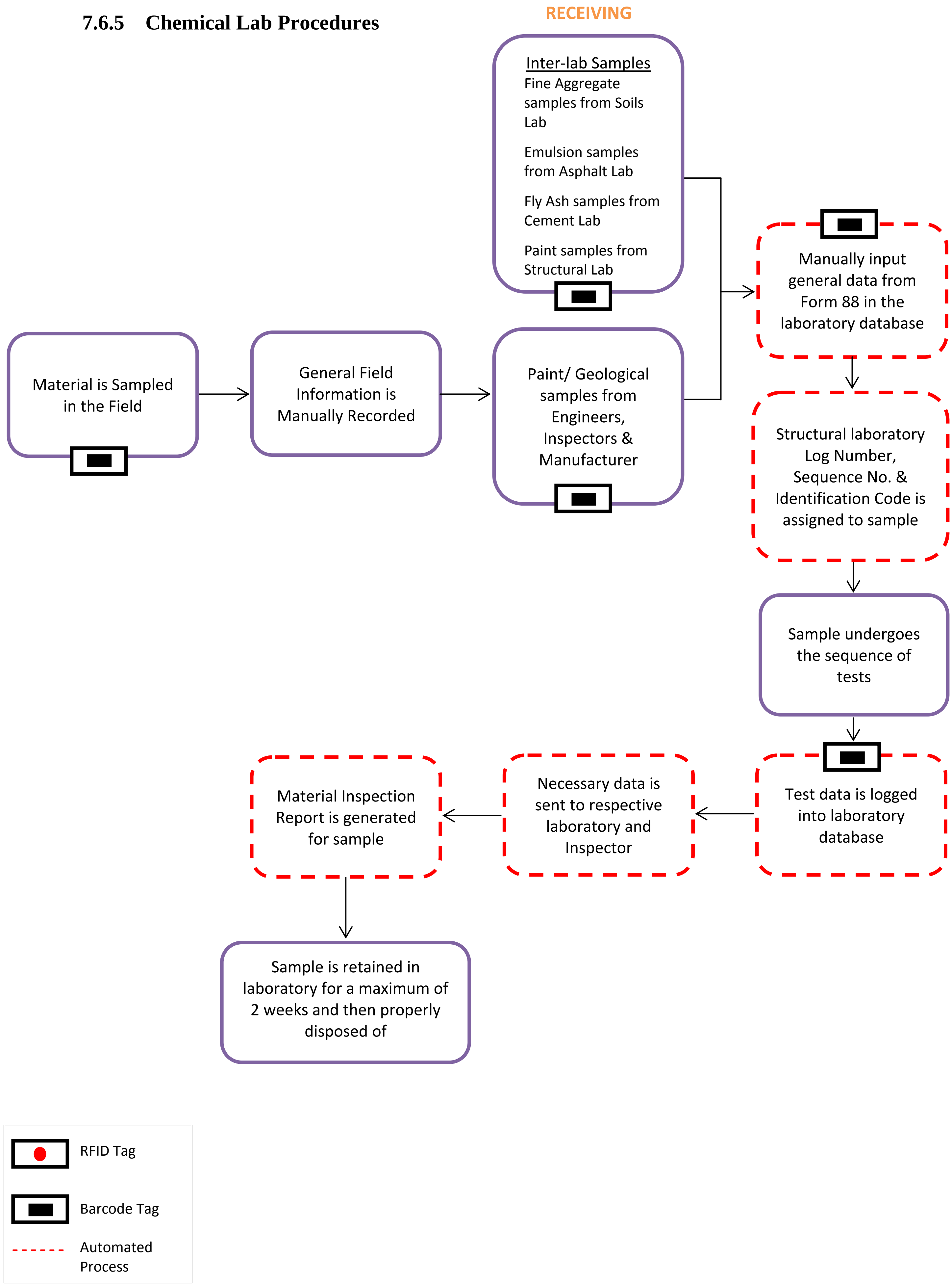
### 7.6.3 Cement Lab Procedures



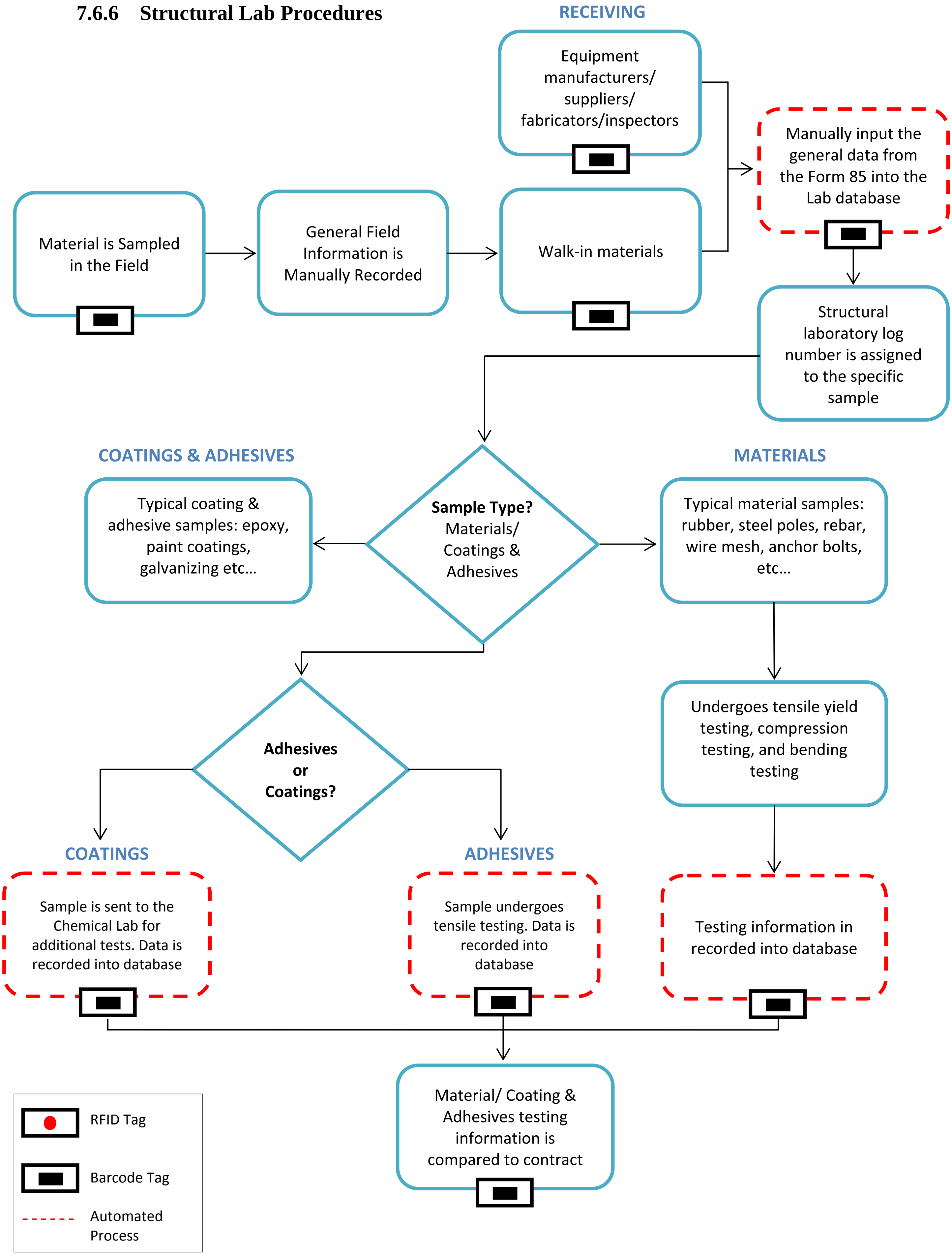
### 7.6.4 Concrete Lab Procedures



### 7.6.5 Chemical Lab Procedures



### 7.6.6 Structural Lab Procedures



# Chapter Eight: Summary, Conclusions and Recommendations

AIT has been shown to provide practical benefits to civil engineering and construction applications. This has been demonstrated through multiple case studies where AIT was used in various stages of material management systems: material planning, tracking, inventory, infrastructure and monitoring. The objective set forth by SHA was similar to the case studies of Chapter Two: to streamline daily operations in order to produce more effective and productive methods of management. After empirical examination of SHA's current material management operations, it is apparent that the implementation of AITs offers a more organized and efficient materials management system. In its current practice, OMT employees have been disrupted by transcription errors when copying data from material certifications, labels or data sheets onto the material sample forms. Auto-ID implementation eliminates hand-written errors or missing information and stores the information electronically. The addition of electronically stored information improves data entry accuracy and allows employees to carry out their daily operations more efficiently. Flowcharts depicting the enhanced procedures for OMT's technology division laboratories are shown in Section 7.7. Furthermore, while AIT replaces the material sample forms, implementation also offers the automatic cross checking of materials against MMS's internal lists of material producers, source of supply, and qualified product lists.

For a smooth integration into the existing MMS, the research team recommends that SHA use a vendor to design an HTML5 server application and data request processer, to allow simultaneous access (level of access will be determined by log-in information) to sample information without disturbing the existing network firewall. The vendor must be able to develop a fully customizable material management server application that provides an interface to MMS and enables the use of AIT for front-end processes (i.e. data acquisition, data collection, wireless communication, and sample material visibility). Chapter Seven provides detailed hardware, system component, and software development recommendations as well as prospective material management application interfaces for OMT to utilize in day-to-day operations.

Initially the vendor should also be responsible for generating barcode labels using direct thermal or thermal transfer printing methods, because it provides quick and easy integration, does not require additional labor, ensures reliable identifiers and decreases the overall investment costs. Labels should be printed on paper stock media, bonded with a protective polyester film which is primarily intended for dry, low impact environments. For application on rough surfaces or harsh environments, plastic media with a polymer coating is recommended. Chapter Seven provides prospective layouts for barcode labels. After SHA becomes confident in using AIT in its business practices, setting up an in-house production operation to handle the large volume of samples coming into OMT laboratories may be considered. Code39 barcode symbologies are recommended because they incorporate a self-checking algorithm for character comparison, reduce the detrimental effects of poor label printing, have inexpensive production costs, and provide flexibility. It is also recommended that the barcode symbology is encoded using an XML format because it provides a generic method of representing information and can be easily implemented using the standard XML schema.

A combination of handheld, mobile, and tablet devices are recommended to decode the barcode symbologies. Devices must have 1D, 2D and RFID reading capabilities, wireless and Bluetooth connectivity, imaging technology, a Microsoft Windows operating system, and be designed to operate in a rugged environment. In each of the four OMT technology divisions, two Motorola MC3100 devices are recommended to instantly transmit data back to MMS and supply pertinent sample related information to Contractors, Quality Inspectors, and Project Engineers. Handheld readers also allow the laboratory personnel to take the reader to the specific sample and provide a wide range of features such as integrated power sources, WLAN connectivity, and user friendly displays. For use in the field, ruggedly designed mobile devices and/or tablets are recommended to allow easier communications with laboratory personnel and device-to-device connectivity.

It is difficult to determine the costs of individual auto-ID systems; therefore it is recommended that SHA request estimates from individual contractors to get a more accurate assessment. Chapter 7 also offers a detailed review on the costs associated with an integrated AIT enhanced business process, return on investment, and training. Barcodes are a less expensive option when compared to RFID and the unit cost decreases as more labels are demanded. Software development and integration for barcode auto-ID systems typically consumes a large portion of the automated system's implementation costs. The largest expense in an automated identification system is associated with the cost of the data capture reader. The recommended UHF readers generally cost from $500 to $2000. Implementation of barcode technology reportedly results in a time savings of 50% and 80% for operational tasks. These tasks include the manual updates of status upon receiving materials and manual entry of information into data reports. Learning to use handheld readers, scanners, or smartphone applications, requires little training. The interface on these systems can be designed to be no different than webpages or basic online forms and the hardware itself is mostly intuitive.

While the advantages of RFID technology have been discussed in this report, the inherent advantages are seemingly nonessential for the specific tasks of OMT's material clearance process; therefore it would be sufficient to employ barcode technology at a lower cost with similar benefits. Furthermore, it is essential that OMT continues the development of its central data repository: the Material Management System. Once MMS has the ability to store laboratory testing information, an auto-ID system will be able to be fully automated and will eliminate stand-alone systems across the divisions, where the testing data is currently entered by lab personnel.

## 8.1 Future Integrations

Although a barcode automated system can be seamlessly implemented into all of OMT's laboratories, several could benefit from the advantages provided by RFID technology such as contactless identification over a wide range, simultaneous interrogation of multiple samples and durability. The Soils and Aggregate and Concrete laboratories can benefit from this technology because both have a large inflow and outflow of samples. Passive GEN2 96-bit Ultra-High Frequency (902 – 928 MHz) RFID inlay labels are recommended for SATD and the Concrete Laboratories, to optimize the sample's visibility and improve the laboratories' organization. SkyeReader SR70 or Motorola FX7400 fixed readers are recommended for installation in the entry and exit points of the laboratory to gather consistent readings because both models support a Microsoft Windows operating system.

Along with the induced benefits from the implementation of auto-ID into OMT laboratories, AITs can also be extended to improve the delivery procedures of prefabricated structural components when they are moved from the manufacturer to the construction site.  Precast units, 'stock' items in particular, are often fabricated well in advance of their planned installation.  Since QA technicians are not usually present to witness the fabrication, there has never been a way of monitoring the quality of the structure's interior construction.  Therefore, when a specific unit is requested for installation, it may be difficult for the contractor to verify that a specific unit is truly represented by the test and inspection data recorded for that unit.  As discussed, AITs can be embedded into these units at the time of construction.  These tags could host the details of the unit, which would ensure that it meets proper specifications.

# A Appendix

## A.1 Sample Survey

**Survey Questionnaire on:**
"The use of RFID and/or Barcodes in DOT projects"

This survey was conducted through SHA as a part of this study. The research team was particularly interested in applications related to concrete, construction materials, structures, and construction projects. The responses from the Alaska, Iowa, and Michigan DOTs are shown in Sections A.1.1 to A.1.3.

| | |
|---|---|
| Question: | **Are RFID and barcodes used in your DOT?**<br>(i.e. concrete/structural applications, material identification, data storage, etc.) |
| Answer: | |
| Question: | **If RFID or barcode technologies are employed, to what extent are they applied?**<br>(i.e. inside concrete specimens, material tracking and inventory control, etc.) |
| Answer: | |
| Question: | **What are some examples where you have applied RFID or barcode technology?** |
| Answer: | |
| Question: | **What benefits or impacts have the use of RFID or barcode technologies provided to your DOT?** |
| Answer: | |
| Question: | **Do you have any future plans for using RFIDs and barcodes in your DOT?** |
| Answer: | |
| Question: | **If you are currently using RFID or barcodes, what challenges did you encounter with implementation?** |
| Answer: | |
| Question: | **Are there any lessons learned that might help a state that is considering the use of RFID or barcodes?** |
| Answer: | |
| **Please attach any documents, links or relevant specs you have related to RFID.** | |
| | |
| **If you are willing to be contacted with follow-up questions, please provide your name, phone number, and e-mail address below:** | |

## A.1.1 Alaska Department of Transportation Survey Response

| | |
|---|---|
| Question: | **Are RFID and barcodes used in your DOT?**<br>(i.e. concrete/structural applications, material identification, data storage, etc.) |
| Answer: No, Alaska DOT is not using bar codes or RFID technologies at this time. | |
| Question: | **If RFID or barcode technologies are employed, to what extent are they applied?**<br>(i.e. inside concrete specimens, material tracking and inventory control, etc.) |
| Answer: [No Response] | |
| Question: | **What are some examples where you have applied RFID or barcode technology?** |
| Answer: [No Response] | |
| Question: | **What benefits or impacts have the use of RFID or barcode technologies provided to your DOT?** |
| Answer: [No Response] | |
| Question: | **Do you have any future plans for using RFIDs and barcodes in your DOT?** |
| Answer: Alaska DOT has experimented with RFID for tracking delivery of asphalt materials. The research effort will likely have a second phase which may include a handheld RFID reader or QR or bar code delivery tickets. | |
| Question: | **If you are currently using RFID or barcodes, what challenges did you encounter with implementation?** |
| Answer: [No Response] | |
| Question: | **Are there any lessons learned that might help a state that is considering the use of RFID or barcodes?** |
| Answer: A research paper on the use of RFID for tracking asphalt loads is expected in the next two months. This research will cover some of the problems and advantages of the technology. | |
| **Please attach any documents, links or relevant specs you have related to RFID.** | |
| **T2-08-09 Feasibility Study of RFID Technology for Construction Load Tracking**<br>Principal Investigators: Oliver Hedgepeth, Morgan Henri (UAA)<br>Funding: $53,000<br>Project Manager: Jim Sweeney<br>Completion Date: December 2012<br><br>Radio Frequency Identification (RFID) is a common technology today. You may not have heard of, but if you've ever seen the security gate at a store being triggered, you've seen it in action. It works by sending data between transponders with radio waves.<br><br>This project uses RFID to try and improve the paving process. Tracking the loads of asphalt for paving in Alaska uses a paper system. Paper tickets are printed at the asphalt plant then handed off to the truck driver and then to a DOT inspector at the paving site. Information about load size, location, and how much area each load covers are recorded on the ticket.<br><br>These tickets, after being passed off several times and written on, must get back to the office, and data get used for payment items. Tickets have to be stored for 3 years after the job.<br><br>RFID will change this paper system to a digital system. Each person that would normally have to handle the ticket would have a transponder. When the transponders come into proximity with one another the data is transferred. The digital data is easy to transfer and easy to store. The real time digital data also allows for text message alerts to managers, so the process can be managed smoothly.<br><br>**Anticipated Benefits**: The successful use of RFID technology will result in more efficient methods to weigh, track and measure unit price items weighed on certified scales. Contractor payments can be process faster and claims documentation will become easier.<br><br>**Report is pending final edits.** | |
| **If you are willing to be contacted with follow-up questions, please provide your name, phone number, and e-mail address below:**<br>James Sweeney, P.E.<br>Research Engineer<br>Statewide Research Section<br>jim.sweeney@alaska.gov | |

## A.1.2 Iowa Department of Transportation Survey Response

| | |
|---|---|
| Question: | **Are RFID and barcodes used in your DOT?** (i.e. concrete/structural applications, material identification, data storage) |
| Answer: Yes to keep an accurate count on raw materials (sign blanks, wood and scothlite) and finished signs. | |
| Question: | **If RFID or barcode technologies are employed, to what extent are they applied?**<br>(i.e. inside concrete specimens, material tracking and inventory control, etc.) |
| Answer: Our shop has barcode/stock number stickers throughout the shop designating the location for all raw material and finished products. The radios tell us where to find a particular sign or where certain raw material is kept. The radios also let us know the amount of signs/raw material in each location which is useful in the restocking of signs/raw material. | |
| Question: | **What are some examples where you have applied RFID or barcode technology?** |
| Answer: see questions 1 and 2. | |
| Question: | **What benefits or impacts have the use of RFID or barcode technologies provided to your DOT?** |
| Answer: It is a very fast and efficient method for keeping track of all raw material and finished signs. | |
| Question: | **Do you have any future plans for using RFIDs and barcodes in your DOT?** |
| Answer: N/A | |
| Question: | **If you are currently using RFID or barcodes, what challenges did you encounter with implementation?** |
| Answer: Since we have hundreds of different sized sign blanks and even more finished signs it was very time consuming getting them all logged into the system. | |
| Question: | **Are there any lessons learned that might help a state that is considering the use of RFID or barcodes?** |
| Answer: Once all the information is downloaded into the system it will save the state a great deal of time and money. | |
| **Please attach any documents, links or relevant specs you have related to RFID.** | |
| [No Response] | |
| **If you are willing to be contacted with follow-up questions, please provide your name, phone number, and e-mail address below:** Cory Anderson- cory.anderson@dot.iowa.gov | |

## A.1.3 Michigan Department of Transportation Survey Response

| | |
|---|---|
| Question: | **Are RFID and barcodes used in your DOT?** (i.e. concrete/structural applications, material identification, data storage.) |
| Answer: Yes | |
| Question: | **If RFID or barcode technologies are employed, to what extent are they applied?**<br>(i.e. inside concrete specimens, material tracking and inventory control, etc.) |
| Answer: Project by project basis, primarily at the request of the project office or for informational purposes. | |
| Question: | **What are some examples where you have applied RFID or barcode technology?** |
| Answer: We use RFID to uniquely identify and communicate with temperature sensors. These sensors have been embedded in concrete, aggregate, and HMA (after the first roller passes), as well as used to monitor ambient temperatures. The data is used for a variety of purposes, including maturity calculations, warping and curling research, and determining specification compliance. | |
| Question: | **What benefits or impacts have the use of RFID or barcode technologies provided to your DOT?** |
| Answer: Maturity testing facilitates earlier open-to-traffic times. Warping and curling research helps us to analyze pavement performance and understand the causes of some cracking, etc. The effectiveness of construction methods, such as flooding an HMA separator layer with water prior to paving an unbounded concrete overlay, can be easily determined using our RFID system. | |
| Question: | **Do you have any future plans for using RFIDs and barcodes in your DOT?** |
| Answer: Yes. The primary new application would be tied to material tracking. | |
| Question: | **If you are currently using RFID or barcodes, what challenges did you encounter with implementation?** |
| Answer: Finding a product that was robust enough for our industry and that offered the features that we need: ability to read through concrete and buried in other materials, range of reading, onboard storage of data including temperature readings and date/time of reading. Finding a company that would do product development for a relatively small market was not easy either. | |
| Question: | **Are there any lessons learned that might help a state that is considering the use of RFID or barcodes?** |
| Answer: Determining what your goals, budget, and abilities are should be the first priority. Consider smaller scale in-house evaluation to determine if these goals have been attained and/or can be achieved. | |
| **Please attach any documents, links or relevant specs you have related to RFID.** | |
| We have a specification that references our RFID requirements in the context of maturity testing, but it is not exclusively for RFID. I can forward it if requested, as well as the website and contact information for a vendor. | |
| **If you are willing to be contacted with follow-up questions, please provide your name, phone number, and e-mail address below:** Tim Stallard stallardt@michigan.gov | |

## A.2 Source of Supply (SOS) Lists

| Company | Headquarters City | Headquarters State | Business/Strategic Consulting | Distribution of RFID Hardware/ Software | Finished RFID Labels | Labeling Making Equipment Materials/Services | Middleware | Networking Hardware/Software | Readers/Interrogators (fixed) | Readers/Interrogators (mobile) | RFID Chips | RFID Manufacturing Applications | RFID Enabled Supply Chain Applications | RFID Enabled Warehouse Management Applications | RFID Enabled Enterprise Applications (other) | RFID Label Printers/Applicators | Systems Integration | Technology Consulting | Wireless Sensors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| InfoChip Systems Inc. | Wetaskiwin | AK | | X | | | | | | | | X | | | X | | X | X | |
| Wachter Network Services, Inc. | Lowell | AR | | X | | | | | | | | | | | | | X | X | |
| American Barcode and RFID | Phoenix | AZ | | X | | | X | | X | X | | X | X | X | | X | | | |
| Ferroxtag | Chandler | AZ | | X | X | | | | | | | | | | | | | | |
| Hypercom Corporation | Phoenix | AZ | | | | | | | | | | | | | | | X | X | |
| RF Code | Mesa | AZ | X | | | | X | | X | X | | X | X | X | X | | X | | X |
| 3-D Marketing | Rancho Santa Fe | CA | | X | X | | X | | X | X | | | X | | | | | | |
| AeroScout | San Mateo | CA | | | | | | | X | | | X | | | X | | | | |
| Alien Technology | Morgan Hill | CA | | | X | | | | X | | X | | X | | | | | | |
| Applied Wireless Identifications Group, Inc | Morgan Hill | CA | | | | | | | X | | | | | | | | | | |
| Apriso Corporation | Long Beach | CA | | | | | X | | | | | X | X | X | X | | X | X | |
| ASK Contactless | Culver City | CA | | X | X | | | | X | X | | | | | | | | | |
| Assetpulse | San Jose | CA | X | | | | X | | | | | | | | X | | X | X | |
| Avery Dennison - Retail Information Services | Westlake Village | CA | | | X | | | | | | | | | | | | | | |
| BEA Systems, Inc. | San Jose | CA | | | | | X | | | | | | | | | | | | |
| Beigel Technology Corporation | Encinitas | CA | X | X | | | X | | X | X | | | | | X | | X | X | X |
| Blue Vector Systems | Palo Alto | CA | | X | | | X | | X | X | | | | | | | X | | X |
| CardLogix | Irvine | CA | | | | | | | | | | | | | | | X | | |
| CaseStack | Santa Monica | CA | X | | | | | | | | | | X | X | | | | | |
| Cisco | San Jose | CA | | | | | X | | | | | | | | | | | X | |
| Crossbow Technology, Inc. | San Jose | CA | | | | | | | | | | | | | | | X | | X |
| CSC Computer Sciences Corporation | El Segundo | CA | X | | | | | | | | | | | | | | X | X | |
| Fujitsu Transaction Solutions, Inc. | Sunnyvale | CA | X | X | | | X | | | | X | | X | | X | | X | | |
| Hewlett-Packard Co., | Palo Alto | CA | X | X | | | | | | | | | | | | | X | X | |
| Infratab, Inc. | Oxnard | CA | | | X | | X | | | X | | | | | X | | | | X |
| Ingram Micro Data Capture/POS Division | Carlsbad | CA | X | X | | | X | | X | X | | X | X | X | X | | X | X | X |
| InSync Software, Inc | San Jose | CA | | | | | X | | | | | X | X | X | X | | | | X |
| Intel Corporation | Santa Clara | CA | | | | | | | | | | | | | | | | X | |
| Omnitrol Networks | Mountain View | CA | | | | | X | | | | | X | X | X | X | | X | | |

| Company | Headquarters City | Headquarters State | Business/Strategic Consulting | Distribution of RFID Hardware/ Software | Finished RFID Labels | Labeling Making Equipment Materials/Services | Middleware | Networking Hardware/Software | Readers/Interrogators (fixed) | Readers/Interrogators (mobile) | RFID Chips | RFID Manufacturing Applications | RFID Enabled Supply Chain Applications | RFID Enabled Warehouse Management Applications | RFID Enabled Enterprise Applicators (other) | RFID Label Printers/Applicators | Systems Integration | Technology Consulting | Wireless Sensors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oracle | Redwood Shores | CA | | | | | X | | | | | X | X | X | X | | | | |
| PINC Solutions | Berkeley | CA | | | | | | | | | | | X | | | | | | |
| Precision Dynamics Corporation | San Fernando | CA | | | | | | | | | | | | | | | X | X | |
| Printronix | Irvine | CA | | | X | | | | | | | | | | | | | | |
| RafCore Systems | Sunnyvale | CA | | | | | | | | | | | X | | X | | | | |
| RightTag Inc., | Santa Clara | CA | | X | X | | | | X | X | | | | | | | | | |
| RSI ID Technologies | Chula Vista | CA | X | X | X | | | | X | X | | X | X | X | X | | X | X | |
| SAIC | San Diego | CA | X | X | X | | X | | | | | | X | X | X | | X | X | X |
| SAP | Palo Alto | CA | | | | | X | | | | | X | X | X | X | | | | |
| Savi Technology | Mountain View | CA | | | | | X | | | | | X | X | X | X | | X | X | |
| ScanPlanet.com | Chatsworth | CA | | X | | | | | X | X | | X | | | | | X | X | X |
| Secura Key | Chatsworth | CA | | | | | | | X | X | | | | | | | | X | |
| SmarTerminal Computers, Inc. | Santa Fe Springs | CA | | X | | | | | | X | | | | X | | | | | |
| Sybase iAnywhere | Dublin | CA | | | | | X | | | | | | | | | | | | |
| T3Ci | Sunnyvale | CA | X | | | | | | | | | X | X | | | | | | |
| TrueDemand Software | Los Gatos | CA | | | | | | | | | | | X | | | | | X | |
| Vue Technology | Lake Forest | CA | | | | | X | | | | | | | | | | | | |
| WaveTrust, Inc. | Palo Alto | CA | X | | | | X | | | | | | | | | | X | X | |
| WaveZero, Inc. | Sunnyvale | CA | | | | | | | | | | | | | | | | | X |
| WhereNet | Santa Clara | CA | | | | | | | | | | X | X | X | X | | | | |
| Wipro Technologies | Mountain View | CA | | | | | | | | | | | | | | | X | X | |
| WJ Communications | San Jose | CA | | | | | | | X | X | X | | | | | | | | |
| AccuCode, Inc. | Denver | CO | X | X | | | | | X | X | X | X | X | X | X | | X | X | X |
| APT Sun Microsystems | Longmont | CO | | | | | | | | | | | | | | | | X | |
| Atmel | Colorado Springs | CO | | | | | | | | | X | | | | | | | | X |
| CIBER, Inc. | Greenwood Village | CO | X | X | | | | | | | | | X | X | X | | X | | X |
| Fluensee | Englewood | CO | X | X | | | X | | | | | X | X | X | X | | X | X | |
| IGE Systems | Longmont | CO | X | | | | | | | | | | | | | | X | X | |
| RFID, Inc. | Aurora | CO | | | | | | | X | X | | X | | | | | | | |
| SkyeTek, Inc. | Westminster | CO | | | | | | | X | X | | | | | | | | X | |
| Stratum Global | Littleton | CO | X | | X | | X | | X | X | | X | X | X | X | | X | X | X |
| TrenStar, Inc. | Greenwood | CO | X | X | | | X | | X | X | X | | X | X | X | | X | X | |

| Company | Headquarters City | Headquarters State | Business/Strategic Consulting | Distribution of RFID Hardware/ Software | Finished RFID Labels | Labeling Making Equipment Materials/Services | Middleware | Networking Hardware/Software | Readers/Interrogators (fixed) | Readers/Interrogators (mobile) | RFID Chips | RFID Manufacturing Applications | RFID Enabled Supply Chain Applications | RFID Enabled Warehouse Management Applications | RFID Enabled Enterprise Applications (other) | RFID Label Printers/Applicators | Systems Integration | Technology Consulting | Wireless Sensors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Village | | | | | | | | | | | | | | | | | | |
| bielomatik | Windsor | CT | | | | | | | | | | | | | | | | X | |
| decisionpoint systems, inc. | Shelton | CT | X | | | | X | | X | X | | X | X | X | X | | X | X | X |
| George Schmitt & Co. | Guilford | CT | | | X | | | | | | | | | | | | | | |
| Queralt LLC | Wallingford | CT | X | X | | | X | | | | | | X | | | | X | X | X |
| SecureRF Corporation | Westport | CT | | | | | X | | | | X | | X | | | | | X | |
| Supply Insight Inc | Hamden | CT | | | | | X | | | | | | | | | | | | |
| TEK Industries, Inc. | Vernon | CT | | | | | X | | X | X | | | | | | | | | |
| Gentag, Inc. | Washington | DC | | X | X | | X | | | X | | | X | | | | | | X |
| McKenna Long & Aldridge LLP | Washington | DC | X | | | | | | | | | | | | | | | X | |
| ADT Security Services | Boca Raton | FL | | | X | | | | X | | | | X | | | | X | | |
| Datamax Corp. | Orlando | FL | | | X | | | | | | | | | | | | | | |
| Datamax O'Neil | Orlando | FL | | | | | | | | | | | | | | X | | | |
| Franwell, Inc. | Lakeland | FL | | X | | | | | X | X | | X | X | X | X | | X | X | X |
| iGPS (Intelligent Global Pooling Systems) | Orlando | FL | | | | | | | | | | | X | | | | | | |
| Innovatier | Lakeland | FL | | | X | | | | | | | X | | | | | | | |
| Sonitor Technologies | Largo | FL | | | | | | | X | X | | X | X | X | | | X | | X |
| AAID Security Solutions, Inc | Peachtree city | GA | | X | | | X | | X | X | | X | X | X | X | | X | X | X |
| Datamars, Inc | Peachtree City | GA | | | | | X | | X | | X | | | | | | | | |
| LXE Inc. | Norcross | GA | | | | | | | | X | | X | X | X | X | | | X | |
| Manhattan Associates, Inc. | Atlanta | GA | | X | | | X | | | | | | X | X | | | X | | |
| NCR Corporation | Duluth | GA | X | X | X | | X | | X | X | | X | X | X | | | | X | |
| RFIDlogic Inc., | Marietta | GA | | | | | X | | | | | | | | | | X | | |
| Siemens Energy & Automation, Inc. | Norcross | GA | X | | X | | X | | X | X | | X | X | X | X | | X | X | X |
| The Danby Group, LLP | Norcross | GA | | X | X | | X | | | | | | | | X | | X | X | |
| Craig K. Harmon | Cedar Rapids | IA | X | | | | | X | | | | | | | | | X | X | X |
| Q.E.D. Systems | Cedar Rapids | IA | X | | | | | | | | | | | | | | | X | |
| Adaptive RFID, Inc. | Wheaton | IL | X | X | | | X | | | | | X | X | X | | | X | X | |
| Click Commerce | Chicago | IL | | | | | | X | | | | | | | | | | | |
| Deloitte Consulting | Chicago | IL | X | | | | | | | | | | | | | | X | X | X |
| LM ELECTRONICS, INC. | Carol Stream | IL | | X | | | | | X | X | | | | | | | X | | |
| Omron | Schaumburg | IL | | | X | | | | X | | | | | | | | | | |
| PLITEK | Des Plaines | IL | | | X | | | | | | | | | | | | | | |

| Company | Headquarters | | Business/Strategic Consulting | Distribution of RFID Hardware/ Software | Finished RFID Labels | Labeling Making Equipment Materials/Services | Middleware | Networking Hardware/Software | Readers/Interrogators (fixed) | Readers/Interrogators (mobile) | RFID Chips | RFID Manufacturing Applications | RFID Enabled Supply Chain Applications | RFID Enabled Warehouse Management Applications | RFID Enabled Enterprise Applications (other) | RFID Label Printers/Applicators | Systems Integration | Technology Consulting | Wireless Sensors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | City | State | | | | | | | | | | | | | | | | | |
| Print-O-Tape, Inc. | Mundelein | IL | | | X | | | | | | | | | | | | | | |
| Tamarack Products Inc. | Wauconda | IL | | | X | | | | | | | | | | | | | | |
| TSRI | Buffalo Grove | IL | X | | | | | | | | | | | | | | X | X | |
| Weber Marking Systems, Inc. | Arlington Heights | IL | | X | X | | | | | | | | | | | | | | |
| William Frick & Co. | Libertyville | IL | X | | X | | | | | | | | | | | | | X | |
| Zebra Technologies | Vernon Hills | IL | | | | | | | | | | X | X | X | | | | | |
| BlueBean | Carmel | IN | X | X | X | | X | | X | X | | X | X | X | X | X | X | X | |
| Northern Apex Solutions Integrator | Fort Wayne | IN | X | X | X | | X | | X | X | X | X | X | X | X | | X | X | X |
| RFIDSupplyChain.com | Mishawaka | IN | | X | | | | | | | | | | | | | | | |
| Preco, Inc. | Lenexa | KS | | | | | | | | | | X | | | | | | | |
| Rush Tracking Systems | Kansas City | KS | X | | | | | | | | | | | | | | X | X | |
| Thermal Solutions Inc. | Wichita | KS | | | | | | | | | | | | | | | | | X |
| Velociti Inc. | Kansas City | KS | | X | | | | X | X | X | | | | | | | X | | X |
| Emerson & Cuming Microwave Products | Randolph | MA | | | X | | | | | | | | | | | | | | |
| OATSystems, Inc | Waltham | MA | X | | | | X | | | | | | X | | X | | | | |
| PanGo | Framingham | MA | X | | | | X | | | | | | | | X | | | X | |
| Patni Computer Systems | Cambridge | MA | | | | | | | | | | X | X | X | X | | X | X | |
| Progress Software | Bedford | MA | | | | | X | | | | | | | | | | X | X | |
| Reva Systems | Chelmsford | MA | | | | | X | | | | | X | X | | X | | | | |
| Sensitech Inc. | Beverly | MA | X | X | | | | X | X | | | | X | X | | | | | |
| SupplyScape Corp | Woburn | MA | X | | | | X | | | | | | X | | | | | X | |
| TagSense, Inc. | Cambridge | MA | | | | | | | X | X | | | | | | | | X | X |
| TAGSYS | Cambridge | MA | | | | | X | | X | X | | | | | | | | | |
| ThingMagic, Inc. | Cambridge | MA | X | | | X | | X | X | X | | X | X | X | X | X | X | X | X |
| ThingMagic, Inc. | Cambridge | MA | X | | | X | | X | X | X | | X | X | X | X | X | X | X | X |
| TR3 Solutions, Inc. | Stoneham | MA | X | | | | | | | | | | | | X | | X | | |
| Tyco Electronics | Lowell | MA | | X | X | | X | | X | X | | X | X | X | X | | X | X | X |
| WaveMark, Inc. | Boxborough | MA | | | | | | | | | | | X | | | | X | | |
| IntelliTrack Inc. | Hunt Valley | MD | | | | | | | | | | X | X | X | X | | X | X | |
| Multispectral Solutions, Inc. | Germantown | MD | | | | | | | X | X | X | X | X | X | X | | X | | |
| PEAK Technologies | Columbia | MD | X | X | X | | X | | | | | | | | | | X | X | |
| RFID Global Solution | Mount Airy | MD | X | X | | | X | | | | | X | X | X | X | | X | X | X |
| RFID Revolution | Silver Spring | MD | X | | | | | | | | | | | | | | | | |

| Company | Headquarters City | Headquarters State | Business/Strategic Consulting | Distribution of RFID Hardware/ Software | Finished RFID Labels | Labeling Making Equipment Materials/Services | Middleware | Networking Hardware/Software | Readers/Interrogators (fixed) | Readers/Interrogators (mobile) | RFID Chips | RFID Manufacturing Applications | RFID Enabled Supply Chain Applications | RFID Enabled Warehouse Management Applications | RFID Enabled Enterprise Applications (other) | RFID Label Printers/Applicators | Systems Integration | Technology Consulting | Wireless Sensors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parco Wireless | Portland | ME | | X | | | X | | X | X | X | X | X | X | | | X | | X |
| Lowry Computer Products | Brighton | MI | X | X | X | X | X | X | X | | | X | X | X | X | X | X | X | X |
| Lowry Computer Products, Inc. | Brighton | MI | X | X | X | | | | X | X | | X | X | X | X | | X | X | X |
| Smart Label Solutions | Brighton | MI | | X | X | | X | | | | | | | | | | X | X | |
| 3M | St. Paul | MN | | | X | | | | X | X | | | X | X | X | | X | | |
| Colder Products Company | St. Paul | MN | | | | | | | X | | | | | | | | | | |
| Comtrol Corporation | Maple Grove | MN | | | | | X | | | | | | | | X | | X | X | X |
| Enterprise Compliance, Inc. | Minneapolis | MN | X | | | | X | | | | | | X | | | | | | |
| HEI Inc. | Chanhassen | MN | | | X | | | | | | | | | | | | | X | |
| HighJump Software, a 3M Company | Eden Prairie | MN | | X | | | X | | X | | | X | X | X | X | | X | | |
| Scout Inc. | Stillwater | MN | X | X | | | X | | | | | X | X | X | X | | | | |
| SPS Commerce | Minneapolis | MN | | | | X | | | | | | | | | | | | | |
| Transaction Data Systems, Inc. | Bloomington | MN | | | | | | X | | | | | | | | | | | |
| Diagraph, An ITW Company | St. Charles | MO | | | | | | | | | | | | | | | X | | |
| Mark Andy, Inc. | Chesterfield | MO | | | X | X | | | | | | X | | | | X | | | |
| RF Controls | St. Louis | MO | | | | | | | X | | | | | | | | | | |
| CGP, Inc. | Clayton | NC | | | X | | | | | | | | | | | | | | |
| Primary Tracking | Winston Salem | NC | X | X | X | | X | | X | | | X | X | X | | | X | | |
| Principal Capital | Raleigh | NC | | X | | | | X | X | X | X | X | X | X | X | | X | | X |
| Prisym ID | Charlotte | NC | | X | X | | | | | | | | | | | | | | |
| Nashua Corporation | Omaha | NE | | | X | | | | | | | | | | | | | | |
| ILS | Nashua | NH | X | X | | | X | | | | | | | | | | X | X | |
| Loftware, Inc. | Portsmouth | NH | | | | | X | | | | | | | | | | | | |
| MARKEM Corporation | Keene | NH | | | | | | | X | | | | | X | X | | X | | |
| Acsis Inc. | Marlton | NJ | | | | | X | | | | | X | X | X | | | X | | |
| AT&T | Bedminster | NJ | X | | | | | | | | | X | X | X | X | | X | X | |
| AVANTE International Technology, Inc. | Princeton Junction | NJ | | | | | | | X | X | | X | X | X | X | | | | X |
| Brooks Technology Products Group | Livingston | NJ | | | | | | | | | | | X | | | | | | |
| CCL Label | Hightstown | NJ | | | X | | | | | | X | | | | | | | | |
| Checkpoint Systems, Inc. | Thorofare | NJ | X | | X | | | | | | | | X | | X | | X | X | |
| Instock Wireless Components, Inc | Boonton | NJ | | | | | | X | | | | X | X | X | | | | | |
| Iris Software, Inc. | Edison | NJ | | | | | | | | | | X | X | X | X | | X | X | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Laudis Systems, LLC | Edison | NJ | X | X | | | X | | | | | X | X | X | X | | X | X | |
| Lisky Associates | Mendham | NJ | X | | | | X | | | | | | | | | | X | X | |
| Maxell Corporation of America | Fair Lawn | NJ | | | | | | | X | X | X | X | | | | | | | |
| New Jersey Packaging | Fairfield | NJ | X | | X | | | | | | | | | | | | | | |
| Parelec Inc. | Rocky Hill | NJ | | X | X | | X | | | | | | X | | | | | | X |
| SureID | Marlton | NJ | X | | | | X | | X | X | | | | | X | | X | X | X |
| Ensyc Technologies | Reno | NV | | | | | | | X | | | | | | | | | X | |
| A.C.C. Systems Inc. | Glen Head | NY | | X | X | | X | | X | X | | X | X | X | X | | X | X | X |
| Accenture | New York | NY | X | | | | | | | | | | | | | | X | X | |
| ADR Advisors Inc. | Jamesport | NY | X | | | | | | | | | | | | | | X | X | |
| CYBRA Corporation | Yonkers | NY | | X | X | | X | | X | | | | | | | | X | X | |
| IBM Corporation | Armonk | NY | X | | | | X | | | | | | | | | | X | X | |
| ICI Health | New Hyde Park | NY | X | | | | | | | | | | | | | | X | X | |
| IconNicholson | New York | NY | X | | | | | | | | | | | | | | X | X | |
| Intellareturn Corp. | New York | NY | | | | | | | | X | | X | X | | X | | | | |
| Motorola's Enterprise Mobility Business, formerly Symbol Technologies | Holtsville | NY | | | | | | | | | | | | | | | | | |
| SMARTCODE CORP. | New York | NY | | | X | | | | X | X | X | X | X | X | X | | X | | X |
| Applied Radio Technologies-USA, LLC | Strongsville | OH | X | X | | | X | | X | X | | | | | | | | X | X |
| CDO Technologies, Inc. | Dayton | OH | X | X | X | | X | | X | X | X | | X | X | | | X | X | |
| ESYNC | Toledo | OH | X | | | | | | | | | | | | | | X | X | |
| OHM System Inc. | Cincinnati | OH | | X | | | | X | | | | X | | | X | | X | X | |
| Paxar Corp. | Miamisburg | OH | | | X | | | | X | X | | X | X | X | | | | | |
| Productivity by RFID | Valley View | OH | X | X | X | | X | | X | X | | X | X | X | X | | X | X | X |
| Repacorp, Inc. | Tipp City | OH | | | X | | | | | | | | | | | | | X | |
| Schober USA Inc | Fairfield | OH | | | | X | | | | | | | | | | | | | |
| Snively Inc. | Mentor | OH | X | X | | | X | | | | | X | | | | | X | X | |
| SPEDE Technologies | Cleveland | OH | X | | | | X | | X | X | | X | X | X | | | X | X | X |
| The Kennedy Group | Willoughby | OH | | | X | | | | X | | | X | X | X | | | | | |
| Thin Battery Technologies, Inc. | Parma | OH | | | X | | | | | | | | | | | | | | |
| TranSystems \| ESYNC | Toledo | OH | X | | | | | | | | | | | | | | X | X | |
| ADASA Inc. | Eugene | OR | X | X | X | | | | | | | | X | | | X | | X | |
| PSC Inc. | Eugene | OR | | | | | | | | X | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Psion Teklogix | Beaverton | OR | | X | X | | | | | X | | X | X | X | | | | | |
| Salient Corp. | Portland | OR | | | | | | | | | | | | | | | X | X | |
| Accu-Sort Systems, Inc. | Telford | PA | | | | | | | X | X | | X | X | X | X | | X | X | |
| AdvantaPure(R) | Southampton | PA | | X | | | | X | | | X | | | | | | | | |
| RCD TECHNOLOGY INC. | Quakertown | PA | | | X | | | | | | | | | | | | | X | |
| TagYourStuff | Lancaster | PA | | | X | | | | | | | | | | | | | | |
| Topflight Corporation | Glen Rock | PA | | | X | | | | | | | | | | | | | X | |
| Two Technologies, Inc. | Horsham | PA | | | | | | | | X | | | | | | | | | |
| Unisys | Blue Bell | PA | X | | | | | | | | | | | | | | X | X | |
| Vanguard ID Systems | West Chester | PA | | | X | | | | | | X | | | | | | | X | |
| SYNNEX Corporation | Greenville | SC | | X | X | | X | | | | | | | | | | X | X | X |
| The R and V Group LLC | Chattanooga | TN | | | X | | | | | | | | | | | | | | |
| AirGATE Technologies | Allen | TX | X | | X | | X | | X | X | X | X | | X | X | | X | X | X |
| Atos Origin | Dallas | TX | X | | | | X | | | | | | | | | | X | X | |
| Axcess International, Inc. | Carrollton | TX | | | | | X | | X | | X | | | X | X | | X | | |
| CipherLab | Plano | TX | | X | | | | | | | | | | | | | | | |
| GlobeRanger Corporation | Richardson | TX | X | | | | X | | | | | X | X | X | X | | X | | |
| Intelligentz Corporation | Austin | TX | X | X | | | X | | | | | | | | | | X | X | |
| RFID Recruiters, LLC | Addison | TX | X | | | | | | | | | | | | | | | X | |
| RFID Tribe | Plano | TX | | | | | | | | | | | | | | | | X | |
| SAVR Communications, Inc. | Irving | TX | X | X | | | | | X | X | | X | | | | | | | |
| Shipcom Wireless | Houston | TX | | | | | X | | | | | X | X | X | X | | X | X | |
| Sirit Inc. | Carrollton | TX | | | | | | | X | X | | | | | | | | | |
| Texas Instruments | Plano | TX | | | | | | | X | | X | | | | | | | | |
| TransCore | Dallas | TX | | | | | | | X | X | | | | | | | X | | |
| Venture Research Inc. | Plano | TX | X | X | X | | X | | X | X | | X | X | X | X | | X | X | X |
| Xterprise, Incorporated | Carrollton | TX | X | X | | | | | | | | X | X | X | X | | X | X | |
| BearingPoint | McLean | VA | X | | | | X | | | | | X | X | X | X | | X | X | |
| Bent Systems | Fairfax | VA | X | X | | | X | | | | | X | X | X | X | | X | X | |
| CODE Plus, Inc. | Fairfax | VA | | | | | X | | | | | X | X | X | X | | X | X | |
| Ekahau, Inc. | Reston | VA | | | | | | | | | | X | X | X | X | | | | X |
| epcSolutions | Great Falls | VA | | | | | X | | | | | | | | X | | | | |
| General Dynamics Information Technology | Annandale | VA | X | X | | | | | | | | | | | | | X | X | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Muhlbauer, Inc. | Newport News | VA | | X | | X | | | | | | | | | | X | | X | |
| ODIN technologies | Dulles | VA | X | X | | | | | | | | X | X | | X | | X | X | |
| RFideaWorks Corp. | Haymarket | VA | X | | | | X | | | | | X | X | X | X | | | | |
| SimplyRFID.com | Warrenton | VA | | | X | | X | | X | X | | | | | | | | | |
| System Planning Corporation | Arlington | VA | X | | | | | | | | | | X | | | | X | X | X |
| VeriSign, Inc. | Dulles | VA | X | | | | | | | | | | | | | | X | X | |
| Wavetrend | Fairfax | VA | | | | | | | X | X | | X | X | X | X | | X | X | X |
| XIO Strategies, Inc. | McLean | VA | X | | | | | | | | | | | | | | | X | |
| Allaura, Inc. | Tacoma | WA | | X | | | X | X | X | X | | X | X | X | X | | X | X | |
| Impinj, Inc. | Seattle | WA | | | | | | | X | | X | | | | | | | | |
| Integral RFID | Richland | WA | X | | | | X | | | | | | | | | | X | X | |
| Intermec, Inc. | Everett | WA | | X | X | | | | X | X | | | | | | | X | X | |
| ITEC America, Inc. | Seattle | WA | | | | | | | | | | | | | | | | X | |
| Lyngsoe Systems | Aars | WA | X | X | X | | X | | X | X | X | | X | | | | X | | |
| Microsoft | Redmond | WA | | | | | X | | | | | X | X | X | X | | | X | |
| Brady Corp | Milwaukee | WI | | | X | | | | | | | | | | | | | | |
| Earth Information Technologies | Madison | WI | X | | | | X | | | | | | | | | | X | X | |
| Enercon Industries Corporation | Menomonee Falls | WI | | | | | | | | | | | | | | | | X | |
| Itasca Automation Systems | Egg Harbor | WI | | | | | X | | | | | | | | | | | | |
| Itasca Automation Systems, LLC | Egg Harbor | WI | | | | X | | | | | | | | | | | | | |
| Panatrack | Delafield | WI | | | | | | | | | | X | X | X | X | | X | X | |
| RedPrairie Corporation | Waukesha | WI | | X | | | X | | | | | | X | X | | | | X | |
| Terso Solutions | Fitchburg | WI | | X | | X | X | X | X | | | | | | X | | X | | |
| WS Packaging Group, Inc. | Algoma | WI | | | X | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |

## A.3 Materials Sample Forms

[Appendix of materials sample forms gathered from the laboratories at the OMT].

### A.3.1 General Materials Sample Form (SHA73.0-88)

OMT88 05/03/04

MARYLAND STATE HIGHWAY ADMINISTRATION

**GENERAL MATERIALS SAMPLE**

Original ☐
Acceptance ☐
I.A.S.T. ☐
Other ☐

**Date Sampled:** ________ **Lab No:** ________ **Project Sample No:** ________

**Type of Material:** ________ **Quantity Represented:** ________

**Contract Number:** ________ **F.A.P. Number:** ________

**Item Number:** ________ **Type of Construction:** ________

**Sample Taken From:** ________ **Plant No:** ________ **Source:** ☐ **Job Site:** ☐

**Produced By:** ________ **Trade Name:** ________

**Source of Supply:** ________

**Shipped From:** ________ ☐ **Batch** ☐ **Lot** ☐ **Heat No:** ________

**Size of Sample:** ________ **Sampled By:** ________ **Witnessed By:** ________

**Remarks:** ________

**Return Original form To** ________ **Regional Laboratory.**

---

**This portion of form to be completed by the Lab.**

**Date Received: In Lab:** ________ **In Testing Unit:** ________ **Lab No:** ________

**Date Put Under Test:** ________ **Date Test Completed:** ________ **Tested By:** ________

**Test Cost:** ________ **Approved By:** ________ **Recorded By:** ________

---

**LABORATORY TEST RESULTS**

### A.3.2 Soil Lab Report

S.H.A. 73.0-27B
Rev. 6-16-06

**MARYLAND STATE HIGHWAY ADMINISTRATION**
**Office of Materials Technology**

ORIGINAL ________
ACCEPTANCE ________
OTHER ________

SOIL TEST REPORT

**DESCRIPTION & IDENTIFICATION**

Contract No. ________ Lab. No. ________ Project Serial No. ________

Date Sampled ________ F A P (s) No. ________

Material Specification ________ Quantity Represented ________

Proposal Item No. ________ Material for Use in/as ________

Material Produced by ________

Sample Taken From ________ Location/Station ________

Sampled by ________ Witnessed by ________

Project Engineer ________ Telephone Number ________ Fax Number ________

Remarks ________ Special Provisions ☐

FOR LAB USE ONLY

**TEST RESULTS**

| % BY WEIGHT PASSING SIEVES | | | | | | | | | | | MINUS NO. IO % BY WEIGHT | | | LL | PI | COMPACTION AASHO T- - | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2½" | 2" | 1½" | 1" | ¾" | ½" | #4 | #10 | #40 | #100 | #200 | Sand | Silt | Clay | ___ | ___ | * Max. Dry Den. pcf | Opt. Moist Cont., % |
| | | | | | | | | | | | | | | | | | |

Soil Classification ________ Organic Content ________% pH________ Other________

To Plot Typical Curve of Field Density Determination, use following information: *Wet Weight at Opt. Moist, ________pcf

Wet Wt. p.c.f. ________ ________ ________ ________ ________ ________

% Moisture ________ ________ ________ ________ ________ ________

Sample tested at the ________ Lab and the material represented does ________ meet specification requirements.

By:________ Date:________

REMARKS: ________

cc:
____Project Engineer
____District Office
____Landscape Operations Division
____QA Field Inspector

Contact the Landscape Operations Division at 410-545-8596 for:
____amending pH
____amending organic matter
____developing a Nutrient Management Plan

## A.3.3 Cement Lab Report

OMT85 2/2011

Design ☐
Early Break ☐
Acceptance ☐
Other ☐

MARYLAND STATE HIGHWAY ADMINISTRATION

**PORTLAND CEMENT CONCRETE TEST RESULTS**

**CONTRACT NO:** ____________ **FAP NO:** ____________ **DATE PLACED:** ________

**MIX DESIGN NO:** ____________ **PRODUCER / LOCATION:** ____________

**USE / LOCATION:** ____________ **ITEM NO:** ________ **Quantity of Test Load** ______**CY** **Total Qty Represented by This Test** ______**CY** (i.e. 8, 36 or 50 c.y.)

**FIELD TEST RESULTS – PLASTIC CONCRETE**

| | |
|---|---|
| LOAD TICKET NO: | |
| WATER CEMENT RATIO | |
| SLUMP (Inches) (AASHTO T-119) | Test 1: ____ Test 2: ____ |
| AIR CONTENT (%) (AASHTO T-152 or T-196) | Test 1: ____ Test 2: ____ |
| AIR TEMPERATURE | |
| CONCRETE TEMPERATURE (ASTM C-1064) | |
| CYLINDER NUMBERS | |
| DATE STRIPPED | |
| CURING METHOD (AASHTO T-23) | |
| MOLDED BY | |

**STANDARD/CURED ACCEPTANCE CYLINDERS (28 DAY)**

☐ AFTER MOLDING: SPECIMENS IMMEDIATELY MOVED TO STORAGE AND UNDISTURBED FOR INITIAL CURING

☐ INITIAL CURING: SPECIMENS WERE STORED AT 60 TO 80 °F IN MOIST CONDITION FOR UP TO 48 HRS

☐ FINAL CURING: AFTER COMPLETION OF INITIAL CURING AND WITHIN 30 MIN. AFTER REMOVING MOLDS, SPECIMENS WERE SUBMERGED IN SATURATED LIME WATER TANKS AT 73 ± 3 °F OR DELIVERED TO LABORATORY

NOTE: SPECIMENS NOT FOR ACCEPTANCE (Early Breaks): STORE IN OR ON THE STRUCTURE AND PROVIDE THEM THE SAME TEMPERATURE AND MOISTURE ENVIRONMENT AS THE STRUCTURE DELIVER TO LAB WITHIN 24 HRS OF REQUESTED TEST AGE

**RESULTS OF FIELD TESTS**

☐ MEETS SPECIFICATIONS

☐ DOES NOT MEET SPECIFICATIONS

SIGNED: ____________________ (Project Engineer / Rep)

**FIELD REMARKS / RESOLUTIONS:**

**LAB TEST RESULTS – HARDENED CONCRETE**

**AASHTO T-22**

| CYLINDER # | BIN # | DATE TESTED | AGE (DAYS) | STRENGTH PSI |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**DATE RECEIVED:**

**LAB REMARKS:**

**RESULTS OF LAB TESTS**

☐ MEETS SPECIFICATIONS

☐ DOES NOT MEET SPECIFICATIONS

SIGNED: ____________________ (OMT/CTD Engineer / Rep)

DISTRIBUTION: PROJECT ENGINEER / PRODUCER / REGIONAL FILE (Original)

### A.3.4 Chemical Lab Report

MATERIALS AND TECHNOLOGY
CENTRAL/NORTHERN REGIONAL LAB

INTRA-LABORATORY TESTS COORDINATION

TO: Chemical FROM: Cement DATE:

☐ MR. FINNERTY ☐ MR. FINNERTY RECEIVED:
☐ MR. KOCHEN ☐ MR. KOCHEN CONTRACT
☐ MS. SMITH ☐ MS. SMITH
☐ MS. STEWART ☐ MS. STEWART PROJECT

SAMPLE IDENTIFICATION

SAMPLE DISCRIPTION: ESSROC SPEED, INDIANA TYPE I/II LOW ALKALI

NUMBER OF SAMPLES: 1

TEST(S) REQUESTED: M85

PRIORITY STATUS
☐ FULL TEST
☐ YEARLY/CERT.
☐ Alkali

TEST RESULTS AND APPLICABLE SPECS.

| | LOG NUMBER | TEST RESULTS | Special Tests/Notes: |
|---|---|---|---|
| 1 | | (OVER) | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |

RECOMMENDATIONS AND COST

TO: FROM: DATE:

☐ MR. FINNERTY ☐ MR. FINNERTY
☐ MR. KOCHEN ☐ MR. KOCHEN
☐ MS. SMITH ☐ MS. SMITH
☐ MS. STEWART ☐ MS. STEWART

AS REQUESTED, LABORÁTORY TESTS HAVE BEEN COMPLETED AND THE RESULTS ARE INSERTED IN THE ABOVE TABLE.

TOTAL COST OF TESTING:

RECOMMENDATIONS, IF ANY:

CENTRAL/NORTHERN LABORATORY

| PHYSICAL TEST | COMPRESSIVE STRENGTH (PSI) AVERAGE OF THREE SPECIMENS | | | SOUNDNESS AUTOCLAVE % | TIME OF SET (MINUTES.) VICAT OR GILLMORE | | FALSE SET % | AIR CONTENT % | FINENESS M2 / KG BLAINE | FINENESS # 325 SIEVE % RETAINED | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 DAYS | 7 DAYS | 28 DAYS | | INITIAL | FINAL | | | | | |
| TEST VALUE | | | | | | | | | | | |
| SPECS. | MIN. | MIN. | MIN. | MAX. 0.80 | MIN. MAX. | MAX. | MIN. | MAX. | 280 MIN. 430 MAX. | MAX. 24 | |
| CHEMICAL TEST | SILICON DIOXIDE % | ALUMINUM OXIDE % | FERRIC OXIDE % | MAGNESIUM OXIDE % | SULFUR TRIOXIDE % | LOSS ON IGNITION % | INSOLUBLE RESIDUE % | TRICALCIUM SILICATE + 4.75 $C_3A$ | TRICALCIUM ALUMINATE % | CALCIUM OXIDE % | ALKALIES % Equiv. |
| TEST VALUE | | | | | | | | | | | |
| SPECS. | MIN. | MAX. 6.0 | MAX. 6.0 | MAX. 6.0 | MAX. 3.0 | MAX. 3.0 | MAX. 0.75 | MAX. 100 | MAX. 8 | | MAX .60 |

### A.3.5 Asphalt Mix Lab Report

## ATD Laboratory Mix Sample Worksheet

**Log Number:**

**Contract Number:** **Mix Number:** **Sample Date:** **Date Received:**

**Sample Type:** **Material Type:** **Tested by:** **Date Completed:** [ ]

Percent Recycled: [ ]
Maximum Sp. Gr. (Gmm):
Bulk Sp. Gr. Agg (Gsb):
Sp. Gr. Binder (Gb):
Ignition Oven Designation:
Ignition Correction Factor:
Estimated Target Gyro Wt.:
Ndesign Gyrations:
Compaction Temperature:

**Mix Properties**

| | JMF | Calc |
|---|---|---|
| VTM: | | |
| VMA: | | |
| VFA: | | |
| Pb: | | |
| Pbe: | | |
| D/Pbe: | | |

**Aggregate Wash Loss**

| **Before Wash** | |
|---|---|
| Weight Agg & Pan: | |
| Weight Pan: | |
| Weight Agg: | |
| **After Wash** | |
| Weight Agg & Pan: | |
| Weight Pan: | |
| Weight Agg: | |
| Loss Weight: | |

**Extracted Aggregate Gradation (T 30)**

| | | JMF | Weight Retained | Weight Passing | RAP % Passing | Percent Passing |
|---|---|---|---|---|---|---|
| 2 " | 50.0 mm | | | | | |
| 1 1/2 " | 37.5 mm | | | | | |
| 1 " | 25.0 mm | | | | | |
| 3/4 " | 19.0 mm | | | | | |
| 1/2 " | 12.50 mm | | | | | |
| 3/8 " | 9.50 mm | | | | | |
| #4 | 4.75 mm | | | | | |
| #8 | 2.36 mm | | | | | |
| #16 | 1.18 mm | | | | | |
| #30 | 0.60 mm | | | | | |
| #50 | 0.30 mm | | | | | |
| #100 | 0.15 mm | | | | | |
| #200 | 0.075 mm | | | | | |
| | | Pan | | | | |
| | | Wash Loss: | | | | |

**Maximum Specific Gravity (T 209)**

| | |
|---|---|
| Weight Sample & Bowl (in Air): | |
| Weight Bowl (in Air): | |
| Sample Weight (in Air): | |
| Weight Sample & Bowl (in Water): | |
| Weight Bowl (in Water): | |
| Sample Weight (in Water): | |
| Sample Volume: | |
| Maximum Specific Gravity (Gmm): | |

**Comments:**

**Bulk Specific Gravity (T 166)**

| Sample Number: | 1 | 2 |
|---|---|---|
| Sample Height: | | |
| Weight Sample (in Air): | | |
| Weight Sample (in Water): | | |
| SSD Weight Sample (in Air): | | |
| Sample Volume: | | |
| Bulk Specific Gravity (Gmb): | | |
| Percent Absorption: | | |

**Ignition Oven (T 308)**

| | |
|---|---|
| Weight Sample & Basket: | |
| Weight Basket: | |
| Sample Weight: | |
| Weight Aggregate & Basket: | |
| Weight Basket: | |
| Aggregate Weight: | |
| Weight Oven Loss: | |
| Correction Factor Used: | |
| Calculated AC % (Pb): | |
| Oven Determined AC % (Pb): | |

## A.3.6 Structures Lab Report

OMT88 05/03/04

MARYLAND STATE HIGHWAY ADMINISTRATION

# GENERAL MATERIALS SAMPLE

Original ☐
Acceptance ☐
I.A.S.T. ☐
Other ☐

**Date Sampled:** ________ **Lab No:** ________ **Project Sample No:** ________

**Type of Material:** ________ **Quantity Represented:** ________

**Contract Number:** ________ **F.A.P. Number:** ________

**Item Number:** ________ **Type of Construction:** ________

**Sample Taken From:** ________ **Plant No:** ________ **Source:** ☐ **Job Site:** ☐

**Produced By:** ________ **Trade Name:** ________

**Source of Supply:** ________

**Shipped From:** ________ ☐ **Batch** ☐ **Lot** ☐ **Heat No:** ________

**Size of Sample:** ________ **Sampled By:** ________ **Witnessed By:** ________

**Remarks:** ________

________

**Return Original form To** ________ **Regional Laboratory.**

---

**This portion of form to be completed by the Lab.**

**Date Received: In Lab:** ________ **In Testing Unit:** ________ **Lab No:** ________

**Date Put Under Test:** ________ **Date Test Completed:** ________ **Tested By:** ________

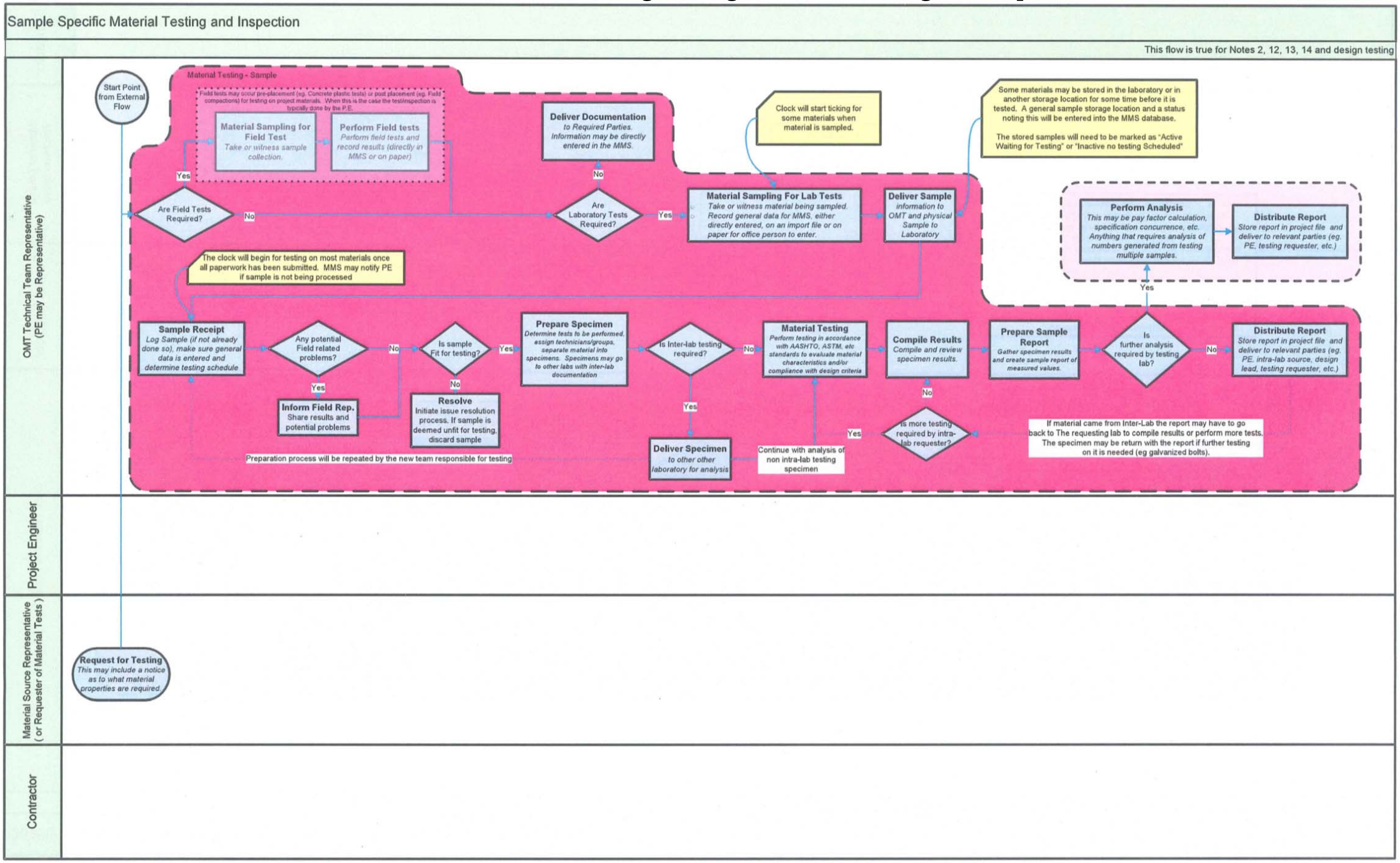
**Test Cost:** ________ **Approved By:** ________ **Recorded By:** ________

---

**LABORATORY TEST RESULTS**

## A.4 SHA Office of Materials Technology Flowchart

### Flow Chart to Illustrate the Flow of Materials Passing Through Material Testing and Inspection within SHA Laboratories



# REFERENCES


**4hSolutions** RFID vs barcode [Online]. - 2010. - August 13, 2012. - http://www.4hsolutions.com/technologies/rfid-vs-barcode.aspx.

**Adams Russ** A Web Of Information About Bar Code [Online] // Bar Code 1. - January 2012. - May 2012. - http://www.adams1.com/faq.html.

**AIM Inc.** The Layman's Guide to ANSI, CEN, and ISO Bar Code Print Quality Documents [Journal]. - Pittsburgh : The Association for Autoatic Identification and Data Capture Technologies, 2002.

**Ala-Risku Mikko Kärkkäinen and Timo** Automatic Identification – Applications and Technologies [Journal]. - [s.l.] : Helsinki University of Technology, 2006.

**Alien Technology** ALH-900x Hand Held RFID Reader Datasheet. - Morgan Hill : Alien, 2011.

**Alien Technology Corporation** ALR-9900 - Enterprise RFID Reader. - Morgan Hill : Alien, 2012.

**Alien Technology Corporation** ALR-9650 Gen 2 RFID Reader with Integrated Antenna. - Morgan Hill : Alien Technology, 2007.

**AMIS Automated Movement and Identification Solutions** Automatic Identification Technology IV [Journal] // AIT-IV Contracts Intermec Technologies Corporation. - 2013.

**Anderson Cory and DOT Iowa** Survey Questionnaire on: "The use of RFID and/or Barcodes in DOT projects" [Interview]. - College Park : University of Maryland, 2012.

**ASCE American Society of Civil Engineers** Repord Card for America's Infrastructure [Online]. - 2009. - July 31, 2012. - http://www.infrastructurereportcard.org/.

**Assetware Technology** An Easy to Understand Guide to Barcodes [Report]. - Hertfordshire United Kingdom : Assetware Technology Ltd.

**Atlas RFID Atlas RFID Solutions Inc** Construction Solutions [Online] // AtlasRFID. - 2010. - 02 13, 2012. - http://www.atlasrfid.com/Solutions/Construction.aspx.

**ATOA Air Transport Association of America** Spec 2000, About Traceability Standards [Online]. - 2011-2012. - February 07, 2013. - http://www.spec2000.com/50.html.

**Bacheldor Beth** Tego Launches 32-Kilobyte EPC RFID Tag [Article] // RFID Journal. - February 2, 2009. - p. http://www.rfidjournal.com/article/view/3850/2.

**Baracoda** Baracoda Traceability // DualRunners 2D. - [s.l.] : Baracoda, February 2010.

**Barcodes Inc.** Add Barcode Scanning to Your Apple iPad, iPhone, or iPod with Socket [Online]. - 10 25, 2012. - http://www.barcodesinc.com/news/?p=6732#more-6732.

**Barcodes Inc.** Falcon 5500 RFID Mobile Computer Data Sheet. - Chicago : Barcodes.

**BarcodesInc** 3D Barcodes [Online] // BarcodesInc. - 2010. - http://www.barcodesinc.com/articles/3d-barcodes.htm.

**Barcoding inc FAQ** What is the typical ROI of a mobile system? [Online]. - 2011. - November 2013. - http://www.barcoding.com/faq/mobile-roi.shtml.

**Barcoding Inc.** Wireless Network Installation [Online]. - 2011. - http://www.barcoding.com/services/wireless_network_installation.shtml.

**Barcoding Incorporated** Comparison of Barcode Printers [Online] // Barcoding Incorporated. - Barcoding Inc., 2011.

**Bartec** MC 9090-K [Online] // Bartec Web site. - July 2013. - www.bartec.de/.

**Bechtel Briefs** Super Power [Online] // http://www.bechtel.com. - May 2007. - 02 19, 2013. - http://www.bechtel.com/super_power.html.

**Bell Lansford C. and McCullouch Bob G.** Bar Code Applications in Construction [Journal] // Journal of Construction Engineering and Management. - 1988. - pp. 263-278.

**Bluebird Soft Inc.** Rugged Handheld Computer // Pidion BIP-6000 Series. - [s.l.] : Bluebird Soft Inc., 2012.

**Chen Jiann-Liang [et al.]** Architecture Design and Performance Evaluation of RFID Object Tracking Systems [Article] // Computer Communications. - [s.l.] : Elsevier, 2007. - Vol. 30.

**Chung Christopher A. and Jones Erick C.** RFID and Auto-ID in Planning and Logistics A Practical Guide for Military UID Applications [Book]. - Boca Raton, FL : Taylor & Francis Group, LLC, 2011.

**CipherLab** CipherLab Windows CE Mobile Computer 9400 [Online] // Cipher Laboratory Web site. - 2011. - July 2013. - www.cipherlab.com.

**Coop Phil** RFID Integrated Solutions System Optimizes Maintenance Efficiency [Online] // AERO, The Boeing Company. - 2012. - May 2012. - http://www.boeing.com/commercial/aeromagazine/articles/2012_q1/2/.

**Crew-Noble** Bar Code Labels and Readers [Online]. - June 2011. - November 2013. - http://www.crewnoble.com/BarCode.html.

**CTE** Coalescent Technologies [Online] // Automatic Data Collection, Contact Memory Button. - Coalescent Technologies Corporation, 2012. - June 20, 2012. - http://www.ctcorp.com/cap_contact_memory.html.

**DeFinis Andrew J.** Concrete Maturity Testing in Michigan [Report] : Progress Report. - Novi, Michigan : Tony Angelo Cement Construction Company, 2004.

**DoD Department of Defense** Radio Frequency Identification (RFID) Industry White Paper [Report] : White Paper. - 2006.

**Dye Management Group Inc** Materials Management System Project Functional Requirements Document [Report]. - [s.l.] : Maryland Department of Transportatoin State Highway Administration, 2008.

**Eisaku Ohbuchi Hiroshi Hanaizumi, and Lim Ah Hock** Barcode Readers using the Camera Device in Mobile Phones [Journal] // International Conference on Cyberworlds. - 2004.

**El Khaddar Mehdia Ajana [et al.]** RFID Middleware Design and Architecture [Book Section] // Designing and Deploying RFID Applications / book auth. (Ed.) Dr. Cristina Turcu. - [s.l.] : InTech, 2011. - Vols. Available from: http://www.intechopen.com/books/designing-and-deploying-rfid-applicatoins/rfid-middleware-design-and-architecture.

**Erabuild** Review of the Current State of Radio Frequency Identification (RFID) Technology, its use and potential future use in construction [Report]. - [s.l.] : Erabuild, 2006.

**ETA-Melco Elevator Co. LLC** Import & Export Script [Report]. - Dubai : Birla Institute of Technology and Science, 2005.

**FHWA and Culmo Michael P.** Accelerated Bridge Construction - Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems [Report]. - FHWA-HIF-12-013 : US DOT, Federal Highway Administration, 2011.

**Finkenzeller Klaus** RFID Handbook Fundamentals and Applications in Contactless Smart Cards and Identifications [Book]. - West Sussex, England : John Wiley & Sons Inc., 2003.

**Geier Jim** Wireless Networks First-Step [Book]. - [s.l.] : Cisco Press, 2004.

**Gizmodo** Tech By Design [Online] // Gizmodo.com. - Gizmodo, 2013. - 2013. - http://gizmodo.com/.

**GS1 Canada** Bar Code Scanning Equipment Selection Criteria: A guide to choosing appropriate scanning equipment [Journal]. - 2010.

**GS1** The Value and Benefits of GS1 System of Standards [Journal] // GS1 Automatic Identification. - 2012.

**Hammersmith Group The and Valhouli Constantine A.** Clicks & Mortar: The use of RFIDs in construction [Report]. - New York, New York : The Hammersmith Group, 2009.

**Honeywell** Optimus 5900 RFID Mobile Computer Data Sheet. - Fort Mill : Honeywell , 2012.

**Honeywell** Bar Code Symbology Descriptions [Online] // Learning Center. - 2D Technology Group, 2013. - http://www.2dtg.com/node/23.

**Honeywell** Choosing the Right Connectivity - Wireless Options That Can Save Money and Improve Productivity [Journal] // Honeywell Scanning & Mobility. - 2012.

**Huifang Deng Ying Chen** Realization of RFID Resolution Service Using “EPCIS Directory + PML” Mode with Structured Cache [Journal] // Auto, Transactions of the IRE Professional Group. - 2010. - pp. Cache, Realization of RFID Resolution Service Using “EPCIS Directory + PML” Mode with Structured.

**Hunt V. Daniel, Puglia Albert and Puglia Mike** RFID A Guide to Radio Frequency Identification [Book]. - Hoboken, NJ : A John Wiley & Sons, Inc., 2007.

**Inc. Staff** How to Use RFID Technology [Online]. - September 20, 2010. - November 2012. - http://www.inc.com/guides/2010/09/how-to-use-rfid-technology.html.

**Indrajaya Mike** [Online] // RFID Tracking System. - October 16, 2010. - May 2012. - http://www.rfidtrackingsystem.org/rfid-price-cost-of-rfid-tags/.

**Infinite Peripherals Inc.** Linea-Pro 4 // iPhone/iPod Touch 1D/2D Scanner. - [s.l.] : Infinite Perioherals Inc., 2012.

**Intensecomp** Construction Material Tracking System [Report]. - [s.l.] : Intensecomp Pte Ltd, 2004.

**Intermec Technologies Corporation** IF30 Fixer - User's Manual. - Everett : Intermec, 2009.

**Intermec Technologies Corporation** IF61 Enterprise Reader. - Washington : Intermec, 2009.

**Intermec Techology Corporation** CN70/CN70e Ultra-rugged Mobile Computers Product Sheet [Online] // Intermech Smart Systems. - 2012. - July 2013. - www.intermec.com/products/cmptrcn70a/.

**Iowa DOT Iowa Department of Transportation** Transportation Research Board of the National Academies [Online] // RFID Tags for Detecting Concrete Degradation in Bridge Decks. - 2012. - July 31, 2012. - http://rip.trb.org/browse/dproject.asp?n=28447.

**Iyer Sridhar** RFID: Technology and Applications [Report] : Powerpoint Presentation. - [s.l.] : IIT Bombay, 2005.

**Jaselskis Edward J. and El-Misalami Tarek** Implementing Radio Frequency Identification in the Construction Process [Journal] // Journal of Construction Engineering and Management. - 2003. - pp. 680-688.

**Jones Eric C and Chung Christopher A** RFID and Auto-ID in Planning and Logistics A Practical Guide for Military UID Applications [Book]. - Boca Raton, FL : Taylor & Francis Group, LLC, 2011.

**KoamTac** KDC400 Barcode/MSR SLED for Smartphone // KDC400 Specifications. - [s.l.] : KoamTac, 2013.

**Liu Yong-Min, Sun Miao-Ping and Xu Zhuo-Nong** Design of Wireless Sensor Networks for Structural Health Monitoring Applications to Damage Detection [Journal] // International Journal of Civil Engineering and Structures. - December 2012. - 1 : Vol. 1. - p. 1.

**McCraven Sue** Inventory Control Comes of Age [Article] // NPCA Precast Solutions Magazine. - May 24, 2011.

**Moselhi Osama and El-Omari Samir** Integrating Bar Coding and RFID to Automate Data Collection From Construction Sites [Conference] // Joint International Conference on Computing and Decision Making in Civil and Building Engineering. - Montreal, Canada : [s.n.], 2006. - pp. 1734-1741.

**Moselhi T. Shehab and O.** An Automated Barcode System for Tracking and Control of Engineering Deliverables [Journal]. - [s.l.] : Construction Research Congress, 2005.

**Motorola** MC9090-G Product Spec Sheet. - [s.l.] : Motorola Solutions, 2010.

**Motorola** Motorola DS9808-R Product Spec Sheet. - [s.l.] : Motorola Solutions.

**Motorola** Motorola FX7400. - [s.l.] : Motorola Solutions, 2011.

**Motorola** MOTOROLA FX9500 FIXED RFID READER. - [s.l.] : Motorola Solutions, 2011.

**Motorola** MOTOROLA MC3190-Z Business-Class Handheld RFID Reader Product Spec Sheet. - [s.l.] : Motorola Solutions, 2012.

**Motorola** Motorola MC9190-Z Handheld RFID Reader Product Spec Sheet . - [s.l.] : Motorola Solutions.

**Motorola Solutions** MC75A Series [Online] // Motorola Solutions Web site. - July 2013. - www.motorolasolutions.com.

**National Instruments** Wireless Networking Standards White Paper Series [Journal]. - [s.l.] : National Instruments, 2013. - Vol. Wireless Networking Standards.

**NRC National Research Council** Radio Frequency Identification Technologies A Workshop Summary [Journal]. - Washington, D.C. : The National Academies Press, 2004.

**O'Connor Mary Catherine** A Guide to RFID Middleware [Online] // rfidjournal.com. - RFID Journal, 2010. - https://www.rfidjournal.com/purchase-access?type=Article&id=7490&r=%2Farticles%2Fview%3F7490.

**O'Connor Mary** RFID Cures Concrete [Journal] // RFID Journal. - October 2006.

**Ogawa Shoichi and Sato Tatsuzo** Monitoring of Concrete Structures Using Passive Type RFID Tags with Sensory Functions [Conference] // The International Conference on Electrical Engineering. - Sakura City, Japan : [s.n.], 2008.

**Opticon** OPN2005 Bluetooth Companion Scanner // Product Specifications. - May 01, 2013.

**Opticon Sensors** H22 Barcode laser scanner & Color camera [Online] // Opticon Web site. - July 2013. - www.opticon.com/H22.aspx.

**Parziale Lydia [et al.]** TCP/IP Tutorial and Technical Overview [Report]. - [s.l.] : Redbooks - IBM, 2006.

**Patel Shivang** ETA –Melco Elevator Co. L.L.C. [Report] : Import and Export Script. - Knowledge Village, Dubai : Birla Institute of Technology and Science, Pilani-Dubai Campus, 2005.

**Peterson and David** How do you find GPS coordinates of your photos? [Online]. - November 2013. - http://www.digital-photo-secrets.com/tip/1401/how-do-you-find-the-gps-coordinates-of-your-photos/.

**Psion Teklogix Inc.** 7535 G2 Psion Teklogix - Handheld Computer [Online] // Psion Web site. - July 2013. - http://www.psion.com/products/handheld/7535.htm.

**Rasdorf William J and Herbert J Mark** Introduction to Automated Identification Systems - With a Focus on Bar Coding [Journal]. - [s.l.] : Journal of Computing in Civil Engineering, 2003.

**Ren Z., Sha L. and Hassan T.M.** RFID Facilitated Construction Material Management - A Case Study of Water Supply Project [Journal] // Advanced Engineering Informatics. - [s.l.] : Elsevier Ltd, April 2010. - 2 : Vol. 25. - pp. 198-207.

**RFID Journal** RFID Journal: The Cost of RFID Equipment [Online] // rfidjournal.com. - RFID Journal LLC, 2012. - August 13, 2012. - http://www.rfidjournal.com/faq/#18.

**Samuel Y.L. Yin H. Ping Tserng, J.C. Wang , S.C. Tsai** Developing a Precast Production Management System Using RFID technology [Journal] // Automation in Construction. - 2009. - pp. 677-691.

**Sandoche Balakrichenan Antonio Kin-Foo and Mohsen Souissi** Qualitative Evaluation of a Proposed Federated Object Naming Service Architecture [Journal] // IEEE International Conferences on Internet of Things, and Cyber, Physical and Social Computing. - 2011.

**Sirkanungo Ruchita** Information Management System using 2D barcodes and Cell Phone Technology [Journal]. - Ames, Iowa : Iowa State University , 2009.

**Skyetek Inc.** SkyeReader SR70 Datasheet. - Colorado : SkyeTek , 2008.

**Smarter Cipher Lab** 9500 series Industrial Mobile Computer [Online] // Motorola Solutions Web site. - 2010. - July 2013. - www.motorolasolutions.com.

**Smarter Cipher Lab** 9600 Series Industrial Mobile Computer // Specification. - 2013.

**Smarter CipherLab** CP40 Series Industrial Mobile Computer [Online] // Made for Mobility: The CipherLab CP40 Series. - 2011. - July 2013. - www.barcodesinc.com/news/?p=5270.

**Stallard Tim and DOT Michigan** Survey Questionnaire on: The Use of RFID and/or Barcodes in DOT Projects [Interview]. - [s.l.] : University of Maryland ; Michigan DOT, 2012.

**Stone Karen M. Furlani and William C.** Architecture for Discrete Construction Component Tracking [Journal]. - Gaithersburg : National Institute of Standards and Technology, 2001.

**Stuart Skip** Spotlight on: RFID in Construction [Online] // www.construction-institute.org. - Construction Industry Institute, February 04, 2010. - February 15, 2013. - https://www.construction-institute.org/news/spot-rfid.cfm?section=impl.

**Su Xiaoyong [et al.]** On The Creation of Automatic Identificaiton and Data Capture Infrastructure via RFID [Report]. - Los Angeles, CA : UCLA-WINMEC RFID Lab, 2007.

**Swedberg Claire** Alaska's Dept. of Transportation Mixes Asphalt and RFID [Journal] // RFID Journal. - 2011.

**Sweeney James** Survey Questionnaire on: “The use of RFID and/or Barcodes in DOT projects” [Interview]. - College Park : University of Maryland, 2012.

**Syscan** Syscan 2D Barcode [Online] // Syscan Technology. - 2010. - http://www.syscantech.com/en/SyscanCode/Syscan_2dcode.asp.

**Taylor J. Mark, Coady Stephen A. and Chesser Jon** Radio Frequency Identification (RFID) and Building Information Modeling (BIM); Integrating the Lean Construction Process [Conference] // Proceedings of the Twelfth International Conference on Civil, Structural and Environmental Engineering Computing. - Stirlingshire, UK : Civil-Comp Press, 2009. - Vol. 91.

**The RFID Network** What is RFID? Radio Frequency Identification [Online] // The RFID Network. - October 24, 2011. - May 2012. - RFID.net/basics.

**Thornton Frank [et al.]** RFID Security [Book]. - Rockland, MA : Syngress Publishing, Inc., 2006.

**Torrent David Grau and Calas Carlos H.** Methodology for Automating the Identification and Localization of Construction Components on Industrial Projects [Journal]. - [s.l.] : Journal of Computing in Civil Engineering. - 01 : Vol. 23.

**Unitech** RH767 RFID Handheld Reader User's Manual. - [s.l.] : Unitech Electronics Co., 2009.

**Unitech** RH767II Smart RFID Reader // RH767II Specifications. - 2009.

**Unitech** RS700 Smart RFID Fixed Reader. - Los Angeles : Enitech Electronics Co., 2009.

**Unitech Technology Corporation** Unitech 690 Mobile Computer [Online] // Unitech Web site. - July 2013. - www.ute.com.

**Unitech Technology Corporation** Unitech PA600 Mobile Computer [Online] // Unitech Web site. - July 2013. - www.ute.com.

**Vela Systems** BIM-enabled Real-Time Supply Chain Management at DPR Construction with Tekla Structures and Vela Systems [Journal]. - California : Case Study: DPR Construction , 2009.

**Ward Matt, Kranenburg Rob van and Backhouse Gaynor** RFID: Frequency, standards, adoption and innovation [Report]. - [s.l.] : JISC Technology and Standards Watch, 2006.

**Wells David** Document Tracking Reduces Repair Time & Improves Service [Journal]. - Madison : Telecome Industry, 2008.

**Wing Robert** RFID Applications in Construction and Facilities Management [Journal] // Journal of Information Technology in Construction. - 2006. - Vol. 11. - pp. 711-721.

**Wireless Dynamics Inc.** iCarte [Online] // icarte.ca. - Wireless Dynamics, 2013. - March 07, 2013. - http://www.icarte.ca/.

**Wireless Dynamics Inc.** SDiD Enabling Mobile NFC/RFID [Online] // sdid.com. - Wireless Dynamics, 2013. - March 07, 2013. - http://www.sdid.com/products.shtml.

**Wireless Dynamics Inc.** Wireless Design, Dynamic Solutions [Online]. - 2012. - 12 01, 2012. - http://www.wdi.ca/about.shtml#aboutRFID.

**WP3** A Structured Collection on Information and Literature on Technological and Usability Aspects of Radio Frequency Identification (RFID) [Report]. - [s.l.] : FIDIS (Future of Identity in the Information Society), 2007.

**Xerafy** Frequently Asked Questions on High Memory RFID [Online]. - 2013. - February 7, 2013. - http://www.xerafy.com/en/resources/frequently-asked-questions/frequently-asked-questions-on-high-memory-rfid/17.

**Yu-Cheng Lin Yu-Chih Su, Yen-Pei Chen** Mobile 2D Barcode/BIM-based Facilities Maintaining Management System [Journal]. - Taipei : [s.n.], 2010. - Vol. 43.