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16. Abstract

Radio frequency identification device (RFID) technology provides the capability to store a unique identification number and some basic attribute information, which can be retrieved wirelessly. This research project studied the feasibility of using RFID technology to support managing assets in the TxDOT right-of-way (ROW). The project focused on using RFID to support managing utilities, outdoor advertising, ROW marker/survey control, and other highway infrastructure features and attributes. Research activities included synthesizing existing information on RFID applications and specific information on utility management, conducting laboratory evaluations of the performance of RFID tags in selected buried applications, developing an integration schema for RFID application, assessing the feasibility of TxDOT using or requiring RFID to manage assets in the ROW, and identifying implementation opportunities for RFID in ROW applications. RFID markers are commercially available for identifying underground utilities and are used by some utility companies for this purpose. But no state transportation agency has required their use on a widespread basis, although one agency has used such markers during a utility relocation project and found the application to have significant benefits. The research team found that RFID technology, while widely used for inventory control, has limited application for a transportation agency in the highway right-of-way. Based on the findings generated from the activities of this project, the research team does not recommend the widespread use of RFID technologies for managing assets in the ROW. However, the research team found that there may be some benefits to using RFID technology in limited applications, such as utility relocation projects and survey monumentation.

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FEASIBILITY AND APPLICATIONS OF RFID TECHNOLOGIES TO SUPPORT RIGHT-OF-WAY FUNCTIONS: TECHNICAL REPORT

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- Ryan Bonner, Waco District;
- John Campbell, Right of Way Division
- John Ewald, Office of General Counsel;
- Don Hill, Environmental Division; and
- Dean Wilkerson, Technology Services Division.

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CHAPTER 1: INTRODUCTION

The Texas Department of Transportation (TxDOT) manages some 1.1 million acres of land that provide right-of-way (ROW) for approximately 80,000 center miles of state-maintained roads. By definition, ROW is a strip of land granted for a rail line, highway, utilities, billboards, signs, mile markers, monuments, pipelines (gas/liquids), parcels, and other transportation facilities. Managing the ROW involves tracking a large number of assets within the ROW, including:

- utility lines
  - gas (liquid or natural),
  - energy,
  - sewer,
  - telecommunications,
  - water, and
  - other types of utilities;
- roadway infrastructure
  - pavements,
  - bridges,
  - traffic signs, and
  - other infrastructure elements;
- ROW parcels; and
- other assets owned by TxDOT (such as fiber optic communication cable) and by others (such as outdoor advertising).

Each year, thousands of new assets are installed within the TxDOT ROW, many of which are underground utilities. Among these assets, tracking utility installations has been a particular challenge as many of the utility assets are located underground, were installed by others, and may have been in place for many years. In regard to the utilities located within the ROW, some are publicly or privately owned and can be found aboveground as well as underground. Whatever the ownership situation, it has become increasingly important to know the location, status, and maintenance history of these assets so that they can be protected and managed more efficiently.

Utility companies and others use many different methods to identify the location of underground utilities. One method that has become more common in recent years is the use of radio frequency identification (RFID) technology. RFID technology provides the capability to store a unique identification (ID) number and some basic attribute information, which can be retrieved wirelessly when the markers detect a radio signal from a remote reader. This technology has the potential to offer TxDOT a unique opportunity to help optimize the management of utility installations within the ROW. It could also offer TxDOT the opportunity to better manage other ROW functions (e.g., outdoor advertising, parcel information, etc.), as well as asset inventory and management needs in connection with TxDOT's own infrastructure (e.g., communication ducts, cable, boxes, manholes, signs, survey/ROW monuments, etc.).

RESEARCH OBJECTIVES

The purpose of this research is to assess the feasibility of using RFID technologies to manage various assets, particularly utilities located in the ROW and other assets that the TxDOT ROW Division is responsible for managing. This research identifies RFID technologies and the potential of those technologies to support ROW activities such as identifying utilities, outdoor advertising, infrastructure, and ROW markers. It also assesses the feasibility and costs/benefits of using RFID technology to support ROW functions. The scope of this report includes background information, current RFID technology practices, evaluation of RFID technologies, and assessment of RFID implementation potential.

POSSIBLE APPLICATIONS FOR RFID TECHNOLOGIES IN THE ROW

There are numerous assets located in the TxDOT ROW. TxDOT is responsible for a few of these assets, but others own most of them. Because of the fact that others own some of these assets, TxDOT does not always have accurate information regarding the location and other details associated with the assets. In particular, buried assets pose a management challenge because they are not visible with some degree of excavation. During the early stages of this project, the research team, in cooperation with the TxDOT panel, identified the following potential applications for using RFID technologies for managing ROW assets:

- Utilities
  - Underground utilities,
  - Aboveground utilities;
- ROW boundary information
  - Survey monuments,
  - ROW parcel information;
- Outdoor advertising
- Traffic signs and/or traffic signals
- Infrastructure elements
  - Bridges,
  - Culverts,
  - Buried infrastructure (foundations, piers, etc.);
- TxDOT's assets of significant monetary or operational value
  - Fiber optic feeds to traffic management centers,
  - Toll plazas,
  - Changeable message signs; and
- No-mow areas.

Based on input from the project panel, the research team identified the following asset applications (listed in priority order with the highest priority listed first) as the primary focus areas for the research project:

- utilities: underground and aboveground,
- outdoor advertising, and
- ROW monument and survey control.

RESEARCH ACTIVITIES

The work plan as presented in the research proposal is shown in Table 1. These tasks were divided between members of the research team at the Texas Transportation Institute and Prairie View A&M University.

Table 1. Scope of Work Research Tasks and Subtasks.

No.	Task and Subtasks
1	Conduct Kick-Off Meeting and Confirm Research Priorities/Requirements
2	Identify Current Practice
3	Conduct Webinar for RFID Applications to ROW Asset Management
4	Evaluate Feasibility of RFID Technology Options for ROW and TxDOT
5	Assess TxDOT's Ability to Implement RFID Technologies for ROW Functions
6	Develop Recommendations and Prepare Reports

CHAPTER 2: BACKGROUND INFORMATION

This section summarizes a literature review that places the research needs and corresponding research approach in proper perspective. The review highlights some of the issues most relevant to the research.

PROJECT DEVELOPMENT PROCESS AND UTILITY MANAGEMENT NEEDS

The TxDOT *Project Development Process Manual* describes the steps required to develop transportation projects from inception to construction letting (*1*). Currently, TxDOT is updating this manual to ensure consistency with the department's strategic plan, which since 2003 has formalized streamlining the 10-year Unified Transportation Program (UTP) with respect to objectives, appropriation strategies, and funding categories (*2, 3, 4*). Standard steps of the current project development process are Planning and Programming, Preliminary Design, Environmental, Right of Way and Utilities, Project Specifications and Estimate Development, and Letting (*1*). There is wide variability in the duration and timing of each major step in the project development process depending on project type, size, and other considerations.

The main participation of ROW and Utilities begins typically after the preliminary design conference, and entails the data collection for ROW and utility needs. A critical piece of information that results from the data collection is the identification of utilities that are in conflict with planned highway design. If a utility conflict exists and the utility is not in use, the utility owner may choose to abandon the utility installation in place. However, quite frequently the utility installation is operational and requires relocation.

To organize utility relocation and subsequent reimbursement activities, TxDOT encourages the use of the Utility Cooperative Management Process (UCMP) (*5*). Of interest to this review are the following process activities, including activities in the project development process that are utility-related:

- initial project notification,
- geometric schematic,
- preliminary design meeting,
- field verification,
- ROW map and property descriptions,
- ROW release,
- design conference, and
- intermediate design meetings.

The ROW utility adjustment subprocess is an integral part of the UCMP that deals with the adjustment, relocation, and accommodation of utility facilities. The process encourages compliance with federal and state laws and regulations, TxDOT Commission minute orders, and TxDOT rules and policies. This process defines the following four separate procedures to accommodate utilities: Federal Utility Procedure (FUP), State Utility Procedure (SUP), Local Utility Procedure (LUP), and Non-Reimbursable Procedure (NRP). The main differences between procedures are with regard to contracts and responsibilities among TxDOT, local participating agencies (LPAs), and utilities, in addition to reimbursement rules and eligibility.

The TxDOT *Utility Manual* outlines provisions for the inspection of utility installations (*5*). The degree of inspection may vary with the nature and location of the facility, e.g., spot checks for overhead lines and close monitoring for some underground utilities. Items subject to inspection include:

- compliance with standards, specifications, and state and federal regulations;
- verification of utility survey control and datum;
- bedding and backfilling density;
- condition of utility materials;
- vertical and horizontal clearances and alignments of proposed utility facilities with respect to other utilities and highway structures;
- placement of poles, towers, and other aboveground installations;
- control-of-access violations; and
- encasement or other protective measures.

Early detection of utility conflicts can help improve the timely adjustment of utilities or even avoid the utility relocation altogether (*6*). In the UCMP, detection of utility conflicts can occur virtually at any time. In the past, utility conflicts were typically managed at the intermediate design meetings, after delivery of environmental clearance and completion of the ROW project release. More recently, the utility conflict detection has been pushed to an earlier stage—Field Verification. Occasionally, there are outstanding utility adjustments after the project has been let, and new utility conflicts can still emerge during this period.

Collecting accurate underground utility location information during project design can be challenging. A starting point to obtain that information is as-builts from utilities. Typically, TxDOT develops design schematics for the project and then contacts utility companies that potentially have installations in the proposed location. Sometimes, utilities can provide electronic as-builts that the TxDOT engineer can overlay on the project schematics. However, available as-builts are rarely scaled or georeferenced and come in a variety of formats. As a result, the design engineer needs to convert the files to a usable format and adjust their scale and alignment to match the underlying information (e.g., planimetrics files) using prominent, discernible features such as pedestals. If the confidence in the utility information is unsatisfactory, or if the reference layer for the utility information is not available, this task can become difficult or even impossible. The incidents could have been avoided by using an engineering process called Subsurface Utility Engineering (SUE). This is one of the reasons SUE has become such a critical tool over the last two decades to help identify and locate utility installations within the ROW.

The national standard CI/ASCE 38-02 defines SUE as a branch of engineering practice that involves managing certain risks associated with utility mapping at appropriate quality levels, utility coordination, utility relocation design and coordination, utility condition assessment, communication of utility data to concerned parties, utility relocation cost estimates, implementation of utility accommodation policies, and utility design (*7*). A critical component of SUE is the attachment of a quality attribute to utility information. This attribute represents a professional opinion about utility information quality at one of four quality levels:

- Quality level D. This is the lowest level, which involves deriving utility information solely from existing records or oral recollections.
- Quality level C. This level involves surveying and plotting of visible features aboveground and correlation with quality level D information.
- Quality level B. This level uses approximate, but reproducible surface geophysical methods to determine approximate horizontal position of subsurface utilities.
- Quality level A. This level involves determining precise horizontal and vertical location through exposure of the utility at certain locations and subsequent measurement.

It is customary to undertake quality levels D and C SUE work during the schematic development phase. Quality levels B and A (normally associated with the detailed design phase) tend to be done at the discretion of the project manager. A critical aspect of the research proposed here is whether it is feasible, and to what degree, to complete certain quality level B SUE activities earlier during the preliminary design phase.

A new development in SUE technology is the gathering of subsurface imagery in 3D. Although availability of 3D subsurface data collection systems is presently limited, such systems are a growing component of SUE. The American Society of Civil Engineers' (ASCE) Committee on Collection and Depiction of Existing Subsurface Utility Data acknowledges this fact and is currently expanding the national CI/ASCE 38 standard to include 3D subsurface utility data submittal requirements.

In some states, public utilities; which mostly consist of water, electric, telecommunication and natural gas companies; are not allowed to place their lines within the right-of-way. The State of Texas, however, gives public utilities the right to bury their lines within the right-of-way (based on the Texas Utility Code and the Texas Utilities Accommodation Policy as outlined in the Texas Administrative Code) (*8*). The Texas Administrative Code contains the rules and regulations adopted by Texas government agencies. The rules are codified within the Texas Administrative Code and have the force and effect of law. One of the significant issues dealt with in the Texas Administrative Code is Utility Accommodation Rules. Utility Accommodation Code defines the minimum standards for the installation, adjustment, and maintenance of utility facilities within a transportation project or new utility installations. In other words, it outlines the manner in which utilities may install utility lines along and across highway right-of-way. The Texas Administrative Code minimum depth of cover requirements considers needs for underground identification as per Table 2.

Table 2. Texas Administrative Code Minimum Depth of Cover Requirements.

Type of Pipe	Minimum Depth of Cover (inches)
Existing lines remaining in place	12
Encased gas or liquid petroleum (under pavement)	18
Communication lines	24
Water/sewer lines	30
Encased gas or liquid petroleum (outside pavement)	30
Unencased gas or liquid petroleum (outside pavement)	48
Unencased gas or liquid petroleum (under pavement)	60

CURRENT PRACTICES OF ROW UTILITY INVENTORY AND MANAGEMENT

Knowing the location and current operating status of the utilities located within the TxDOT ROW is crucial for managing the ROW and for planning and executing transportation improvements. Unfortunately, TxDOT has no system-wide capability to capture and inventory utility interests or medium to document and display them in reference to existing and proposed transportation improvements. An earlier TxDOT research project (Project 0-2110) showed that very few districts had maps displaying exact utility locations including their elevations and none of the districts had accurate utility location (e.g., XYZ coordination) data (*9*). Although most utility installation notices included drawings or maps, a minor fraction of them were scaled and/or georeferenced. In addition, most of them did not include precise location and other necessary attribute information. Without their exact location and necessary attribute information, it is extremely difficult to effectively manage and inventory the utility facilities.

Most existing utility data sources at TxDOT do not provide a solid foundation for building a robust utility data management system. Installation notice documentation provides most of the available information. However, the quality (from the point of view of suitability for inclusion in a geographic information system) of this information is poor and the spatial coverage is sparse. Even assuming good spatial data quality, a sparse spatial coverage means that installation notice documentation alone would be insufficient for developing the utility data management system. It follows that the foundation of this system should be based on a more comprehensive data collection effort. Installation notice documentation would still play an important role, though, because it could be used to update specific utility features and attribute data on a regular basis. As opposed to installation notice documentation, SUE reports and highway improvement plan sheets typically provide enough level of detail and linear referencing information to build components of the utility data management system. Unfortunately, they represent only a fraction of the amount of utility data sources available at TxDOT.

One possible solution to address this limitation could be to use data already available in utility company databases. One of the benefits of this approach would be that a number of utility companies already have automated mapping/facility management (AM/FM) information systems in place to document their assets. Others have been using electric passive markers (locators) to locate their utility facilities. However, a number of practical reasons could prevent TxDOT from tapping into this apparently vast data source, as follows:

- Utility data management practices vary widely among utility companies. Companies that have used AM/FM systems for years may be able to document spatial and attribute data characteristics associated with their assets to a certain degree. However, other utility companies, particularly small, "mom-and-pop" type operations, tend to follow more informal approaches to asset management and, consequently, have a limited capability to document their assets effectively. Regardless of how sophisticated the information system may be, however, utility companies are under no legal obligation to share their databases and digital maps with TxDOT and/or other agencies.
- The data needs of a transportation agency such as TxDOT are usually quite different from those of a typical utility company. Like most transportation agencies, TxDOT has an aggregated interest with respect to utility installations within the ROW and focus on location, basic data attribution, and physical interaction among all utility installations located within the ROW. In contrast, utility companies have a detailed interest in the safety and operational characteristics of their own installations. The AM/FM systems available in the market focus on providing vertical integration, i.e., they are tailored to satisfy the specific operational, maintenance, and dispatching needs of individual utility companies. The electric markers, as used for years by utility companies, only provide essential information such as utility location and type. Despite the insufficient information available, this reality makes the process of exchanging and/or integrating data with other utility companies and transportation agencies difficult.
- Utility companies tend to be specialized. For example, electric utility companies do not normally operate water utilities and telephone companies do not normally operate gas utilities. In the field, however, there is considerable interaction among utilities. Still, utility data management systems tend to be utility-specific and contain limited information that may only be sufficient for their operations. For example, take the situation of an aboveground utility, knowing that the situation is even more complicated for underground utilities (e.g., different utility cables sharing the same excavations). A utility pole supports three installations, each one owned by a different utility company: an electric line, a telephone line, and a data line. Each utility company uses a separate AM/FM system to document utility assets, which results in three different system representations for the same utility pole. The coordinates assigned to the pole, as indicated in the AM/FM systems, could be different. As a result, if one overlays sample files from the three AM/FM systems, it might not be possible to determine whether the point features on the screen are representations of the same pole on the ground. Even if the point features match perfectly on the screen, it might not be possible to know with absolute certainty whether the single point represents one pole or three poles that just happen to be very close to each other on the ground. The uncertainty of not knowing what is actually installed in the field could contribute to delays in the highway design or installation notice review process, not to mention potential liabilities in case there is any conflict among utility installations or between utility installations and highway structures.

RADIO FREQUENCY IDENTIFICATION DEVICE TECHNOLOGY

Since the appearance of the first true ancestor of modern RFID in 1973 (*10*), the RFID technology has been widely used in many areas, especially in enterprise supply chain management and inventory tracking and management. The basic technology of RFID tags is the same regardless of whether the technology is used to track an inventory item in a retail store or to identify a buried utility. This section provides a brief description of basic RFID technology. RFID can be viewed as a competitor to the barcode, or a more advanced technology than the barcode. Barcode may remain the better solution, particularly in the short to medium term. However, RFID has many advantages; for example, the reader and tag do not have to be in direct line of sight, the tag can contain serial number information as well as product data, and RFID tags can be made much more rugged and durable. The major downside at present is the price of individual RFID tags and the system setup costs (*11*). Table 3 provides a comparison of the attributes for barcodes and RFID.

Table 3. Comparison of Barcode vs. RFID (*12*).

Attribute	Barcode	RFID
Positive	Low cost Broad utilization Human readable	No line of sight Large memory: data moves with product/asset Dynamic data reads
Negative	Data transfer requires line of sight Limited data storage Environmentally sensitive	Higher costs Read sensitive to product attributes Limited adoption

Components of an RFID System

RFID technology is a wireless sensor technology that is based on the detection of electromagnetic signals. A typical RFID system includes three components: an antenna or coil, a transceiver (with decoder), and a transponder (RFID tag) electronically programmed with unique information (*13*), as illustrated in Figure 1. There is emission of radio signals by the antenna in order for the tag to be activated and data to be read and written to it. Antennas establish the communication between the tag and the transceiver. The transceiver is responsible for the data acquisition. The antenna can be packaged with the transceiver and decoder in order to become a reader. An RFID reader contains a power supply and software to enable it to communicate with both RFID tags and an upstream computer system. In case an RFID tag is found in the electromagnetic zone that is produced by the antenna, it detects the activation signal of the reader. The reader decodes the data that are encoded in the integrated circuit of the tag and the data can then be transferred to any computer system for processing (*13*).

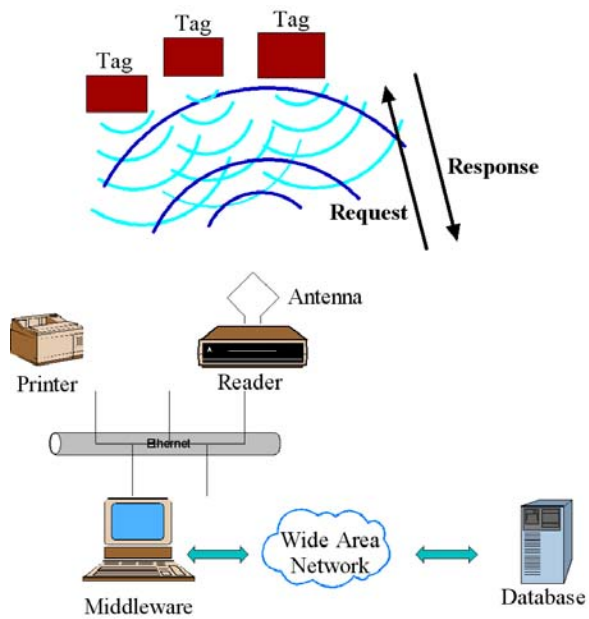


Figure 1. Typical RFID System (*14*).

Middleware is needed to form an interface between the reader and enterprise software systems such as Warehouse Management Systems (WMS). The use of RFID technology results in considerably increased volumes of data within the enterprise; the increase comes about through the addition of serial number information to each individual record, and a greatly increased number of data records (*11*).

Tags

Most RFID tags have at least two parts: 1) a silicon chip for storing information and 2) an antenna for receiving and transmitting a signal. Tags come in various shapes and sizes, depending on the application. The RFID tags typically used in shipping labels combine a tiny square chip (smaller than the head of a pin) with a 3- to 4-inch wide antenna. Two of the most common antenna shapes for shipping labels are squiggle and double cross (*15*). Typically a low frequency (LF) tag, intended for implanting into an animal, takes the form of a narrow, glass encapsulated cylinder. High Frequency (HF) and LF tags may be enclosed in a small, hard plastic package such as a key fob, or in a flat credit card sized form (*11*). The antennas for HF and Ultra High Frequency (UHF) tags can be etched onto a flexible plastic base for affixing as an adhesive label to a case or pallet. RFID tags can even be embedded into a product at the time of manufacture (*11*). Figure 2 presents samples UHF RFID tags.

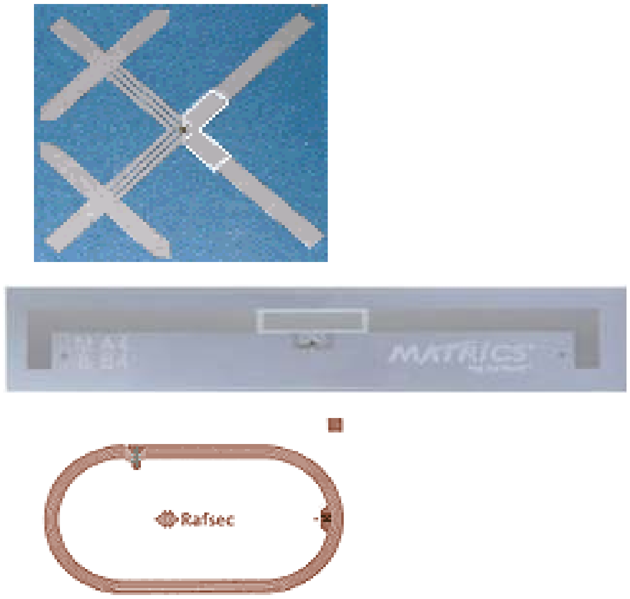


Figure 2. Sample UHF Tags (*12*).

Depending on data storage capability, RFID tags can be classified into two categories, including read-only and read/write tags. Most read-only tags do not have data storage capacity. They only have a unique ID and limited attribution prewritten to them that points to a database, thus providing information about the object to which the tag is attached (*13*).

More commonly, RFID tags are categorized into three general varieties including passive, active, and semi-passive or battery-assisted (*15*). The active RFID tags have their own internal power source that is used to power the integrated circuits and broadcast the response signal to the reader. Communications from active tags to readers are typically much more reliable (i.e., fewer errors) than from passive tags. Due to their on-board power supply, active tags may transmit at higher power levels than passive tags, allowing them to be more robust in “RF challenged” environment with humidity and spray or with dampening targets (including humans/cattle, which contain mostly water), reflective targets from metal (shipping containers, vehicles), or at longer distances. Many active tags today have operational ranges of hundreds of meters, and a battery life of up to 10 years. Active tags may include larger memories than passive tags, and may include the ability to store additional information received from the reader. However, active tags are generally bigger and more expensive to manufacture (*15*).

Unlike active RFID tags, passive RFID tags have no internal power supply. The minute electrical current induced in the antenna by the incoming radio frequency signal provides just enough power for the integrated circuit in the tag to power up and transmit a response. Most passive tags signal by backscattering the carrier wave from the reader. This means that the antenna has to be designed both to collect power from the incoming signal and also to transmit the outbound backscatter signal. The response of a passive RFID tag is not necessarily just an ID number; the tag chip can contain non-volatile, possibly writable EEPROM (Electrically Erasable Programmable Read-Only Memory) for storing data (*15*).

Semi-passive tags are similar to active tags in that they have their own power source, but the battery only powers the microchip and does not power the broadcasting of a signal. The response is usually powered by means of backscattering the RF energy from the reader, where energy is reflected back to the reader as with passive tags. An additional application for the battery is to power data storage. Semi-passive tags have three main advantages: a) greater sensitivity than passive tags, b) longer battery powered life cycle than active tags, and c) ability to perform active functions (such as temperature logging) under its own power, even when no reader is present for powering the circuitry. However, the enhanced sensitivity of semi-passive tags places higher demands on the reader concerning separation in more dense population of tags. Because an already weak signal is backscattered to the reader from a larger number of tags and from longer distances, the separation requires more sophisticated anti-collision concepts, better signal processing, and some more intelligent assessment of where each tag may be located. For passive tags, the reader-to-tag link usually fails first. For semi-passive tags, the reverse (tag-to-reader) link usually fails (or dies) first (*15*).

RFID tags can be designed to transmit at one of several frequencies. Generally, the higher frequency tags transfer data more quickly but are less able to penetrate water, grease, and other obstructions. Two of the most common frequencies are 13.56 MHz and 860-920 MHz (*15*):

- 13.56 MHz: This frequency is known as HF tags and is popular for ID badges, library books, and anti-counterfeiting applications.
- 860-920 MHz: This frequency is known as UHF tags and is the most common choice for case, pallet, and shipping container tracking.

A device called an encoder writes information to an RFID tag. RFID encoders are usually integrated with RFID readers because the two devices use many of the same components. Encoders are also commonly integrated with label printers (*15*).

Reader

An RFID reader, sometimes called an interrogator, reads the data stored on an RFID tag and passes it to a host computer for processing. A reader is essentially a box of electronic components connected to one or more antennas. The antennas emit radio signals to activate RFID tags and to read and write data (*15*).

RFID readers can be configured either as a handheld or a fixed-mount device. Readers range from large tunnel structures to devices small enough to fit inside a cell phone. The major difference is the antenna. The size and shape of an antenna varies by application, frequency and the required read range and the larger the antenna, the longer the range (*15*). Fixed location readers are mounted in one place, near a conveyor line, for example, or surrounding a dock door. Portable readers can be mounted on lift trucks or designed as handheld devices. Handheld readers typically have a short read range because their antennas are small. Figure 3 illustrates example readers and antennas.

Figure 3. Readers and Antennas (*12*).

Middleware

For data collected from RFID tags to be useful, it usually can be filtered and interpreted by multiple layers of software. RFID readers usually gather much more data than necessary and they read the same tag multiple times, or read the data stored on a tag when only portions are needed for the application. For this reason, most RFID systems require filtering software often called edgeware or middleware that recognizes the significant data and filters out the rest. Edgeware can also translate tag data into a format that can be used in other systems. This filtering and translating software can reside on the RFID reader or host computer (*15*).

Once the information has been filtered and translated into usable format, it must be interpreted and applied to business processes. Different uses of RFID require different applications software. Using RFID tags to track inventory requires an RFID-enabled management system that can identify and track inventory using the electronic product code (EPC) stored on the tags (*15*). Examples of software include:

- software (middleware) and integration requirements (in order to enable the smooth completion of the transaction using several types of tags, readers, network connectivity, etc.) and
- identification of RFID technologies for network connectivity and software (middleware) architecture.

Classification of RFID Tags and Readers

RFID tags and readers can be grouped under a number of categories (*16*). Table 4 shows the classification of RFID tags.

Table 4. Classification of RFID Tags (*16*).

Power	Passive	• Also called 'pure passive,' 'reflective,' or 'beam powered.' • Obtains operating power from the reader. • The reader sends electromagnetic waves that induce current in the tag's antenna' the tag reflects the RF signal transmitted and adds information by modulating the reflected signal.
	Semi-passive	• Uses a battery to maintain memory in the tag or power the electronics that enable the tag to modulate the reflected signal. • Communicates in the same method as the other passive tags.
	Active	• Powered by an internal battery; used to run the microchip's circuitry and to broadcast a signal to the reader. • Generally ensures a longer read range than passive tags. • More expensive than passive tags (especially because they usually are read/write). • The batteries must be replaced periodically.
Memory Type	Read-only	• The memory is factory programmed and cannot be modified after it is manufactured. • Its data are static. • A very limited quantity of data can be stored, usually 96 bits of information. • Can easily be integrated with data collection systems. • Typically are cheaper than read-write tags.
	Read/ write	• Information can be read as well as written into. • Its data can be dynamically altered. • Can store a larger amount of data, typically ranging from 32 kB to 128 kB. • Being more expensive than read-only chips makes it impractical for tracking inexpensive items.
Commu-nication Method	Induction	• Close proximity electromagnetic, or inductive coupling - near field. • Generally use LF and HF frequency bands.
	Propagation	• Propagating electromagnetic waves - far field. • Operate in the UHF and microwaves frequency bands.

Table 5 shows the classification of RFID readers.

Table 5. Classification of RFID Readers (*16*).

Function of the Device	Read	• Only reads data from the tag. • Usually a micro-controller-based unit with a wound output coil, peak detector hardware, comparators, and firmware designed to transmit energy to a tag and read information back from it by detecting the backscatter modulation. • Different types for different protocols, frequencies, and standards exist.
	Read/write	• Reads and writes data from/on the tag
Fixation of the Device	Stationary	• The device is attached in a fixed way, for example at the entrance gate, respectively at the exit gate of products.
	Mobile	• In this case the reader is a handy, movable device.

RFID Frequencies and Characteristics

The frequencies used in RFID systems typically fall into the following ranges (*17*):

- 125-134 kHz: This is the low frequency that allows the detection of RFID tags in a distance of less than 0.5 meter. This frequency is used for animal identification.
- 13.56 MHz: This frequency allows the detection of RFID tags for a distance of up to 1.5 meters. This frequency is used for applications related to access and security.
- 433-956 MHz: The frequencies that belong to this range are characterized as ultra-high frequencies. The frequencies at the range from 433 to 864 allow the detection of RFID tags for a distance of up to 100 meters, while the frequencies at the range from 865 to 956 MHz allow the detection of RFID tags for a distance that varies from 0.5 to 5 meters. Applications in logistics use the frequencies at this range.
- 2.45 GHz: This frequency enables a RFID reader to detect a tag from a distance of 10 meters. The specified frequency is used for applications related to mobile vehicle toll. In addition, the US Federal Communications Commission (FCC) has allocated spectrum in the 5.9 GHz band (*13*).

RFID Standards

The standards for RFID are developed by a number of organizations (*11*):

- International Organization for Standardization (ISO), in collaboration with the International Electrotechnical Committee (IEC) has produced a set of standards for the interface between reader and tag, operating at various radio frequencies. These standards are numbered in the series ISO/IEC 18000-n;
- International Electrotechnical Council;
- European Telecommunications Standards Institute (ETSI); and
- EPCglobal.

In addition to the global and regional standards, a system design for Europe will need to meet certain requirements defined by national standards organizations.

International Standards for RFID

There is strong interest currently in the UHF frequency band between 860 MHz and 960 MHz. The ISO standard, now in publication, is ISO/IEC 8000-6, with options for two differing communications protocols, type A and type B. It is likely that the recently agreed EPCglobal Generation 2 standard will be incorporated into ISO 18000-6 as type C (*11*).

European Standards Issues

Previously, only a relatively small amount of bandwidth at restrictively low power was available in Europe in the newly exploited band around 900 MHz. This is because the frequency range between 902 MHz and 928 MHz as used in North America is assigned to Global System for Mobile (GSM) services in Europe (*11*).

The situation has improved immensely following the recent approval by European standards bodies of the use of 10 channels at 2 Watts Effective Radiated Power (ERP) in the band from 865.6 MHz to 867.6 MHz, together with five additional lower powered channels. The European Telecommunications Standards Institute has recently produced and approved technical standards to meet these parameters (*11*). While the available bandwidth may prove to be a restriction in the long term, the increase of radio frequency power to 80 percent of that allowed in North America means that the performance in terms of range will be quite similar in both regions (*11*).

EPCglobal

The purpose of EPCglobal is to provide the technology to increase efficiency and reduce errors in the supply chain, achieved by the use of low cost RFID tags and a framework for global information exchange. EPCglobal is a joint venture of EAN International and the Uniform Code Council (UCC). EAN International has announced that it will be renamed to GS1 (*11*).

The organization has set itself tough targets in developing standards and interfaces for most of the elements of an RFID system, as follows (*11*):

- The Electronic Product Code;
- The standards for the ID system describing the functions, interfaces, and communications protocols for the reader and tag;
- EPC Middleware that will sit between RFID readers and enterprise applications, ensuring that erroneous, duplicated and redundant information is filtered out;
- The Object Name Service (ONS) that Verisign will operate under contract to EPCglobal;
- The EPC Information Service (EPC-IS) that will store, host, and provide access to serial number specific information about products as they pass along a supply chain; and
- The EPC Discovery Service providing subscribers to EPCglobal and EPC-IS with additional information about individual items for tracking and tracing purposes.

RFID Technology Advantages and Limitations

Advantages

Though RFID is a strong competitor and is gaining momentum, the following advantages suggest that by applying RFID, it will bring added value in the area of asset identification (*16*).

- Tag detection not requiring human intervention reduces employment costs and eliminates human errors from data collection.
- As no line-of-sight is required, tag placement is less constrained.
- RFID tags have a longer read range than barcodes.
- Tags can have read/write memory capability and barcodes do not.
- An RFID tag can store large amounts of data in addition to a unique identifier.
- Unique item identification is easier to implement with RFID than with barcodes.
- Tags are less sensitive to adverse conditions (dust, chemicals, physical damage, etc.).
- Many tags can be read simultaneously.
- RFID tags can be combined with sensors.
- Automatic reading at several places reduces time lags and inaccuracies in an inventory.

- Tags can locally store additional information; such distributed data storage may increase fault tolerance of the entire system.
- RFID reduces inventory control and provisioning costs.
- RFID reduces warranty claim processing costs.

Issues of Concern and Limitations

Although many RFID implementation cases have been reported, the widespread diffusion of the technology and the maximum exploitation of its potential still require technical, process, and security issues to be solved ahead of time. Today's limitations of the technology are foreseen to be overcome and specialists are already working on several of these issues, as follows (*16*):

- Standardization
- Cost
- Collision
- Frequency – The optimal choice of frequency depends on several factors, such as:
  - transmission mode,
  - behavior of tagged goods and environment, and
  - international standards in frequency allocation.
- Faulty manufacture of tags
- Faulty or deficient detection of tags
- Tags may be damaged during usage
- Adverse conditions of the environment and improper placement may corrupt reading
- Registration of data from tags that pass within range of an RFID reader accidentally
- Reader malfunction
- Quick technology obsolescence
- Security and Privacy Issues
- Possible virus attacks

Unlike many technology markets, RFID has been driven by the end user in the US such as Wal-Mart and the Department of Defense, rather than by technology suppliers (*11*). As this trend continues to evolve, more sectors of the economy appear to potentially gravitate toward implementing this technology to enhance the efficiency of their business operations.

Current RFID Technologies

RFID Hardware Manufacturers

Table 6 presents a list of vendors that specifically manufactures passive tags, active tags, and readers. As per the ABI Research industry analyst, the top three producers of UHF and HF passive RFID products were ranked as follows (*18*):

- UHF – 1) Alien Technology; 2) UHF – Avery Dennison; and 3) UHF – UPM Raflatac
- HF – 1) UPM Raflatac; 2) HF – TAGSYS; and 3) HF – Texas Instruments

Table 6. RFID Hardware General Manufacturers (*15*).

Company	Passive Tags	Active Tags	Readers	Middleware	ROW or Utility Application
3M	X		X	X	X
Accenture				X	
Accu-Sort Systems			X		
AeroScout		X	X		
Alien Technology	X				X
Avery Dennison	X				X
AWID			X		
Confidex	X				
Ekahau		X			
GlobeRanger				X	
Hi-G-Tek		X	X		
HighJump Software					
Identec Solutions		X	X		
Impinj	X		X		
InnerWireless		X			
Intermec Technologies Corp	X		X	X	
LXE			X		
Manhattan Associates, Inc.				X	
Metalcraft	X				
Metro Group				X	
Motorola	X		X		X
Omron	X		X		
RF Code		X	X		X
Savi Technology		X	X		X
Sirit			X		
Sun				X	
Provia Software Inc.				X	
Psion Teklogix			X		
TAGSYS	X		X		
ThingMagic			X		
UPM Raflatac	X				
WhereNet		X			

ABI Research selects these vendors based on a "Vendor Matrix" it creates for each product class. The matrices consider a variety of criteria within two main categories—innovation and implementation.

Capabilities of Current RFID Technologies

Table 7 outlines the capabilities of HF, UHF, and SHF tags. With the array of different tags, each one is designed to meet a specific purpose. Based on the data, this greatly assists the research team in further determining the tag frequencies that will be used in Chapter 4.

Table 7. RFID Capabilities by Operating Frequencies (12).

Capability	Operating Frequency		
	13.56 MHz HF Tags	**915 MHz UHF Tags**	**2450 MHz (2.45 GHz) SHF Tags**
Wavelength	• In the FM frequency band 22m, near field effect	• Similar to the GSM mobile phone frequency. 33cm, plane wave	• Similar to WLAN frequency (ISM band). 12cm, plane wave
Tag to Reader Field Interaction	• Near field effect • Waves circumvent around conductive substrate unless it is several meters wide and length	• Far field effect • Waves "bounce" around conductive substrates in most substrates	• Far field effect • Waves "bounce" around conductive substrates in almost all substrates
Water and Liquid Sensitivity	• Insensitive to water, snow, and other liquids even when immersed	• Read distance greatly affected by water, snow, and other liquids either in front or behind the tag	• Read distance is dramatically affected by water, snow, and other liquids
Reflection vs. Absorption	• Transmit through surfaces and substrate that contain moisture and water. Circumvent small conductive subject. Reflection from conductive surfaces larger than wavelength	• Absorption on surfaces that contain moisture and water • Reflection and bounces back from conductive surfaces that are invariably larger than wavelength	• Absorption on surfaces that contain moisture and water • Reflection and bounces back from conductive surfaces that are invariably larger than wavelength
Applications	• Can place directly on containers that contain water • Not subject to attenuation and thus read rate reduction when placed under substrates that contains moisture • Cannot be placed on metal surfaces • Longer read distance of several feet only for larger tags	• Cannot place directly on containers that contain water • May be subject to attenuation and thus read rate reduction when placed under substrates that contains moisture • Cannot be placed on metal surfaces • Longer read distance of several feet	• Cannot place directly on containers that contain water • May be subject to attenuation and thus read rate reduction when placed under substrates that contains moisture • Cannot be placed on metal surfaces • Longer read distance of several feet

RFID TECHNOLOGIES FOR UTILITY APPLICATIONS

While there are a number of manufacturers of RFID tags/markers for buried utilities, all are based on electronic marking (radio frequency emissions) technology. They can be installed at regular intervals along the facility (cable, pipe, etc.) or at key points (e.g., junctions) and located and identified with handheld locator devices. They resist moisture and varying temperatures and as a result, they have high reliability and long life expectancy.

Each marker has a unique factory-assigned identifier that can be associated with the location where it is installed. The usefulness of the first generation of RFID markers was limited since they just showed that a utility was buried at the marked location. Therefore, where more than one utility occupied the same ROW it was necessary to investigate that location to obtain more information. The next generation of passive markers incorporated the ability to include programmed information. They have a memory capacity for storing custom and pertinent data.

A series of scripts can be developed that can include various details about the associated utility. Some of the potential details can include:

- agency or company name,
- owner (likely to be redundant or synonymous with the company name),
- name of subcontractor,
- what is conveyed in the facility/utility type,
- usage status,
- location of the maker (latitude and longitude),
- depth of the facility below the surface,
- size of facility (pipe, cable, etc.) at that specific location,
- material type of facility,
- junction information,
- date installed,
- agreement with agency (if there is a subcontract),
- lease amount (if there is a subcontract),
- previous maintenance, and
- previous modifications.

Locator devices (Figure 4) are usually multipurpose and have two capabilities. The abovementioned data can be written to the chip (i.e., the markers can be programmed with the information) by means of the locator device anytime before placement of the marker in the ground. The information is also stored in the devices. Locator devices can be connected at a later time to external computers to download marker information for record management and mapping. In addition, the locator device can detect the markers from the surface (usually with an audible tone and visual indication) and remotely read the information stored in them, if the general location of the underground markers is known. Therefore, it makes it possible to locate and identify the depth and properties of an asset without excavation.

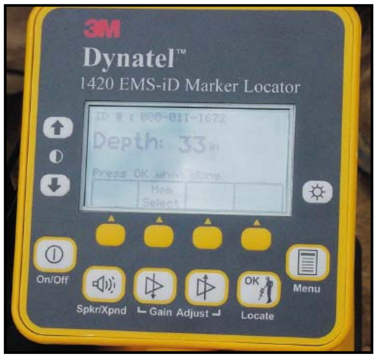


Figure 4. A Handheld Marker Locator Device, Manufactured by 3M (*19*).

Some locator devices have Global Positioning Satellite (GPS) features or the capability to interface with a GPS receiver to measure and record global GPS coordinates (latitude and longitude values) for each marker. The GPS data are also stored in the locator device to be downloaded at the end of the shift. An alternative approach is to embed the GPS data in the RFID tag. This allows a reader without GPS capability to identify the GPS coordinates of the location.

A type of RFID marker is the 4-inch diameter round balls produced by the 3M Company. The shell is tough, made of polyethylene and is resistant to the effects of moisture, minerals, chemicals, and varying temperatures. The ball contains a coil antenna and a passive RFID chip floating in a non-toxic liquid. When ball markers are placed in the ground, the internal components are automatically oriented (horizontally self-leveling component) to ensure best signal strength, regardless of the position of the ball. The balls are color coded to the American Public Works Association (APWA) standards for visual reference and distinguishing between gas (yellow), wastewater (green), potable water (blue), cable television (CATV, black and orange), telephone (orange), electrical power (red), and general purpose (purple) underground marking applications (Figure 5). Also individual standard radio frequencies (66 ~ 169 kHz) are assigned to them based on each utility type (utility-specific radio frequency signals).

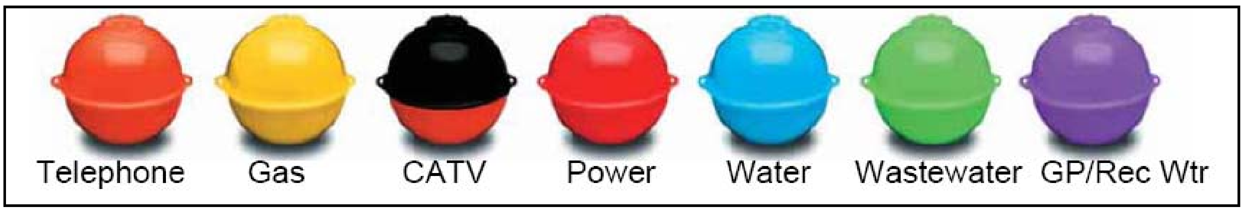


Figure 5. Color-Coded Ball Markers (*20*).

3M ball markers have adhesive labels with a bar code and unique serial number (Figure 6). Before the ball markers are placed in the ground, the labels can be removed and placed on a field map to initially record the location of the markers in the field. The labels provide another record in addition to storing the pertinent data in the marker locator device to be downloaded at the end of the shift.

Figure 6. Ball Marker with Adhesive Label (*20*).

The marker is programmed with the pertinent data before placement in the ground. The ball is buried in the ground in a measured distance above the facility (Figure 7). That distance should be accurate since it is programmed into the marker using the locator device before it is buried. The distance between the marker and the surface (which varies with grading and might be 3 to 5 ft) is not necessary to be accurate since the locator device is able to accurately measure it later. The depth of the facility will be the sum of those two distances.

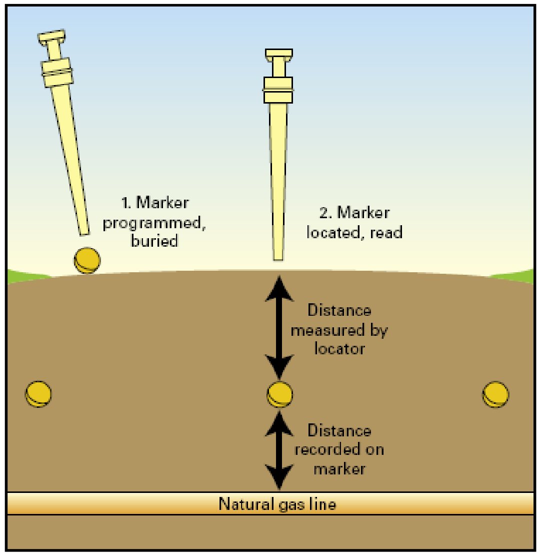


Figure 7. Ball Marker Burial and Use, Applied to Natural Gas Line (*21*).

The potential benefits of using the technology for underground infrastructures are listed as follows:

- accurate and permanent access to underground utility location and depth without need for repeated excavation;
- recording and mapping facilities;
- potential improvements in maintenance efficiency, maintenance scheduling, and field work;
- reduction of the likelihood of accidental damage and associated safety hazards during excavation or trenching;
- ensuring that future excavation, maintenance, and construction work will not compromise worker safety or the integrity of other adjacent facilities;
- identifying aging underground and aboveground infrastructures more accurately;
- easily recreating the information, if the records are lost;
- reducing the possibility of error and speeding the process of creating (if required) and updating map information.

Synthesis of Practices Supporting ROW Utility Management in the US and Overseas

Agencies in both the US and overseas use RFID technologies to some extent with respect to ROW and utilities management. Electronic marking was first adopted by telecommunication and power companies and subsequently by water and gas utilities across the country. RFID markers have been used in some projects both in the United States and out of the country. Some of the projects that applied the technology are described below.

Atlanta

At Hartsfield-Jackson Atlanta International Airport (*22*), heavy concrete markers had been used to identify the location of airport facilities. The 2 ft×2 ft×6 inches concrete markers had been installed immediately above marked features, but there were some issues in using these types of markers. For example, the markers cost about $100 each and required painting as well as ongoing attention to remove grass clippings and repair soil erosion. They could easily be displaced by mowing equipment, which could compromise facility records and excavation accuracy.

A recent airport expansion and construction of a new 9,000 ft runway required the installation of 30,000 ft of new cables, including new switchgears and transformers buried adjacent to the new runway to support navigational aids. RFID markers were placed at either side of each intermediate manhole, on each side of every system facility, and every 200 ft along straight cable runs to mark approximately 1,000 discrete locations of these buried facilities. The underground records did provide the capability to not only locate the facilities for future extension of airport taxiways, turnoff aids, and equipment replacement, but also avoid construction-related wire and cable cuts, which are extremely costly and present unacceptable safety risks and airport delays. The color of the markers installed in the airport was red for facility power cables and black/orange for fiber optic and other communication cables.

California

According to the California Underground Service Alert program and California Government Codes, utility companies should be able to locate all buried facilities with an accuracy of 2 ft or less. Sacramento Area Sewer District (SASD) (*23*) traditionally used tracer wires to satisfy mandated standards, but that technology had problems over the long haul since tracer wires could break or be damaged due to corrosion and soil conditions. SASD started applying ball markers in two individual force main construction projects (two 10-mile routes to convey wastewater). The projects passed under Interstate 5, the Union Pacific Rail Road, irrigation ditches and sloughs, and other buried utilities. They included straight-line segments and several vertical and horizontal bends. The locations where the markers were installed included turn points, around the radius of curves, every 350 ft along straight segments of the pipelines, and at cross points of the force mains with other utilities. Later, SASD included electronic marking in their current construction standards and required contractors to install electronic markers whenever a new force main was built.

Santa Clara Water District, one of the largest water districts in California, also applied an RFID system. The system developed by Wysetree Corporation consists of using RFID tags as unique identifiers, RFID readers, wireless handheld devices and a server or host computer with a location database to provide utilities with accurate information in real-time. While this solution is designed to locate underground and other fixed assets immediately and with precision, additional products for other complex enterprise management needs will be implemented in the near future (*24*).

Florida

Charlotte County in Florida (*25*) marks water and wastewater facilities, including pipe routes and key utility features (pipe deflections, Ts, junctions, service points, etc.) by using RFID ball markers as it expands its water and wastewater infrastructure. The RFID ball markers are buried along the pipeline (every 150 ft on straight runs) and also in each key feature location. Field crews store important information related to the utility (e.g., pipe type, pipe size, date of installation, depth, etc.) in the RFID markers using a marker locator just before placing them underground. The data are also stored in the marker locator along with the collected GPS data (longitude and latitude coordinates). The information will be downloaded later in a GIS database of the utility department. Additionally, the CAD department uses the data to create as-built drawings more accurately and quickly.

New Mexico

Operators of underground facilities in New Mexico (*19*, *21*) are required to specify and maintain locations and depths of all crossing points of pipelines with highways, streets, and roads according to state road-crossing legislation. Rural roads in New Mexico are gravel or dirt, and are usually graded at least twice each year. Grade levels of those roads can change depending on different conditions (local conditions, soil conditions, rain and winter runoff, and grading activity). Information about the depth of pipelines where they pass under roadways is required for road worker safety before grading is started. BP America Production Company (BP) has a policy that does not permit grader operators to use their mechanical equipment within 24 inches of buried pipelines to protect not only the road grader operators but the public and environment. To manage road crossing information in northwest New Mexico, BP applied RFID ball markers on both sides and in the center of each road crossing, maintained accurate location and depth records, and provided grading operators with that information in the map format. Using RFID marker locater, BP could also check depths of the gas pipes periodically, especially in the locations with grade shifts or line movements due to soil conditions.

Texas

Locating service-line stubs is a major issue in the gas service industry. High overhead costs are billed to the gas companies by service-line contractors due to spending hours in the field to excavate and locate service-line stubs. In some cases, companies spend additional man-hours to help contractors in locating the stubs.

Lone Star Gas Company started using electronic ball markers for marking service stubs in a new installation near Dallas and a new subdivision near Austin in 1993 (*26*). The goal of the company was to improve operations throughout the company and control lost time and long-term costs in different operation areas including overall equipment costs, contractor prices, and lost man-hours. Lone Star Gas Co. had two problems using surface markers (light plastic, metal marker, and tracer wire) before applying the new technology (electronic markers). The surface markers were not able to accurately identify where the service stub ended. Additionally, the surface markers were often damaged or removed since different contractors specializing in different fields worked on a project before gas service was connected. Losing the markers was an unrecoverable overhead expense for the company, but in the case of using marker balls, the markers were returned for future installation. Applying marker balls also resulted in lower costs for costumers in restoring their yards since there was no need for excessive excavation to locate a stub or repair surface markers.

RFID technology has also been applied at Dallas/Fort Worth International Airport (DFW) in Texas. The Federal Aviation Administration (FAA) has specified and used electronic ball markers at the airport, incorporating corresponding requirements in the various project construction designs for installation and marking of underground cables to the FAA facilities. The ball markers serve as a very useful and important tool to assist in cable locating/marking to facilitate construction or repair activity while protecting the utility and thus maintaining essential facility operation, in particular at an airport such as DFW with its extensive cable and facility infrastructure. FAA believes it provides a good surveyed database shared by both FAA and DFW airport.

Arizona and Nevada

Southwest Gas Corporation (operating in Arizona, most of Nevada, and portions of California) (*27*) adopted electronic marking technology with use of ball markers to mark service laterals, stubs and line ends (temporary), and also pipeline features such as pressure control fittings, excess flow valves, main shutoff valves and squeeze points (permanent). Marking service stubs and line ends helped contractors to connect service to new customers; locating pipeline features was necessary for repair purposes.

China

Shanghai Pudong Gas Company, Ltd. (*28*) began installing 3M ball markers in a two-square-mile site of the 2010 World Exposition to track the network of underground gas pipes and identify the locations of pipes, valves, bends, T-connectors and other components. The site includes about 13 miles of mostly polyethylene pipe, and the company intends to apply GIS and GPS technology for maximum speed and efficiency in managing underground infrastructure.

Germany

The city of Warendorf in Germany (*29*) started using approximately 5,500 RFID tags in 2003 to track the maintenance of its 127-mile network of sewage canals and pipes. It took three months to tag the pipes and the system improved the city's ability to comply with laws mandating that sewage canals be checked on a regular basis.

Scotland

Dziadak, Sommerville, and Kumar (*30*) developed a buried asset tagging and tracking system that would accurately identify the precise location of assets buried underground (non-metallic pipes) using RFID technology. More specifically, the ultimate project goal was to identify the location (depth) of buried assets up to 3 meters within an accuracy of ±5 centimeters and to relate the location of buried assets to GPS/GIS and UK's Ordnance Survey (OS) framework, and to record it to the UK's Digital National Framework (DNF).

United Kingdom

BAA Ltd. (*31*), owner and operator of seven airports in the UK, has chosen a RFID electronic marker system to record and map underground utilities. The airport's underground infrastructures are more diverse than that under the public highways, due to the additional proprietary utilities such as fuel, aircraft ground lighting, and water supplies reserved exclusively for use by the fire and rescue services. In addition to the utilities, there are many manhole chambers onsite, each housing various services. It can take hours to lift a manhole cover in order to find out what the chamber contains due to the need for safety and the complexities and weight of a manhole. BAA hopes to make significant savings in time and money by using ball markers to identify contents of manhole chambers, too.

This section investigated a broad overview of pertinent research that highlights the current state and a few of the trends associated with RFID technologies used in the utility industry. Even though the empirical evidence is limited in breath, it can already be seen that enterprises concerned with item class identification and location identification are definitely benefiting from incorporating aspects of a RFID system, or the entire RFID system, into their business operations.

CHAPTER 3: CURRENT PRACTICES

RFID type technologies have been in existence for a significant period of time and are used in different fields of industry, including transportation and transportation engineering fields. A key issue in the current research is the extent to which transportation agencies use RFID technology for ROW assets.

RFID APPLICATIONS IN TRANSPORTATION

RFID technology has been widely used in many fields where entity identification and tracking is required. Some of the engineering and industrial areas that have been popularly using RFID include retail industry, construction industry, automotive industry, and aeronautics industry (*13*). The technology has been applied in various transportation engineering fields, some of which are (*32*):

- Supply chain management. Current RFID applications in supply chain management include inventory control, electronic payment and automated transactions, access control, theft prevention, counterfeit detection, recycling and disposal management, recall management, and asset and chain of possession tracking. When integrated with roadside sensing and transportation systems, RFID also can assist with load and route optimization, regulatory screening, and security monitoring activities.
- Safety and security. RFID has been used as a component of tracking, monitoring, and reporting systems to secure the shipping of hazardous materials, secure ports, and aid in customs and border crossings. Research is also ongoing in safety applications such as using RFID for automotive collision avoidance and traveler information systems.
- System operations. RFID is currently used for transportation operations such as electronic toll and traffic management, automatic car identification, and location in rail and public transit, and commercial vehicle mainline clearance.
- Construction. Some of the current and potential applications of RFID in construction of transportation infrastructure include asphalt concrete truck load tracking, equipment and material tracking on construction sites, and supply chain tracking for critical components.
- Infrastructure management. RFID can be utilized to manage and inventory a wide range of transportation infrastructures. For example, researchers in Texas developed a Highway Reference Markers Locating System using passive long-range RFID technology to more effectively locate and manage TxDOT highway reference markers (*33*).

While the advantages of the RFID technology are evident, there have been challenges that transportation engineers and researchers need to address. As identified in previous research (*32*), immediate ones include:

- determining how to power tags on items with long lifetimes (active and semi-active tags only);
- determining the system design and installation techniques required for reading and maintaining tags in installations such as road signs and in pavement;
- determining likely performance characteristics in harsh environments;
- evaluating and certifying product sets now and in the future so that capabilities and limits are known for new applications;

- using RFID for object location determination within an acceptable precision for the application (e.g., vehicle location within a lane, stop sign location at an intersection); and
- improving security and privacy of data transferring (*34*).

RESEARCH ON APPLICATION OF RFID TECHNOLOGY IN ROADWAY ASSETS

RFID technology application in roadway assets has been used in some research. For example, the potential application of RFID in road asset management has been studied and described in a road sign asset management system (*35*), in which a roadside sign's location, type, size, height, and condition are noted and encoded onto passive RFID tags placed on the sign. Readers would be located in official vehicles to query the signs and to encode sign condition.

The Virginia Department of Transportation (VDOT) has maintenance contractors working on improving quality of interstate highways. Virginia Polytechnic Institute and State University (Virginia Tech) assesses the condition of the assets within selected segments of highways included in a section contracted for maintenance in order to monitor progress and efficiency of the contracts. The condition of the assets is collected through field inspections for VDOT where the data are analyzed and stored for future comparison. One of the issues in this asset assessment procedure was that the inspection data were not stored onsite where it was most useful to VDOT and field inspectors. To examine how RFID technology could be implemented in the VT-VDOT Partnership for Highway Maintenance Monitoring Program (HMMP) and to enhance the data storage and retrieval applications, research (*36*) was conducted with the following objectives:

- determining optimal RFID specifications for field implementation,
- purchasing RFID system that best meets the optimal specs,
- implementing RFID technology in a pilot study, and
- evaluating and determining the potential uses of RFID technology for interstate asset management if implemented in the field.

The researchers conducted a market analysis to determine the optimal RFID specifications for field implementation (based on a proposed Flow Diagram and the list of available RFID manufacturers in Construction Industry Institute 2001 Report) and also to choose and purchase an RFID system that best met the optimal specifications. The researchers found that finding a long-range read/write system that matched all the necessary characteristics, including being capable of mounting to metal, was going to be challenging. Both long-range and short-range products were available on the market, each with their own advantages and disadvantages. There were long-range systems that could read RFID tags from a distance but were not capable of storing any appreciable amount of data. The second type of system available was a short-range system that had a larger data storage capacity in which the readers were able to read and write to the tags. Finally, the researchers chose a product from each of the long-range and short-range groups using a ranking matrix analysis. They conducted a pilot study on the RFID tags that had been applied to the mile markers signs. The mile markers had been installed every tenth of a mile along the two-mile stretch of the Smart Road facility at Virginia Tech (22 total signs). The objective of the pilot study was as follows:

- checking the ability of an RFID reader to read a tag attached to a metal mile marker sign (motionless for the long-range system [from 5, 10, 25, 50, and 100+ ft] and also while

driving, and motionless for the short-range system [from 1, 2, 3, 6 inches, and 1, 2, 5, and 10+ ft]);
- determining the speed an RFID reader can travel and consistently read tag (drive past RFID tag at 10, 15, 20, 30, and 60 to 65 mph for long-range systems);
- determining the size of memory on the tag and type of information that can be stored on the tag (test storing data in memory block for short-range);
- determining the time required to write to a tag and to read a tag; and
- checking the ease of writing/reading a tag.

The researchers concluded with the following results for the pilot study:
- The long-range system can consistently read up to 115 ft from mounted RFID tags under static conditions.
- The maximum dynamic read range of the long-range system traveling at 10 mph was 115 ft.
- The short-range system can read an RFID tag mounted 1 centimeter from metal at a distance of 2 inches.
- At highway speeds, the long-range system was not very consistent and was capable of reading a tag at a maximum distance of only 25 ft.
- The short-range system, storage capacity of 2000 bits, is capable of storing the baseline asset information collected for 40 asset items.
- The tag read time for both RFID systems was less than 2 sec.

Another research study (*37*) was conducted in Virginia Tech to further analyze the long-range RFID system. The objective of the research was:
- establishing an interface between the system and inspection data,
- performing a market analysis to purchase an optimal wireless internet card as a part of the RFID-data interface,
- evaluating performance of the toolkit in predicted implementation scenarios,
- exploring possible use of long-range RFID system in conjunction with the short-range RFID system, and
- performing a total cost analysis of the entire toolkit.

The researchers created a long-range retrieval program that grasped control of the tag reading function of the long-range RFID system and displayed the correct data when wirelessly connected to the data placed online. The interface created through the retrieval program linked tag ID numbers corresponding to highway inspection data and supplemental materials. Using a scoring system and considering various factors, the wireless broadband internet card was selected and purchased (USB Modem WIC by Verizon). The researchers reiterated the static and dynamic testing of the long-range system that had been performed in the previous pilot study. They tested all facets of the retrieval program using real data and supplemental materials. The result showed that the maximum static reading distance found in the previous study was about twice the distance away when performing the same experiment. The dynamic reading distance at 10 mph found before was more than twice the distance away when performing the same experiment. At highway speeds of 60-65 mph, the reading distances in the previous pilot study were found at 25 ft, while some of the experiment trials performed in the current study did not have a tag reading until passing the mile marker. Therefore, there were noticeable negative differences between the two tests with the RFID system in the static and dynamic tag reading distances, yet the retrieval program was still able to read tag ID numbers dynamically and display the corresponding data posted online to the user. They also concluded that the asset location program of the short-range system could share results with the long-range retrieval program. The cost analysis of the toolkit showed that its implementation is expensive because of the cost and quantity figures for the tags.

One of the important issues that the researches did not address in this study is the fact that the wireless internet card was supported exclusively by the Verizon network. As a result, it might be an issue for the location with weak or without network coverage.

RFID PRACTICES IN TRANSPORTATION AGENCIES AND OTHER STAKEHOLDERS

One of the major tasks in this research project was to assess the current RFID practices for transportation agencies and other stakeholders. Researchers conducted a survey to identify the current practices in RFID technology, perspectives on any successes and failures experienced by the agencies, and knowledge of practices in other countries. The goal of the survey was addressing the following issues:

- how agencies currently use RFID technologies for ROW assets;
- what information is associated with the RFID tags;
- what lessons have been learned; and
- what would be TxDOT's use of RFID technologies in non-ROW application.

The research team decided to conduct the survey in two phases. In the first phase, the agencies and companies that currently apply RFID technology for their assets were to be identified through a preliminary survey with general questions. Then, the respondents who applied the RFID technology would be contacted for a more detailed survey in the second phase.

For the first phase, two groups were selected to be contacted: 1) transportation agencies, and 2) utility companies and public agencies responsible for utilities. The survey questionnaires included general questions to identify if the respondents used the RFID technology, and if not, what were the reasons. The survey was designed to include questions with preselected answers, but the option to add an answer was also provided. Additionally, open-ended questions were used to give respondents the opportunity to explain reasons for their answers. The questionnaires ended with a brief description of RFID use in the highway right-of-way in order to give some information about the technology to the respondents. That information was important since the respondents were asked if they were aware of other agencies' use of the technology apart from their own use. Appendices A and B provide the survey questionnaires used in this phase of the research.

The first survey was conducted via email in May 2009. The questionnaire related to this survey was sent to a list including the 54 members of the American Association of State Highway and Transportation Officials (AASHTO) subcommittee on ROW and also the 54 members of the AASHTO subcommittee on utilities.

Among all the state agencies, 16 completed survey responses were received (see Table 8). The responses were from Alabama, Colorado, Connecticut, Georgia (both ROW and Utility departments), Indiana (both ROW and Utility department), Maine, Maryland, Minnesota, Mississippi, Nebraska, South Dakota, Virginia, and Wisconsin (two responses). The survey responses showed that none of the state transportation agencies currently use RFID technology for their assets located within the state highways' rights-of-way. They do not even require using the technology for the assets of other agencies or companies that are located in the state highways' rights-of-way, but five of the respondents stated that they are considering using the technology in the future. Those states were Georgia, Maryland, Mississippi, Virginia, and Wisconsin. The agencies did not have information if other agencies or companies (such as utility companies) use RFID technology for their assets located in the right-of-way of state highways. Connecticut stated that they might consider application of RFID in their sign inventory. They have recently established a committee charged with the task of investigating the options available to establish a sign inventory to meet the possible future FHWA mandate on sign reflectivity requirements. Mississippi is also deciding to implement either barcode or RFID for managing and tracking finished traffic signs and the raw materials used to manufacture them, but they have not applied these technologies yet. Lack of evaluating or addressing the potential application of RFID technology was cited as a reason why almost all of the state agencies do not use or monitor their assets using the technology.

The second survey was conducted in June 2009. The American Public Work Association was selected as the main reference for the survey contact list in this step, since most of the APWA members are the employees of utility companies, public agencies responsible for utilities, or consultants. The questionnaire was sent to 515 APWA local chapter officers and 16 members of the APWA utility and public ROW committee. In addition to the APWA local chapter officers and utility and public ROW committee members, 20 utility companies and public agencies were selected and contacted as well.

Among all the contacts, only three completed survey responses were received from three different states: Pennsylvania, California, and South Carolina (see Table 9). One of the responses was from a utility company (gas company) and the other two were from public agencies (city) responsible for electricity and storm water drainage. The survey respondents stated that none of them currently use RFID technology for utility locating, tracking, or asset management. The respondents either have not evaluated or addressed the potential application of the RFID technology, or were waiting for the technology to mature and have greater use. The utility company intends to apply the RFID technology in the future but the two cities do not have any plan to consider using the technology in the future.

Table 8. AASHTO Subcommittee on ROW and Utilities Survey Results.

State	Name	Currently use RFID for agency assets located in ROW?	Currently require or recommend the use of RFID for others' assets located in ROW?	If does not use or monitor RFID, why?				If not currently using RFID for ROW applications, is it considering doing so in the future?	Does agency know if others that use RFID for their assets located in ROW?		Aware of other agencies that use RFID for managing ROW assets?
				Evaluated and determined that it would not be desirable to implement	Not evaluated/ addressed the potential application	Waiting for the technology to mature and/or have greater use	Other		Knows such technology is used, but does not track/ monitor the information associated with use.	Not aware of such use	
AASHTO Subcommittee – Utilities											
AL	Robert G. Lee	N	N		X						
CO	Dahir Egal	N	N			X		N		X	N
GA	Jeff Baker	N	N		X			Y[1]		X	N
ID	Matt Thomas	N	N		X			N		X	N
MD	Nelson Smith	N	N		X			Y		X	N
AASHTO Subcommittee – ROW											
CT	David Kilpatrick	N	N				2		X		N
GA	Howard (Phil) Copeland	N	N		X						
IN	Todd Shields	N	N		X			N		X	N
ME	William Pulver	N	N		X			N		X	N
MN	Peter W. Jenkins	N	N		X			N		X	N
MS	Wes Dean	N	N				3	Y		X	N
NE	Gary Britton	N	N		X			N		X	N
SD	Joel Gengler	N	N		X			N		X	N
VA	Gregory Wroniewicz	N	N		X			Y	X		N
WI	Drew Kottke	N	N		X			N		X	N
WI	Lisa Billerbeck	N	N			X		Y		X	N

1. Georgia DOT Utilities would like to explore the use in the future for managing assets and/or marking test holes (QL-A Subsurface Utility Engineering [SUE]).
2. They have just established a committee charged with the task of investigating the options available to establish a sign inventory to meet the possible future FHWA mandate on sign reflectivity requirements.
3. They have plans to implement a barcode or RFID solution for managing and tracking finished traffic signs and raw materials used to manufacture them. They hope to go forward with this plan in the next year.

Table 9. APWA Utility and Public ROW Committee and Local Chapters Survey Results.

State	Name	Company/ Agency	What type of utilities responsible for?	Currently use RFID technologies for utility locating/ tracking and asset management?	If company/agency does not use RFID for managing utility installations, why?				If not currently using RFID technology for ROW applications, is it considering doing so in the future?	Aware of other companies/ agencies that use RFID for utility locating/ tracking or asset management?
					Evaluated and determined that it would not be desirable to implement	Not evaluated/ addressed the potential application	Waiting for the technology to mature and/or have greater use	Other		
APWA – Utility and Public ROW Committee										
PA	Edward Haugh	PECO Energy Co.	Gas	Y[1]					Y	N
APWA – Local Chapter Officers										
CA	Mark Sambito	City of Moreno Valley	Electricity/ Power - Storm Drain	N			x		N	N
SC	Laura S. Cabiness	City of Charleston	Storm Water Drainage	N		x			N	N

1. Just starting to test.

The first phase of the survey revealed that not only the state transportation agencies, but almost all the utility companies and the agencies responsible for utilities do not currently use RFID technology for the asset management purposes. Furthermore, literature review showed that no agencies or companies in other countries use the technology in the large scale for their assets within ROW. Based on the literature review, the research team found out that only a few limited pilot studies have been conducted in some states and in some other countries that cannot provide any constructive conclusion due to their small size of the project and short duration of the application. No outdoor advertising companies were found that had used the technology for sign asset management.

Three different web-based survey forms had been designed for the second phase. The research team had planned to contact the respondents who had been recognized in the first phase as the users of RFID technology. They were to be contacted via email and provided with a link that guided them to the web-based survey with the detailed questions related to the application of RFID technology in ROW, but the second phase of the survey was not conducted since the results of the first phase showed that none of the respondents was applying the technology.

CHAPTER 4: BENCHMARK RFID TAG PERFORMANCE

In this effort, the researchers evaluated RFID technologies' ability to detect and read the RFID tags that can be potentially located in a ROW environment. The researchers tried to answer questions such as:

- Is the memory of RFID sufficient for storing additional information as needed?
- Can TxDOT modify the information after the tags are installed?
- To what degree will the added information affect data transfer speed and accuracy?

BENCHMARK PROCESS

The benchmarking process includes testing the most common types of RFID tags in both the laboratory and in the field environments. Of particular interest for this project is the performance of RFID technologies in underground environments (e.g., those faced by buried pipelines and monumentation) and aboveground environments (e.g., advertising billboards and traffic signals).

Selected RFID technologies for the benchmark testing were leveraged by a standard "Gen2" passive technology and a non-standard active technology that is currently commercially available. These are the most widely used and readily available technologies. The specific Gen2 passive technologies selected used tags and readers produced by Motorola. The active technologies selected used a reader and tags produced by RF Code.

METHODOLOGY FOR BENCHMARKING RFID TAG PERFORMANCE

The methodology utilized for benchmarking RFID technology performance was broken into underground and aboveground testing. Each of these will be discussed in detail in the following subsections.

Underground Testing Performed

Underground testing was facilitated through building test pits used to control affecting environmental factors. Tags were placed in these pits and measured at different levels of selected parameters. The primary parameter was depth of buried assets. Selected levels of depth were based on the Texas Administrative Code and its minimum depth of cover (distance from the surface to the top of the pipe or asset) requirements for different assets, as listed in Table 10 (*8*). The selected depths for testing were 0, 12, 18, and 24 inches.

Table 10. Depth of Cover.

Type of Pipe	Minimum Depth from Surface (inches)
Existing lines remaining in place	12
Encased gas or liquid petroleum (under pavement)	18
Communication lines	24
Water/sewer lines	30
Encased gas or liquid petroleum (outside pavement	30
Unencased gas or liquid petroleum (outside pavement)	48
Unencased gas or liquid petroleum (under pavement)	60

Source: Reference (*8*)

Other factors that would affect the RFID technologies' performance were identified as:

- soil type,
- moisture content,
- asset material, and
- both the horizontal and vertical distance from the tag to the reader's antenna.

Soil types selected for testing, based on the Unified Soil Classification System (USCS), were course grained soils (sands and gravels), fine grained soils (silts and clays), and highly organic soils (peat). Asset material types were grouped into metallic (steel, lead, iron, and copper) and non-metallic (fiberglass, polyvinyl chloride (PVC), concrete, fiber optic, and wood). Vertical antenna distance from the ground was assessed at 0, 1, 2, and 3 ft. Horizontal antenna distance from the tag was assessed at 0, 1, 2, 3, and 4 ft. A total of 128 trials were performed for each active and passive tag.

Above Ground Testing Performed

Aboveground testing utilized existing billboard structures that varied in selected parameters. Selected parameters for testing the performance of the elevated assets were vertical tag distance from surface (V1), vertical antenna distance from ground (V2), and horizontal antenna distance from the tag (H), as shown in Figure 8. The levels of each parameter were 40, 30, 20, and 10 ft for V1; 4 ft for V2; and 30, 20, 15, and 10 ft for H. Given the distances of interest, only active technologies were utilized.

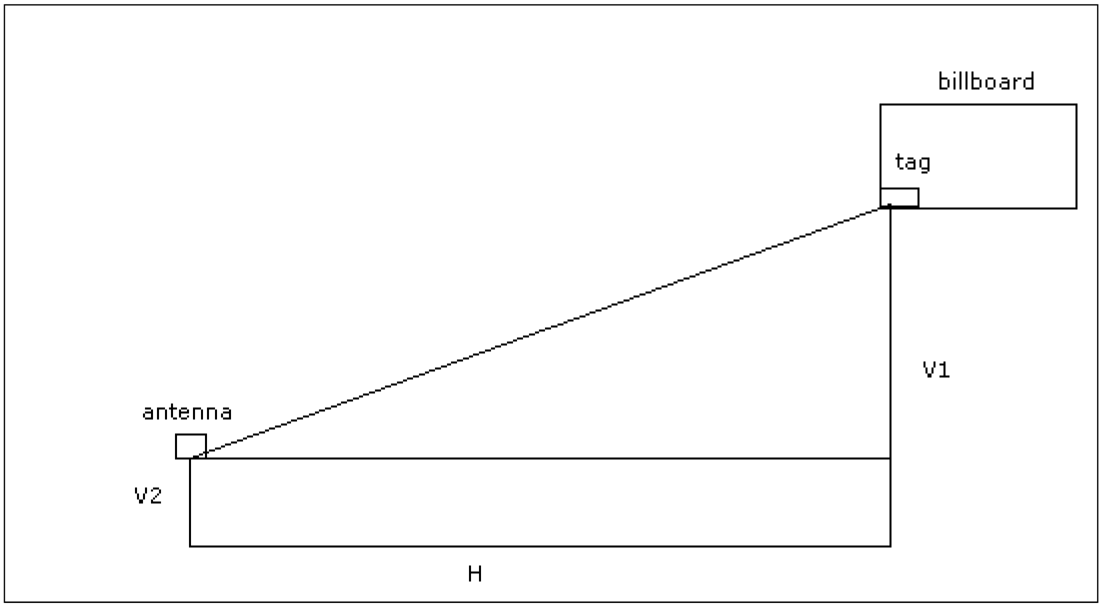


Figure 8. Graphical Representation of Parameters.

TEST RESULTS AND ANALYSIS

As mentioned earlier, a total of 128 trials were performed for each active and passive tag. The data collected were analyzed using the analysis of variance (ANOVA) statistical method. The justification for using the ANOVA method was based on the need to determine the effect of more than one factor on differences in the dependent variable as well as determine whether a significant relation exists between variables. Detailed results are presented next.

Underground Test Results for Passive and Active Technologies

The independent variables that were significant to model were:

- material type,
- buried tag depth,
- vertical antenna distance from the ground, and
- horizontal antenna distance from the tag.

The interactions that were significant to model were:

- material type and buried tag depth;
- material type and vertical antenna distance from the ground;
- material type and horizontal antenna distance;
- buried tag depth and vertical antenna distance from the ground;
- buried tag depth and horizontal antenna distance from the tag;
- vertical antenna distance from the ground and horizontal antenna distance;
- material type, buried tag depth, and vertical antenna distance from the ground;
- material type, buried tag depth, and horizontal antenna distance from the tag;
- material type, vertical antenna distance from the ground, and horizontal antenna distance from the tag;

- buried tag depth, vertical antenna distance from the ground, and horizontal antenna distance from the tag; and
- material type, buried tag depth, vertical antenna distance from the ground, and horizontal antenna distance from the tag.

The means for determining whether these factors are significant was that the p-value for these factors and their interactions had values less than 0.05, which meant the null hypothesis was rejected. When using the coefficient of determination, R-square values over 70 percent indicate that the model represents and predicts future performance of the modeled parameters. Generally, values between 60-69 percent are acceptable in a real world setting. In our evaluation, we determined that the R-square value equals 87.16 percent and this indicated that the model was acceptable for determining performance.

Moreover, Table 11 provides the numerical data for the four factors that were modeled. The variables found in the table are explained as follows:

- **Degrees of Freedom (DF)** – a full factorial design with factors F1, F2, F3, and F4, and a blocking variable.
- **Sum of Squares (SS)** – is the sum of squared distances.
- **Sum of Square Total** – is the total variation in the model.
- **Sum of Square Block** – is the variation in the data explained by the blocking variable.
- **SS (F1), SS (F2), SS (F3), and SS (F4)** – are the deviation of the estimated factor level mean around the overall mean. They are also known as the SS between treatments.
- **Sum of Square Error** – is the deviation of an observation from its corresponding factor level mean.
- **Sequential SS** – is the unique portion of the sum of squares explained by a term given any previously entered terms. The mini tab breaks down the SS regression or treatment component of a variance into sequential SS for the main effects, interactions, blocks, and each covariate. The sequential SS depend on the order the terms are entered into the model.
- **Adjusted (Adj) SS** – is the unique portion of SS regression explained by a factor, given all other factors in the model, regardless of the order they were entered into the model. The mini tab breaks down the SS regression or treatments component of variance into the Adj SS for the main effects, interactions, blocks, and each covariate. The Adj SS do not depend on the order the factors are entered into the model.
- **Adjusted Mean Square (Adj MS)** – the formula for the Adj MS is $AdjMS = \frac{AdjSS}{DF}$.
- **F** – determines whether the interaction and main effects are significant. The formula is $F = \frac{MS(Factor)}{MS(Error)}$. The DF for the test is numerator equal DF of factor and the denominator equal DF for error. Larger values of F support rejecting the null hypothesis when there is not a significant effect.
- **P** – is here instead of p-value. It is used in hypothesis tests to help decide whether to reject or fail to reject a null hypothesis. The p-value is the probability of obtaining a test statistic that is at least as extreme as the actual calculated value, if the null hypothesis is

true. A commonly used cut-off value for the p-value is 0.05. For example, if the calculated p-value of a test statistic is less than 0.05, you reject the null hypothesis.

- **S** – is the estimated number of α (type I error). The estimated standard deviation of the error in the model. Note that S = MS Error.
- **R-square** – is coefficient of determination, and indicates how much variation in the response is explained by the model. The higher the R-sq, the better the model fits the data. The formula is $R - square = 1 - \frac{SSError}{SSTotal}$.
- **R-square Adjusted (R-sq [adj])** – accounts for the number of factors in the model. The formula is $R - sq(adj) = 1 - \frac{MS(Error)}{SSTotal / DFTotal}$.

Table 11. Analysis of ANOVA for Four Factors.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	3	2.605	2.605	0.868	2.01	0.112
Material type (F1)	1	34.689	34.689	34.689	80.27	0
Buried tag depth (F2)	3	499.030	499.030	166.343	384.90	0
Vertical antenna distance (F3)	3	14.530	14.530	4.843	11.21	0
Horizontal antenna distance (F4)	4	648.241	648.241	162.060	374.99	0
F1 * F2	3	38.980	38.980	12.993	30.07	0
F1 * F3	3	6.555	6.555	2.185	5.06	0.002
F1 * F4	4	23.053	23.053	5.763	13.34	0
F2 * F3	3	64.627	64.627	7.181	16.62	0
F2 * F4	3	145.009	145.009	12.084	27.96	0
F3 * F4	4	142.947	142.947	11.912	27.56	0
F1 * F2 * F3	9	19.702	19.702	2.189	5.07	0
F1 * F2 * F4	12	41.747	41.747	3.479	8.05	0
F1 * F3 * F4	12	31.734	31.734	2.645	6.12	0
F2 * F3 * F4	36	177.303	177.303	4.925	11.40	0
F1 * F2 * F3 * F4	36	53.166	53.166	1.477	3.42	0
Error	477	206.145	206.145	0.432		
Total	639	2150.061				
S = 0.657397 R-Square = 90.41% R-Sq(adj) = 87.16%						

From Table 11, we were able to obtain the effects of the four factors that are significant. In Figure 9, the effect of material type is significant and the tags with metal get better reads than those of non-metal. As shown in Figure 10, the effect of buried tag depth is significant. The difference in the readings between the two material types when buried at 0 inches and 12 inches is large. However, the difference between the two material types when buried below 12 inches does not change very much.

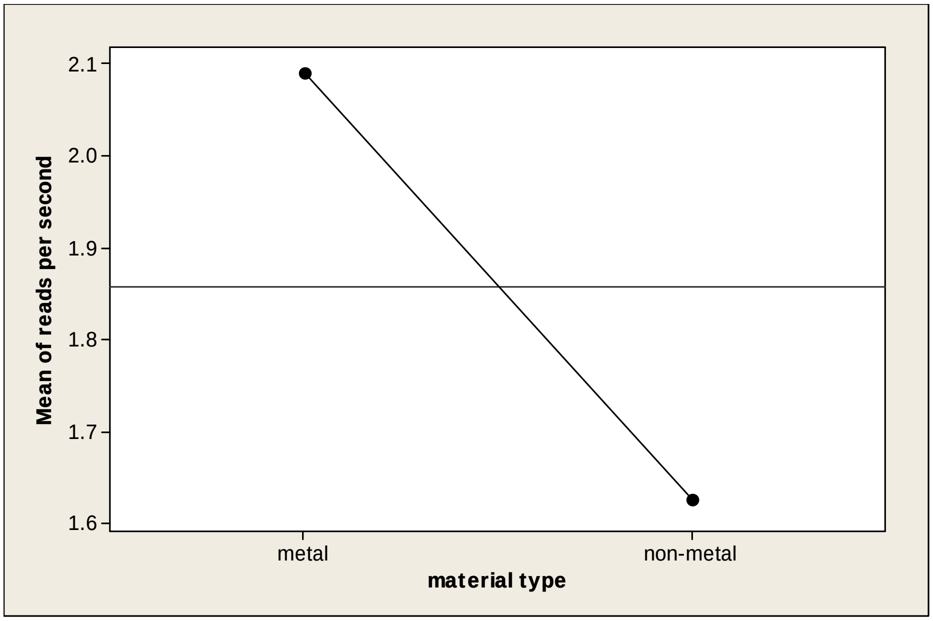


Figure 9. Main Effect of Material Type.

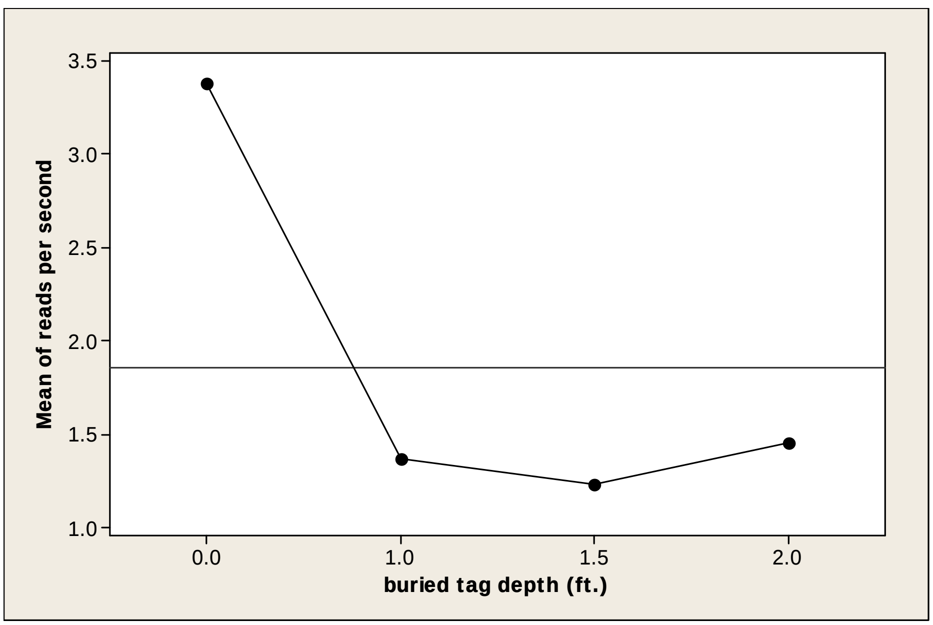


Figure 10. Main Effect of Buried Tag Depth.

As shown in Figure 11, the vertical antenna distance does not have an influential impact on the results; nevertheless, we get the best reads with a 1 ft vertical antenna distance. As shown in Figure 12, the horizontal antenna distance has significant effect on the response and the number of reads per second decreases as the horizontal antenna distance increases.

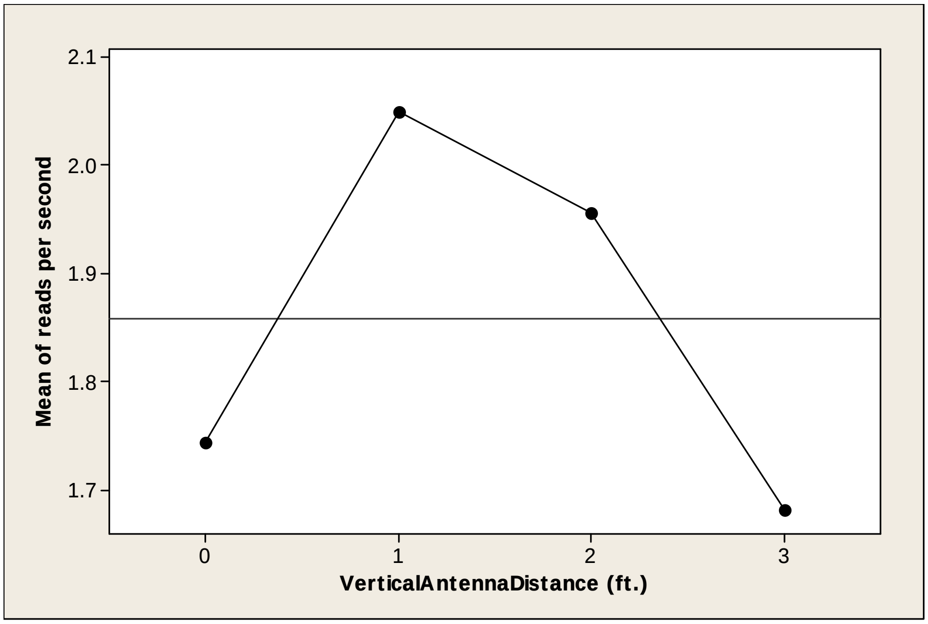


Figure 11. Main Effect of Vertical Antenna Distance.

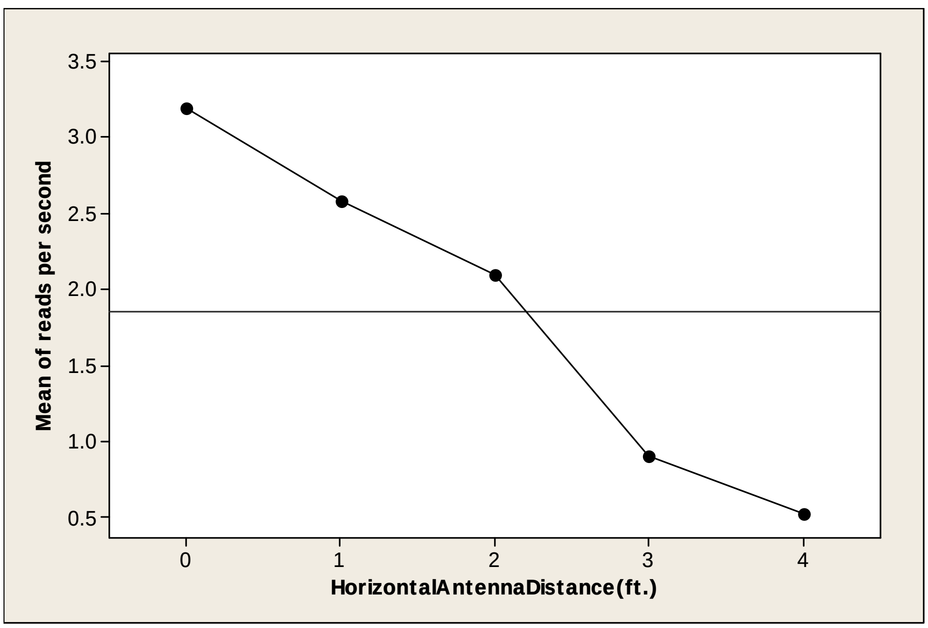


Figure 12. Main Effect of Horizontal Antenna Distance.

Figure 13 displays results similar to the ANOVA output and they are all non-significant.

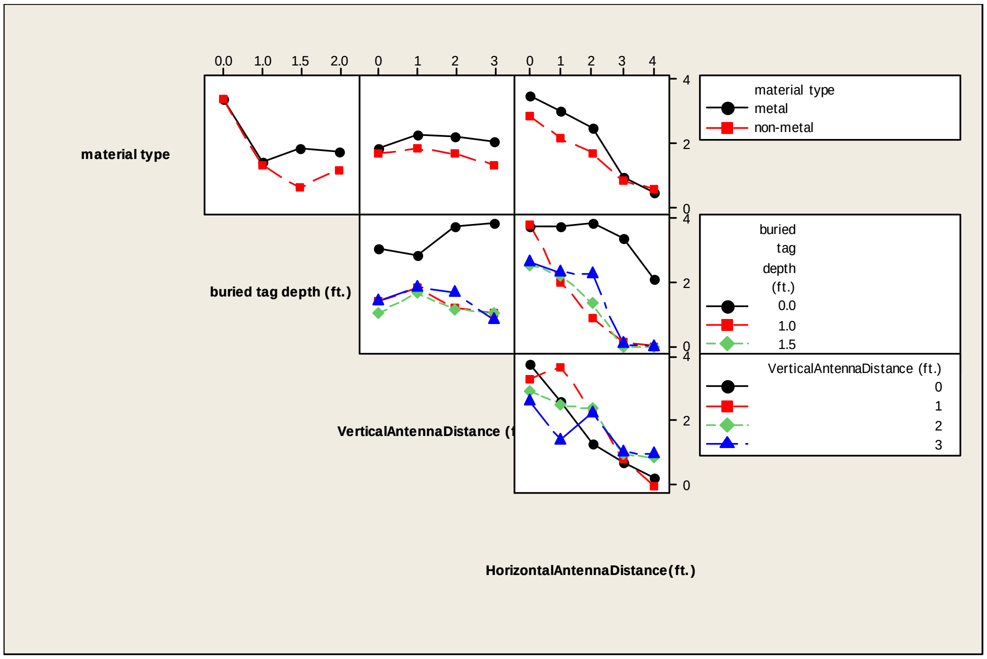


Figure 13. Interaction of the Four Factors.

Moreover, by ignoring the importance of the buried tag depth and the pipe material, the antenna placement would have to be evaluated. Table 12 shows the number of trials in which the tag was successfully read, and Table 13 represents these values as the percentage of trials where the tag was successfully read for each antenna position. The rows and columns were summed to form an average read percentage for each vertical distance and each horizontal distance, respectively.

Table 12. Number of Successful Reads.

Percentage of Reads		Antenna Distance (Horizontal)/ft					
		0	**1**	**2 3**		**4**	
Antenna Distance (Vertical)/feet	0	32/32	24/32	12/32	8/32	4/32	80/160
	1	28/32	31/32	24/32	10/32	0/32	93/160
	2	27/32	26/32	21/32	9/32	8/32	91/160
	3	28/32	14/32	22/32	10/32	8/32	82/160
		115/128	95/128	79/128	37/128	20/128	

Table 13. Percentage of Reads.

Percentage of Reads		Antenna Distance (Horizontal)/ft					
		0	**1**	**2 3**		**4**	
Antenna Distance (Vertical)/feet	0	100	75.00	37.50	25.00	12.50	50
	1	87.50	96.88	75.00	31.25	0	58.12
	2	84.38	81.25	65.62	28.12	25.00	56.88
	3	87.50	43.75	68.75	31.25	25.00	51.52
		89.84	74.22	61.72	28.91	15.62	

The sum of each column can be translated to a graph to visually represent the effect that the variable horizontal antenna distance has on the probability of a successful read. This is demonstrated below in Figure 14. It can also be seen that by placing the reader at 0 ft or directly at the ground level, the tag has a reliable read 90 percent of the time. The graph also shows a steady decrease in the read percentage; however, after 2 ft there is a significant decrease and the read rate percentage falls to 29 percent.

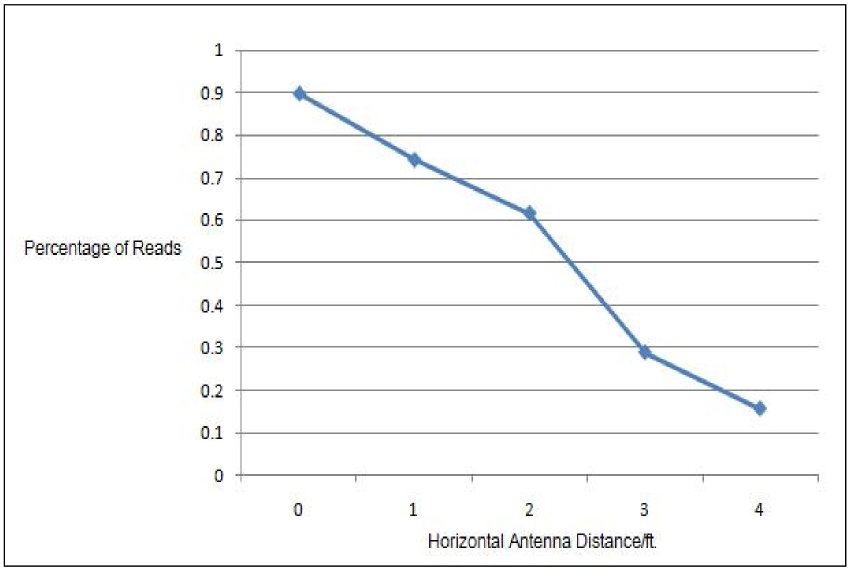


Figure 14. Percentage of Reads with Horizontal Antenna Distance.

Similarly, the vertical antenna distance can be evaluated by summing the rows to find the overall percentage for each distance, which is shown in Figure 15. There is very little change (8 percent difference) between the trials at each of the four vertical heights.

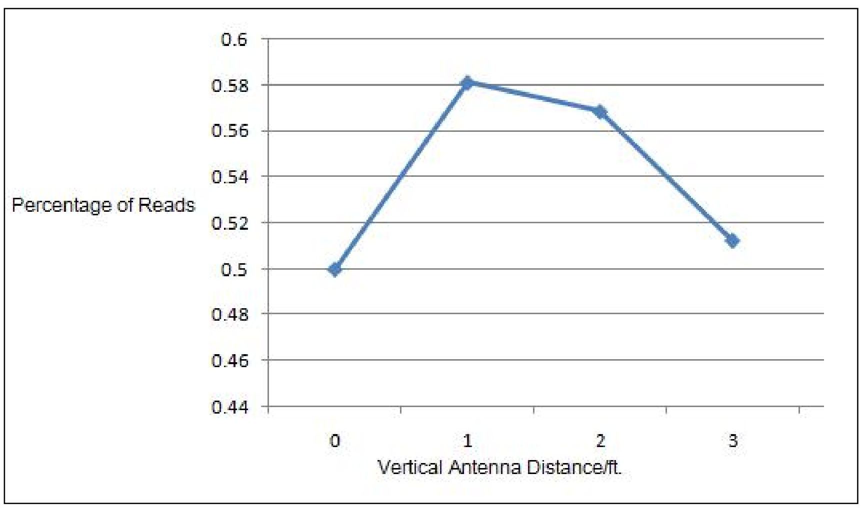


Figure 15. Percentage of Reads with Vertical Antenna Distance.

Using Table 12, Table 13, Figure 14, and Figure 15, we can see that the percentage of reads falls quickly as the horizontal antenna distance increases. It was determined that the tag can be read at least 60 percent of the time when the horizontal distance is no more than 2 ft. This percentage increases as the reader gets closer to the tag. By comparison, the percentages of reads do not change significantly with the variety of vertical antenna distance. Therefore, we can say that the horizontal distance has a greater effect than the vertical distance of the reader.

Lastly, when performing underground testing of the active technology, the test results showed a 100 percent performance rate for all selected parameters.

Aboveground Test Results for Passive and Active Technologies

Aboveground testing of passive technologies was not performed due to project constraints and previous assessments of the technology not having sufficient capability to show results at the test parameters. However, aboveground testing with active technologies gave a 100 percent performance rate with all measured factors.

CONCLUSIONS

When testing the active technology, it showed the capability to perform in both environments of interest for all selected parameters. Passive technology test results revealed that it was not capable of performing in the aboveground environment and it had limitations while being tested underground. As distances below the ground increased, the readability decreased and as the distance between the reader and the ground decreased, the readability increased. The maximum testing depth was 24 inches, but minimum standards for some assets were 60 inches deep or deeper. Based solely on the results obtained from the benchmarking methodology, one option to consider is the proposal of a simplified system consisting of active technologies to perform all prescribed functions associated with underground and aboveground ROW applications. However, with additional testing of other technologies, a combined active/passive system could also be considered.

CHAPTER 5:
OPERATIONAL PERFORMANCE TESTING
OF RFID TECHNOLOGIES

In conducting the operational performance test of the various RFID technologies, the methodology used was based primarily on the conclusions and the baseline results of the benchmarking subtask discussed in Chapter 4. Protocols were developed to test each technology listed in Table 14 in both the aboveground and underground environments. The remaining sections of this chapter present the details of the operational testing.

Table 14. RFID Technologies for Testing Consideration.

Readers	Tags	RFID Category	Aboveground	Underground
Motorola	Motorola	Passive	✓	?
Motorola	Confidex	Passive	✓	✓
Motorola	Smartmark	Passive	✓	✓
3M Locator	3M – ID Ball Marker 3M – Near Surface Marker	Passive	?	✓
RF Code Mobile RF Code Fixed	RF Code	Active	✓	?

PROTOCOL FOR UNDERGROUND APPLICATIONS (UTILITIES)

In order to simulate field behavior conditions, several parameters were taken into consideration with regard to developing the protocol for underground applications. A few of the parameters were extracted from the Texas Administrative Code (*8*) regarding minimum depth of cover requirements. Other parameters included soil types, moisture content, compaction, and the various type of industry standard utility piping.

Using USCA information, the general soil map of Texas' four native soil types were identified. The four soil types were purchased from Brenham Ready Mix, Incorporated and tested by Terracon Consultants, Incorporated. The specific soil types are: clay, concrete sand, limestone, and silty sand. These soil types are commonly used for burying utilities and provide a good representation of soil located in the ROW.

Terracon Consultants, Incorporated was responsible for performing the following initial test on the soil samples:

- Atterbery Limits Determination,
- Percent Passing No. 200 Sieve,
- Moisture Content Determination,

- Standard Proctor (ASTM D 698), and
- Minimum/Maximum Relative Density.

During the actual testing of the RFID tags, Terracon Consultants, Incorporated was responsible for performing the following test:

- Nuclear Density and Moisture Field Test Measurements.

These field tests provided soil compaction and moisture content measurements for each soil time used in the laboratory experiment. Regarding the industry standard utility piping, the research team procured piping samples used for gas, storm sewer, cable television, sewer, and water. Figure 16 presents pictures of each sample.

Figure 16. Utility Piping Samples.

In the early stages of developing the protocol, the surfaces of each type of piping was considered. Knowing the surface type would assist in determining how to best affix the RFID tags to be buried with the pipe. The picture below is an example of this thinking. However, since one of the RFID tags does not require being attached to the piping, the research team adjusted the protocol to accommodate consistency in the testing of all tags.

PROTOCOL FOR ABOVEGROUND APPLICATIONS (ADVERTISING AND MONUMENTATION)

The protocol for aboveground applications was designed for capturing data related to advertising signs and monumentation sites. The outdoor advertising sign permit application was used as a starting point for designing the protocol. The protocol allows the tags to be read from two different positions, fixed and mobile, respectively. The fixed position would require an individual to use a handheld reader to read the tag. The mobile position allows an individual to use a special reader that will read the tag while riding in a vehicle. Moreover, the monumentation protocol is developed for having the tag read using only the handheld reader.

UNDERGROUND APPLICATIONS – PASSIVE AND ACTIVE RFID TECHNOLOGY

Testing Environment and Tests Performed

Four test pits were built and the four different soil types (clay, concrete sand, limestone, and silty sand) mentioned earlier were used to simulate homogenous underground conditions to further investigate the operational performance of the Gen2, 3M, and RF Code technologies. The testing was performed in a laboratory environment and a few pictures of the pits as well as placement of the tags throughout the different pits are shown in Figure 17.

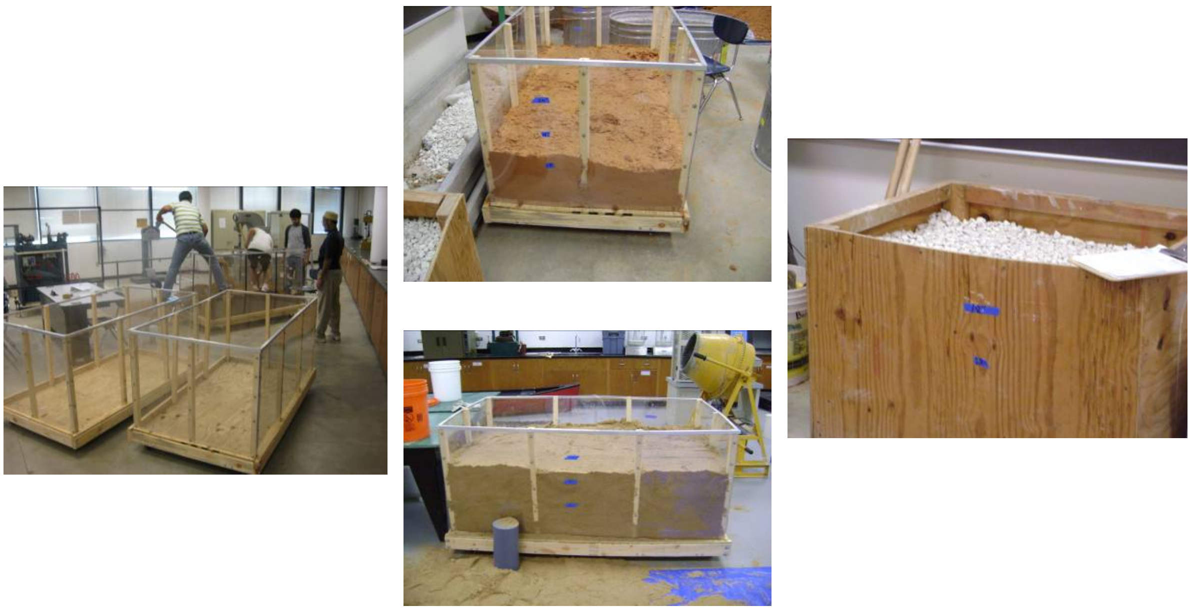


Figure 17. Soil Testing Pits.

The protocol used in collecting data captured readings of RFID tags and markers buried at depths ranging from 12 inches to approximately 68 inches. The maximum vertical heights and horizontal distances of the RFID readers from the buried tag ranged from 36 inches and 48 inches, respectively. Each time a new layer (lift) of soil was added to a respective pit, soil compaction and moisture content measurements were taken. Values for these measures are displayed in the section on test results and analysis. Figure 18 illustrates this process.

Figure 18. Data Collection Using Motorola Reader and Nuclear Density and Moisture Content Measurements Apparatus.

In preparation for testing the 3M near-surface and marker ball tags, four holes with diameters of approximately 12 inches were dug and a number of markers were coded with preliminary schema related information. These markers were placed in four holes that varied in depths ranging from 24 inches to approximately 68 inches. Once the markers were dropped into the respective hole, one of the four different soil types (clay, concrete sand, limestone, and silty sand) was placed in as backfill and compacted using a taper and/or jumping jack. The buried depths of the markers were measured and the 3M Locator's vertical heights and horizontal distances were collected for each marker reading trial. The 3M Locater's maximum vertical heights and horizontal distance field readings ranged from 36 inches to 48 inches, respectively. Compaction and moisture content measurements of the soil in each hole were recorded as well.

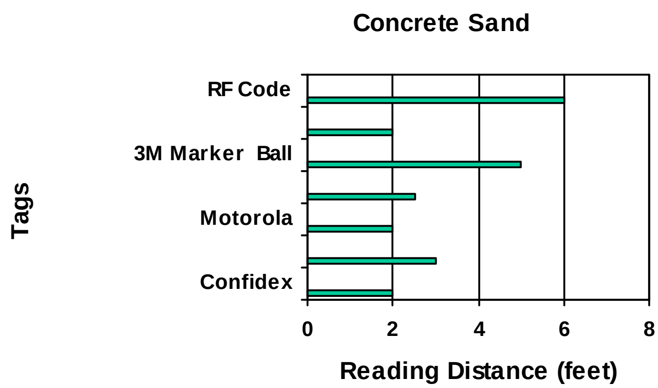
Figure 19. Data Collection Using 3M Technology.

Test Results and Analysis

Table 15 lists the manufacturer's specifications for the various passive and active RFID tags tested. The performance results associated with each soil type, as well as the respective compaction and moisture content values are shown in Figure 20 through Figure 23. For each soil type, the 3M (passive) and RF Code (active) technologies out-performed the other vendors consistently. This is a clear indication that these two technologies are prime candidates to consider when determining the type of system to recommend for underground applications with the ROW.

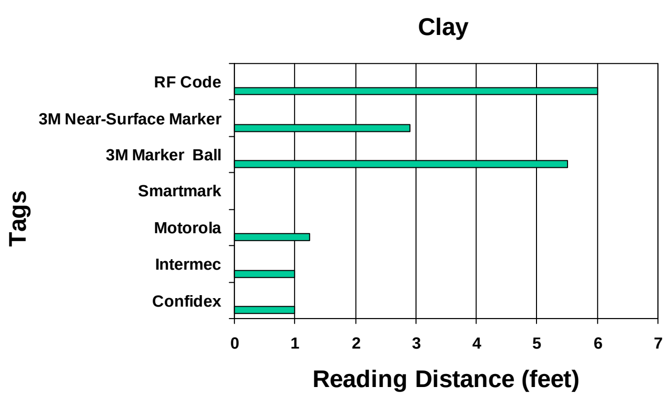
Table 15. Manufacturer's Specifications.

Tags	Type	Above-ground	Underground	Read Ranges (ft)	Memory (bit)	Operating Temperatures (degree F)
Motorola	Passive	X		40	128	
Confidex Ironside	Passive	X	X	20-30	128	-67 to +221
Smartmark	Passive	X	X	3-5	128	-20 to +125
Intermec	Passive	X	X	25-30	128	-40 to +250
3M Marker Balls	Passive		X	5	256	-4 to +122
3M Near Surface Markers	Passive		X	2	256	-4 to +122
RF Code M1 70	Active	X		230 max	No Standard	-4 to +158



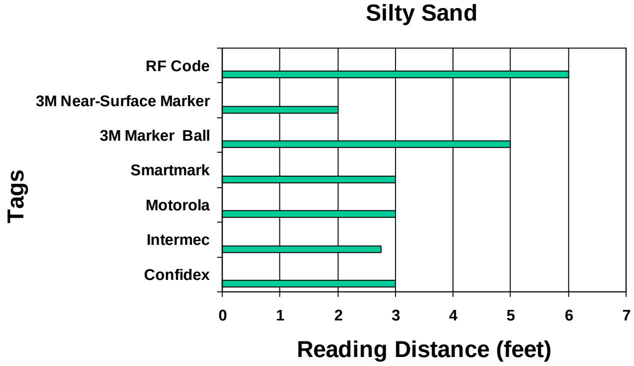
Test	Values
Compaction	89.4%
Moisture Content	6.4%

Figure 20. Concrete Sand Soil Tag Readings.



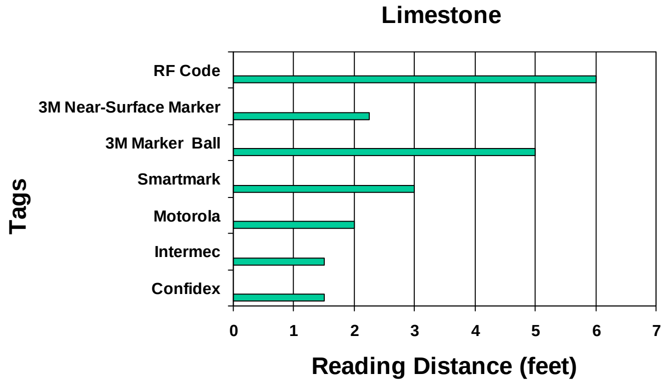
Test	Values
Compaction	81.9%
Moisture Content	14.9%

Figure 21. Clay Soil Tag Readings.



Test	Values
Compaction	93.5%
Moisture Content	10.1%

Figure 22. Silty Sand Soil Tag Readings.



Test	Values
Compaction	0%
Moisture Content	0%

Figure 23. Limestone Soil Tag Readings.

Table 16 illustrates the performance of tags and markers after a 60-day time lapse. Based on the data, the 3M (passive) and RF Code (active) tags were still functioning. The other vendors were functional in the limestone soil and only the Motorola (passive) tags were able to be read after 60-days in the concrete sand and silty sand soils.

Table 16. Tag Readings based on 60-day Time Lapse.

Tags	Type	Concrete Sand	Silty Sand	Clay	Limestone
Motorola	Passive	X	X		X
Confidex Ironside	Passive				X
Smartmark	Passive				X
Intermec	Passive				X
3M Marker Balls	Passive	X	X	X	X
3M Near Surface Markers	Passive	X	X	X	X
RF Code M1 70	Active	X	X	X	X

ABOVEGROUND APPLICATIONS – ACTIVE RFID TECHNOLOGY

Testing Environment and Tests Performed

For aboveground applications, only the RF Code technology was used. This is an active RFID technology and its tag was affixed to existing outdoor advertising signs with various structure materials, structure designs, and dimensions. They were placed strategically in several different positions, orientations, and heights on each sign so that the maximum signal between the reader and tags could be achieved. Figure 24 shows not only a few of the advertising signs used in several of the field data collection experiments, but also provides an illustration of executing all aspects of the protocol.

Figure 24. Outdoor Advertising Field Testing.

Test Results and Analysis

As mentioned earlier, the protocol was designed to capture tag readings from two different positions. As shown in Table 17, the reading distances for the fixed reader are on average 33 percent above the manufacturer's specifications. The surfaces of the advertising signage significantly affect the performance of the tags in terms of readability. As shown in the table, the greatest reading distance was achieved when the tag is affixed to a wooden surface.

Table 17. Outdoor Advertising Field Results.

Advertising Site	Height of Tag Placement (ft)	Surface of Advertising Sign	Reading Distance (Fixed Reader) (ft)	Mobile Reading	Average Car Speed, mph (mobile reading)
FM 1098	8.3	Metal	150	X	35
FM 1488	13.5	Wood	~378		
FM 1097 (Pizza Shop)	28.3	Metal	172		
FM 1097 (I-45)	34.4	Metal	228	X	
SH 105 (Double Tier)	10	Metal	115	X	45
SH 105 (Double Tier)	20.7	Metal	237		35

Moreover, when using the mobile reader, the tags' performance is not as reliable. Fifty percent of the tags were able to be read when traveling at vehicle speeds between 35 mph and 45 mph. A few factors that may obstruct the tags' performance are weather, positioning of the antenna, interferences from the vehicle, etc. Additional testing is needed to further investigate the factors that have been identified as serving as potential obstacles impacting tag performance.

OTHER DESTRUCTIVE TESTS PERFORMED

There were a number of destructive (freeze, load [crush], and underwater) tests performed on the technologies that showed consistent reliability. These were the 3M markers (passive technology) and the RF Code tags (active technology). Table 18 shows the performance results of the tags for each test performed.

Table 18. Destructive Testing Results.

Tag Type	Signal Reading Freeze Temperature (30 degrees F)	Signal Readings Underwater (maximum depths measured, inches)	Load (N)	Load (lb)
3M Near Surface Marker	Yes	6	1710	384
3M Marker Ball	Yes	36	64,172	14,426
RF Code	Yes	6	90,689	20,238

The 3M marker balls were able to be submerged 36 inches under the water surface with the vertical height of the 3M Locator being positioned at a maximum of 42 inches above the marker itself. Both the 3M near-surface markers and the RF Code tag were only able to be read successfully when submerged no more than 6 inches below the water surface and the vertical height of the 3M Locator and RF Code fixed reader both being positioned at a maximum of 12 inches above the tags.

The other observations show that all markers and tags were able to be read at temperatures of 30 degrees Fahrenheit. Additionally, the RF Code tag was able to withstand the greatest vertical load before crushing into pieces as opposed to both of the 3M markers.

CONCLUSIONS

Based the operational testing data, the technologies that have proven to show the most promise is 3M and RF Code. The 3M is a proprietary passive technology and the RF Code is a proprietary active technology. While each technology has its own set of limitations, both outperformed the other vendor technologies participating in this research study.

CHAPTER 6: HIGH-LEVEL RFID SOFTWARE INTEGRATION SCHEMA

This chapter presents the development and implementation of the sample schemas for using the above RFID technologies. The purpose of the sample schemas is to present to TxDOT an idea of how the RFID technology can be used from a business process perspective. For each of the three categories of RFID technologies (standard passive [Gen2], proprietary passive [3M], and proprietary active [RF Code]), the subsection presents the software and hardware combinations for conducting sample business processes for underground utilities, outdoor advertising, and monumentation. The schemas were designed and implemented for a few combinations (and not all possible combinations) to present the salient features of the combination of technology and application.

The description first presents some information about the various TxDOT resources that were accessed to understand the business process for the three processes, then presents the various business data fields selected and the reasons for selecting the fields to display for each business process. Note that due to the different limitations of the various technologies (RFID chip memory, battery life, etc.), it is not possible to select all the data fields. The actual fields selected will vary based on a more precise definition of the use of the technology for a specific business process. The actual schemas are presented for the various technologies and the prototype implementation (screenshots) of using the schemas to conduct a business process using the technologies. The chapter closes with a few concluding remarks.

BACKGROUND

Underground Application (Utilities)

To develop the sample schema for the underground utility applications, the various documents from the TxDOT website of the San Antonio District were accessed to determine the schema requirements for the business processes. The website accessed was: http://www.dot.state.tx.us/SAT/permit.htm.

Aboveground (Advertising Signs)

To develop the sample schema for the aboveground advertising signs, the various documents from the TxDOT website (http://www.txdot.gov/business/doing_business/outdoor_signs.htm) were accessed to determine the schema requirements for the business processes. More specifically, the information in the "Control of Outdoor Advertising Booklet" was used.

Aboveground (Monumentation)

To develop the sample schema for the aboveground monumentation, the document from the TxDOT website (http://onlinemanuals.txdot.gov/txdotmanuals/ess/monumentation.htm) was accessed to determine the schema requirements for the business processes.

SAMPLE SCHEMA FIELDS AND SELECTION CRITERIA

Irrespective of the RFID technology being used (active or passive), it is necessary to view and manipulate certain data fields in order to conduct a business process. Some of this information should be writable (at the time of laying the pipe), or should only be readable, based on the business process. The sample fields that we selected for our schema and the reasons for selecting them are mentioned here. The fields selected during an actual implementation may vary based on the technology and a more precise definition of the business process.

Underground Utilities

For the Passive Gen2 tags, we selected the following fields: Company Name, Type of Utility, Size of Utility, Depth of Utility, and a special code of uniquely identifying the tag. For each of the fields a numeric code was used (see section on schema for details), to enable the entry of more information on the chip. The reasons for selecting these fields are that they were the most common fields mentioned in the documentation of underground utility permits. While Gen2 tags can carry 128 bits of information, only the lower 32 bits are writable by the common hardware and software available for printing or writing to these tags. Using only the 32 bits will enable the use of this technology using commonly available readers and printers made by several different vendors. The advantage is that one is not tied to a particular company for the hardware and software. In addition, the price of the devices and the quality is driven by competition.

For the specialty tags (3M) we selected the following fields: Company Name, Type of Utility, Size of Utility, Depth of Utility, Material, and Pressure in pounds per square inch (psi). The first four fields are the same as the Gen2 Tags. 3M software allows a maximum of six fields, and even those are restricted by the “bit-length” based on the label-value pair. By selecting the predefined labels, we were able to use all six fields.

For the active tag, we selected the RF Code with the Mobile Trak Lite application. Currently there is no industry standard for active tags and RF Code is a proprietary specialty active tag. The RFID tag number is preprogrammed by the manufacturer and cannot be reprogrammed. The Mobile Trak Lite application allows the user to enter a text string for Asset Name and Asset Description. In order for these text strings to be seen, the tag information must be read with the Mobile Trak Lite application file, along with the particular configuration file, for the text strings to display. These text strings reside in the application, and not on the RFID tag. RF Code provides a website through which the XML configuration file can be created for each tag. This XML file is then read by the Mobile Trak Lite application. For the RF Code specialty active tags, we selected the following fields: Company Name, Type of Utility, Size of Utility, Depth of Utility, Material, and Pressure in psi. Each field is separated by a comma. The reason for selecting these fields is to be consistent with the other tag schemas.

Aboveground Advertising Signs

For the passive Gen2 tags, we selected the fields of Company Code, Type of Sign, Material of Structure, Size of Sign (square feet), and a special code to identify the billboard uniquely. These fields and the range of values that it can represent were selected from the permit application for advertising signs. For each of the fields, a numeric code is used.

For the specialty tags (3M) we selected the following fields: Company Code, Type of Sign, Material of Structure, Size of Sign (square feet), and Faces. The first four fields are the same as the Gen2 Tags and use the same codes. A custom field of Faces is used to indicate a single-digit number for the number of faces on the sign.

For the active tag specialty tag (RF Code) we selected the following fields: Company Code, Type of Sign, Material of Structure, Size of Sign (square feet), and Faces. The first four fields are the same as the Gen2 Tags and use the same codes. A custom field of Faces is used to indicate a single-digit number for the number of faces on the sign. Each field is separated by a comma. The reason we chose these fields is to be consistent with the other tag schemas.

Aboveground Monumentation

For the passive Gen2 tags we selected the fields of the type of the marker and the monument stamping number. The type of the marker is a numeric code, whereas the stamping number is the actual seven-digit numeric stamping number of the marker. For the specialty tags (3M) we selected the field of Type that indicates the type of marker and the custom field of Stamp that indicates the seven-digit stamping number.

For the active tag specialty tag (RF Code) we selected the field of Type that indicates the type of marker and the field of stamp that indicates the seven-digit stamping number. Each field is separated by a comma. The reason we chose these fields is to be consistent with the other tag schemas.

DESCRIPTION OF SAMPLE SCHEMA

In this section, we describe the sample schema that we developed for each category of the technology (passive, proprietary passive, and proprietary active). For each technology, we present the schema for belowground and aboveground use (advertising signs and monumentation).

Sample Schema for Passive Technology (Gen2)

The schema for the passive technology (Gen2) is presented for underground utilities, aboveground advertising signs, and aboveground monumentation in Table 19, Table 20, and Table 21. As indicated earlier, the top 32 bits of the RFID tag are used for programming the labels. Four bits are used for each numeric code and hence e8 numeric characters can be programmed.

Table 19. Sample Schema for Underground Utilities.

Character No.	***Purpose***	***Possible Values***	***Description***	***Maximum Values***
1 2	2 character company code	00 to 99	Company Code for Company	100 values
3	Type of Utility	1, 2, 3, 4, 5, 6, 7, 8	1 – Low pressure NG, 2 – High pressure NG, 3 – Telephone, 4 – Cable TV, 5 – Fiber Optic, 6 – Sewer, 7 – Water, 8 – Electric	10 values (number 0 to 9)
4	Size code for utilities	Number from 0 to 9	*Size of utility pipe is in inches* 0 for size > 0 and <= 1 1 for size > 1 and <= 3 2 for size > 3 and <= 5 3 for size > 5 and <= 7 4 for size > 7 and <= 9 5 for size > 9 and <= 11 6 for size > 11 and <= 13 7 for size > 13 and <= 15 8 for size > 15 and <= 17 9 for size > 17	Number 0 to 9
5	Depth Code	Number from 0 to 9	*Depth of utility pipe is in ft* 0 for size > 0 and <= 1 1 for size > 1 and <= 3 2 for size > 3 and <= 5 3 for size > 5 and <= 7 4 for size > 7 and <= 9 5 for size > 9 and <= 11 6 for size > 11 and <= 13 7 for size > 13 and <= 15 8 for size > 15 and <= 17 9 for size > 17	Number 0 to 9
6 7 8	Special Code	Number from 000 to 999	Code used for either identifying the tag uniquely or for other identification	1000 values

Sample RFID Code for Utilities:

1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***Description***
0	1	1	2	3	1	2	1	Pipe of Company 01, LP Natural gas pipe of size between 3-5 inches, buried between 5-7 ft. Tag # is 121.

Table 20. Sample Schema for Aboveground Billboards/Advertising Signs.

Character No.	*Purpose*	*Possible Values*	*Description*	*Maximum Values*
1 2	2 character company code	00 to 99	Company Code for Company	100 values
3	Type of Sign	1, 2, 3, 4	1 – Open Roof, 2 – Solid Roof, 3 – Projection, 4 – Ground Mounted	0 to 9
4	Structure Material	1, 2, 3	1 – Wood, 2 – Metal, 3 – Composite	0 to 9
5	Size code	Number 0 to 9	*Size of the sign in square feet* 0 for size > 0 and <= 25 1 for size > 25 and <= 100 2 for size > 100 and <= 225 3 for size > 225 and <= 400 4 for size > 400 and <= 625 5 for size > 625 and <= 900 6 for size > 900 and <= 1225 7 for size > 1225 and <= 1600 8 for size > 1600 and <= 2025 9 for size > 2025	Number 0 to 9
6 7 8	Special Code	Number from 000 to 999	Code used for either identifying the tag uniquely or for other identification	1000 values

Sample RFID Code for Advertising Signs:

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Description*
3	6	4	2	4	2	1	5	Sign belongs to Company #36, Ground mounted, metal, between 400 to 625 sq ft. Tag # is 215.

Table 21. Sample Schema for Aboveground Monumentation.

Character No.	*Purpose*	*Possible Values*	*Description*	*Maximum Values*
1	Type of Marker	1, 2, 3, 4, 5	1 – ROW, 2 – Survey Control Point, 3 – Benchmark, 4 – Property Corner, 5 – Denial of Access	0 to 9
2 3 4 5 6 7 8	Monument stamping number	Format is 0000000	Unique number that is a stamping number	0000000 to 9999999

Sample RFID Code for Monumentation:

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Description*
4	2	0	1	2	0	6	9	Property corner marker with a stamping number 2012069.

Sample Schema for Specialty Technology (3M)

3M provides its own software package to develop the schema. In 3M terminology, the schemas are called Templates. The software provides a set of default templates. The use of the default templates has the advantage that the data labels are internally coded to take the least amount of space on the RFID chip. Figure 25 shows the list of default templates.

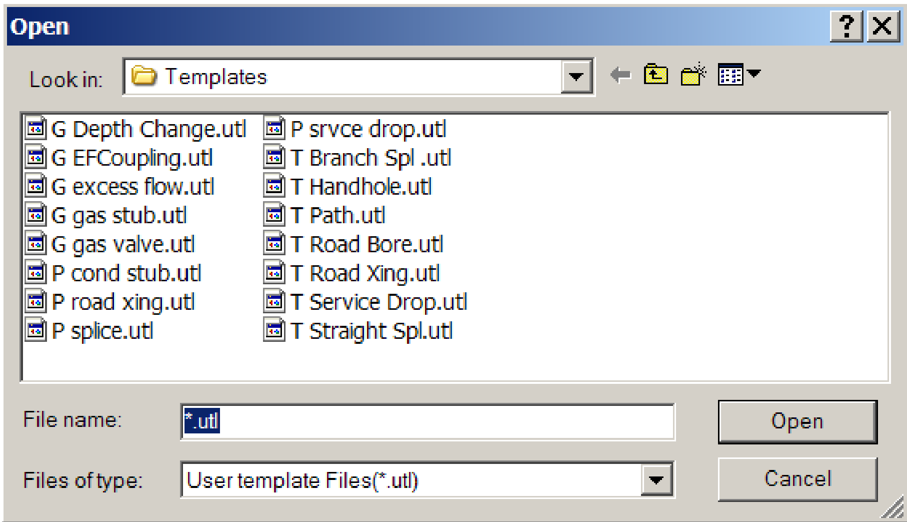


Figure 25. List of Default Templates (3M Software).

The templates can also be created using the 3M reader device. However, it is a more tedious process because it provides limited keys on the device and is hence not recommended. 3M software allows users to program a maximum of six fields (data labels and values for those fields). Those six fields and their values can be selected from a predefined list (preferred because it conserves the most amount of bit-space on tag) or can be developed using custom labels and values. Based on the label-value pair selected from the predefined list, or a custom label-value pair, it may not be possible to get all six field values—depending on the number of bits taken by each field and its value. Since the total number of bits is restricted, the fields and their values have to be selected carefully. The software provides a "meter" to indicate the percent of space left, to enable designers to configure the tag values.

Sample Schema for Underground Utilities

Figure 26 shows the sample schema (template) for the 3M system for belowground utility. By using predefined values (except for company name and the numeric value fields), we were able to squeeze in six fields. The first four fields are the same as the ones used for Gen2 tags, and the next two are material and pressure. The values entered are for a 6-inch PVC gas utility pipe at a depth of 10 ft with flow at 200 psi.

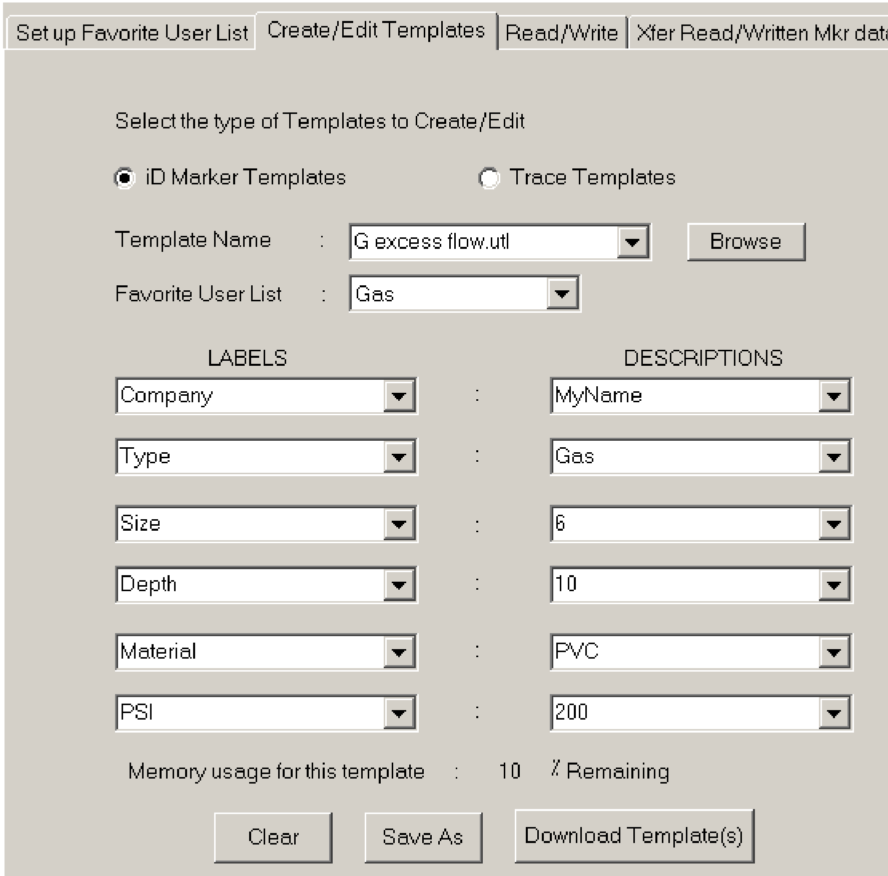


Figure 26. Sample Schema for Underground Utilities (3M Software).

Sample Schema for Aboveground Advertising Signs

Figure 27 shows the sample schema (template) for the 3M system for the aboveground advertising signs. Since default templates are not available for advertising signs, a custom template (schema) called Advertising is set up. The first four fields of Company, Type of Sign, Material of Structure, and Size are the same as the schema for the Gen2 Tag. To save bit space, the values are also coded using the same code as the Gen2 Tag. The remaining space allows for one additional label (custom label) called Faces that indicates the number of faces on the billboard. It can take a single-digit numeric value. The 10 percent remaining space is not enough space for any additional custom label-value pair. In the template shown in the figure, the schema is for an advertising sign that is a ground-mounted, metal structure of size 1600 square ft and two faces.

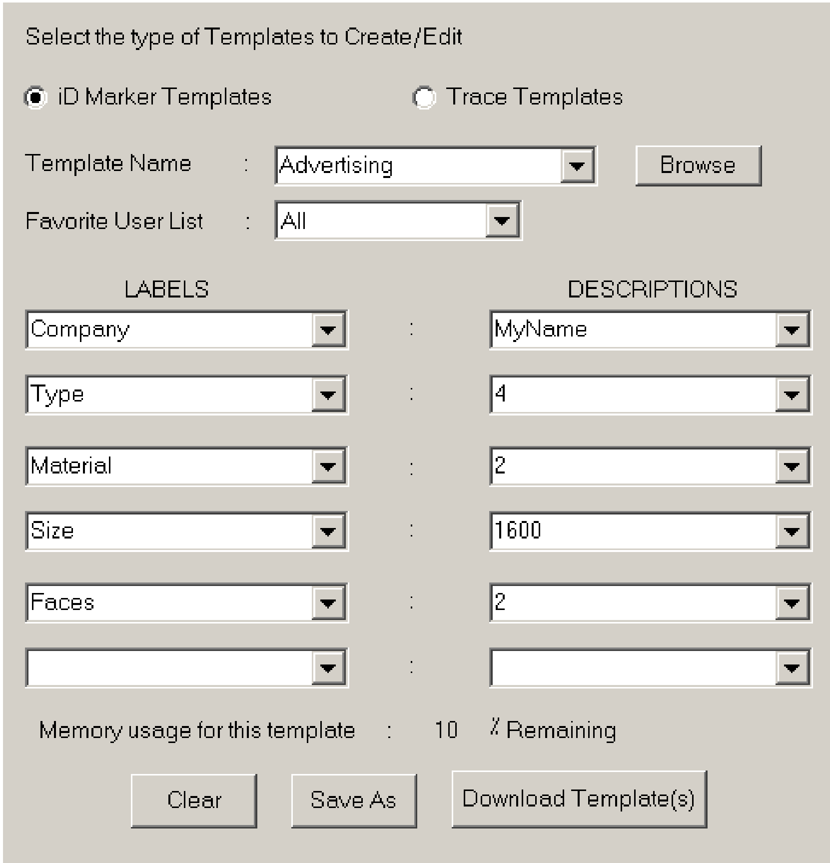


Figure 27. Sample Schema for Aboveground Advertising Signs (3M Software).

Sample Schema for Aboveground Monumentation

Figure 28 shows the sample schema (template) for the 3M system for the aboveground monumentation. Since default templates are not available for monumentation, a custom template (schema) called monumentation is set up. The first field is the Type (monumentation type) and can take values of ROW, Survey Control, Benchmark, Property Corner, and Denial Access. The second field is the Stamp that takes the seven-digit value of the Stamping Number. In the template shown in the figure, the schema is for Property Corner Marker whose stamping number is 2012069.

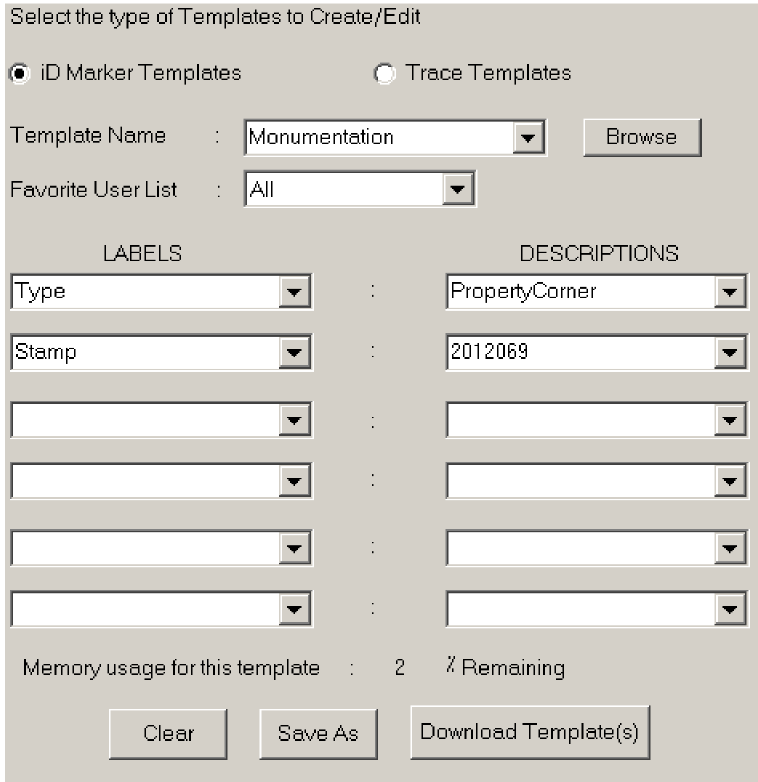


Figure 28. Sample Schema for Aboveground Monumentation (3M Software).

Schema for Specialty Active Technology (RF Code)

Currently there is no industry standard for active tag and RF Code is a proprietary specialty active tag. The RFID tag number is preprogrammed by the manufacturer and cannot be reprogrammed. The Mobile Trak Lite application allows the user to enter a text string for Asset Name and Asset Description. In order for these text strings to be seen when the tag is read, the tag information must be read with the Mobile Trak Lite application file, along with the particular configuration file. These text strings reside in the application, and not on the RFID tag. RF Code provides a website through which the XML configuration file can be created for each tag. This XML file is then read by the Mobile Trak Lite application.

Schema for Underground Utilities

Figure 29 shows the sample schema (template) for the RF Code system for belowground utility. Six fields were used which are: Company Name, Type of Utility, Size of Utility, Depth of Utility, Material, and Pressure in psi. The first four fields are the same as the ones used for Gen2 tags, and the next two are material and pressure. The values entered are for a 6-inch PVC gas utility pipe at a depth of 10 ft with flow at 200 psi.

Tag Data File Generator for MobileTrak Lite

Enter Tag Data

	Group Code	Tag #	Asset Name	Description
1	Locate	00012691	Williams,Gas,6,10,PVC,200	Company, Type, Size, Depth, Material, PSI

Figure 29. Sample Schema for Underground Utility (RF Code Software).

Schema for Aboveground Advertising Signs

Figure 30 shows the sample schema (template) for the RF Code system for the aboveground advertising sign. The first four fields of Company, Type of Sign, Material of Structure, and Size are the same as the schema for the Gen2 Tag. An additional label called Faces that indicates the number of faces on the billboard is added at the end. It can take a single-digit numeric value. In the template shown in the figure, the schema is for an advertising sign that is a ground mounted, metal structure of size 1600 square ft and two faces.

Tag Data File Generator for MobileTrak Lite

Enter Tag Data

	Group Code	Tag #	Asset Name	Description
1	Locate	00012692	ClearChannel,4,2,1600,2	Company,Type,Material,Size,Faces

Figure 30. Sample Schema for Aboveground Advertising Sign (RF Code Software).

Schema for Aboveground Monumentation

Figure 31 shows the sample schema (template) for the RF Code system for the aboveground monumentation. The first field is the Type (Monumentation Type) and can take values of ROW, Survey Control, Benchmark, Property Corner, and Denial Access. The second field is the Stamp that takes the seven-digit value of the Stamping Number. In the template shown in the figure, the schema is for Property Corner Marker whose stamping number is 2012069.

Tag Data File Generator for MobileTrak Lite

Enter Tag Data

	Group Code	Tag #	Asset Name	Description
1	Locate	00012693	PropertyCorner,2012069	Type, StampingNumber

Figure 31. Sample Schema for Aboveground Monumentation (RF Code Software).

IMPLEMENTATION OF SAMPLE SCHEMA

The above sample schemas were implemented using the software provided by the vendors. After the implementation, a few screenshots were taken to give the reader a walkthrough of a sample business process scenario. For all RFID technologies, the limitation of bit-space on the tag has to be considered when developing the business application.

Implementation of Schema for Passive Technology (Gen2)

Gen2 passive tags are designed for programming their lower 32 bits (eight 4-bit numeric values). For the supply-chain domain, this provides over 4 billion combinations, which is enough for each manufacturer (since the manufacturer information is stored on a different part of the tag). By reading the unique RFID tag, the backend database is accessed, and records associated to the tag can be accessed and displayed on the reader (handheld or mounted) in near-real time.

In the sample schema that we have provided, we use 5 of the 8 numeric values to code various schema information (name, type, size, etc.) leaving three numeric values for unique identification (for a maximum of 1000 unique tags of each combination). The information that is coded in the tag can be displayed on the reader based on the type of utility, sign, or monumentation being read. For the sample schema implementation, we walk through a scenario of how to program a Gen2 tag, and then present the flow of reading the tag and displaying its information. The software was developed using the CATAMARAN software provided by the RFID vendor Shipcom Wireless.

Initial Setup

A custom application for this project was developed using the CATAMARAN software. The software was developed using a development environment. After the screens and the business logic were developed, the application code was transferred to the reader using a universal serial bus (USB) port or over the wireless network. Once the application was transferred to the handheld reader, it could be used directly from the handheld reader. The application has a login-screen (not shown). After successful login (which can be authenticated by the backend database or just by the reader), the initial menu screen shown below was displayed.

Scenario of Creating and Printing Tags

Once we login to CATAMARAN, the screen in Figure 32 appears that allows you to Create Asset (Tag), Read Asset (Tag) or Logout. The first step is to create a Tag. When we click on Create Asset the screen in Figure 33 appears that tells you to select the type of Asset (Utility, Billboard, or Monumentation) you want to create. Click on the type of the Asset you want to create. We first select the Type Utility. The screen in Figure 34 is displayed where we need to input the tag details. Initially, each field is blank. The values of each field are entered using the handheld reader or by running the software on a computer. The values are determined by the codes mentioned in the schema. To print the RFID tag, the print option is selected.

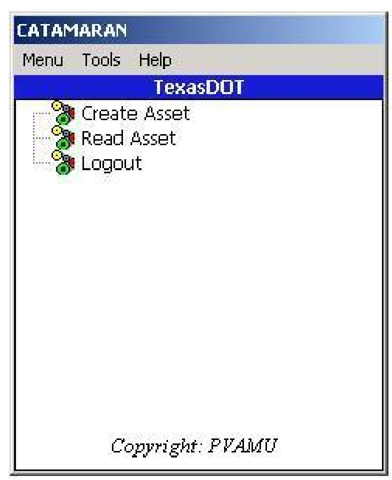


Figure 32. Initial Screen.

Figure 33. Select Asset Type.

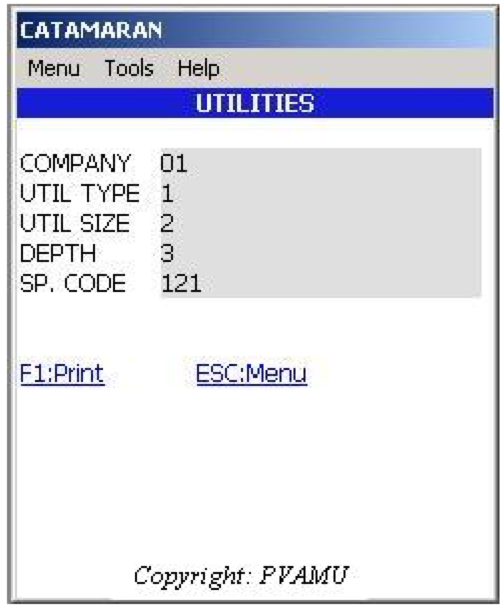


Figure 34. Utility Information on Tag.

The tag will then print on an RFID printer, as shown in Figure 35. The printer connects to the application server that runs the CATAMARAN software. To create and print the tags, it is not necessary to use the handheld reader. They can be created by running the software, in an office environment, on the server or any other computer connected to the application server.

The Tag has a human readable label and the RFID number that is encoded on the chip. The software will take the combination of the various codes and convert it into a hexadecimal number that is printed on the label. Based on the size of the physical RFID label, the various human readable text lines can be configured. After the tag is printed, it can be attached to the asset. The physical label shown has a peel-off backing that when peeled exposes a layer of adhesive.

Figure 35. Printed Tag with Information Code.

Scenario of Reading Tags

After a tag is printed and put in the appropriate location, it is ready to be read. The application is started on the handheld reader. After login, the Read Asset item is selected from the main menu. The screen in Figure 33 appears where you select the type of asset you want to read. We select the first type (Utility). The screen in Figure 36 appears where the RFID tag number must be entered. The tag is read by pressing the trigger on the device. A RF wave is emitted and the tag is read. A beep sounds when the tag is read successfully, and the field gets populated with the tag number.

Figure 36. Scanned Tag Number.

To process the tag, click on the submit button. When you click on submit the screen in Figure 37 appears that will show the information present in the tag about the asset.

The software will process the code and display the various fields that were read from the tag. The information is displayed as codes. To see the values of the codes, press the Details Key. The screen shown in Figure 38 displays the detailed information of the codes shown on the screen above. When you click on Menu it will take you to the main menu screen.

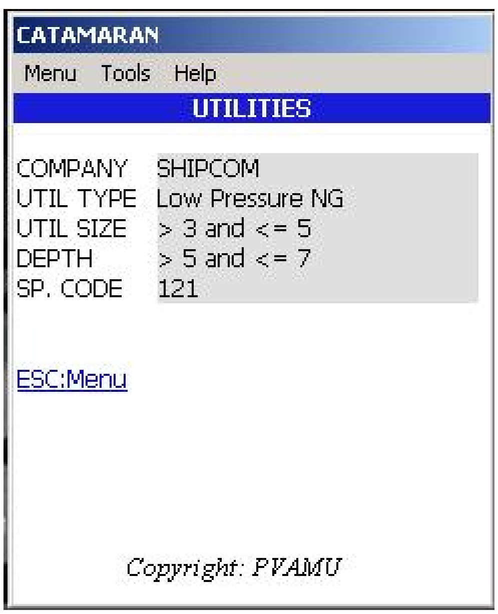


Figure 37. Tag Utility Information.

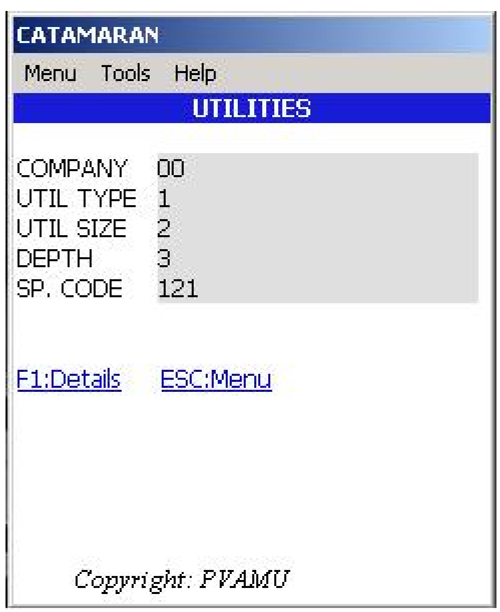


Figure 38. Detailed Utility Information.

The advantage of using Gen2 Tags is that there are many commercially available software and hardware vendors that have products that can be configured and used interchangeably. A tag can be programmed using the printer from one manufacturer and read by a reader from another manufacturer. The software used to design the prototype sample schema implementation is based on the Microsoft Windows mobile interface. Any Gen2 reader that runs Windows mobile (in this case it is a Motorola reader) can be used to upload the software, and any other vendors' reader can be used to read the tag and interpret its code.

To extend the versatility of the Gen2 tag, a backend database can be associated to the tag code (in our schema, the last three digits). If the reader is connected to a Wi-Fi network and connected to a database, then any information that is associated to the tag number can be displayed on the reader, in near-real time (based on network latency). In summary, other than the physical limitations of the Gen2 Tag, it provides the most versatility in terms of the programming capability, and tools and vendor products that are available.

Implementation of Schema Using Specialty Technology (3M)

Initial Setup

Since 3M uses custom proprietary technology, their tags can only be read by 3M readers (called locators by 3M) designed to read at that particular frequency. The tags cannot be read by other readers from other manufacturers. The tags consist of two components: a unique pre-programmed tag number (called the ID #), which 3M guarantees is unique from all tags of that type (water, gas, etc.). The second part is the programmable part that can be programmed (discussed earlier) using the template (schema) software provided by 3M.

Once the schema is coded using the software, it is transferred to the handheld locator device. The locator is connected to the computer using a USB or serial connection. The schema has to be loaded on each locator device through a physical cable.

Programming Marker Balls and Near-Surface Marker Tags

Each ball and near-surface tag (marker in 3M terminology) has an RFID tag inside it. The ball has a physical label attached to it, which has the tag number of the pre-programmed (non-changeable) part of the tag. The programmable part of the tag number is non-human readable. To program a ball, the locator is placed on top of the ball and a menu item is selected on the locator. By selecting a menu option on the locator, a RF signal is sent and the entire schema gets written to the tag inside the marker ball.

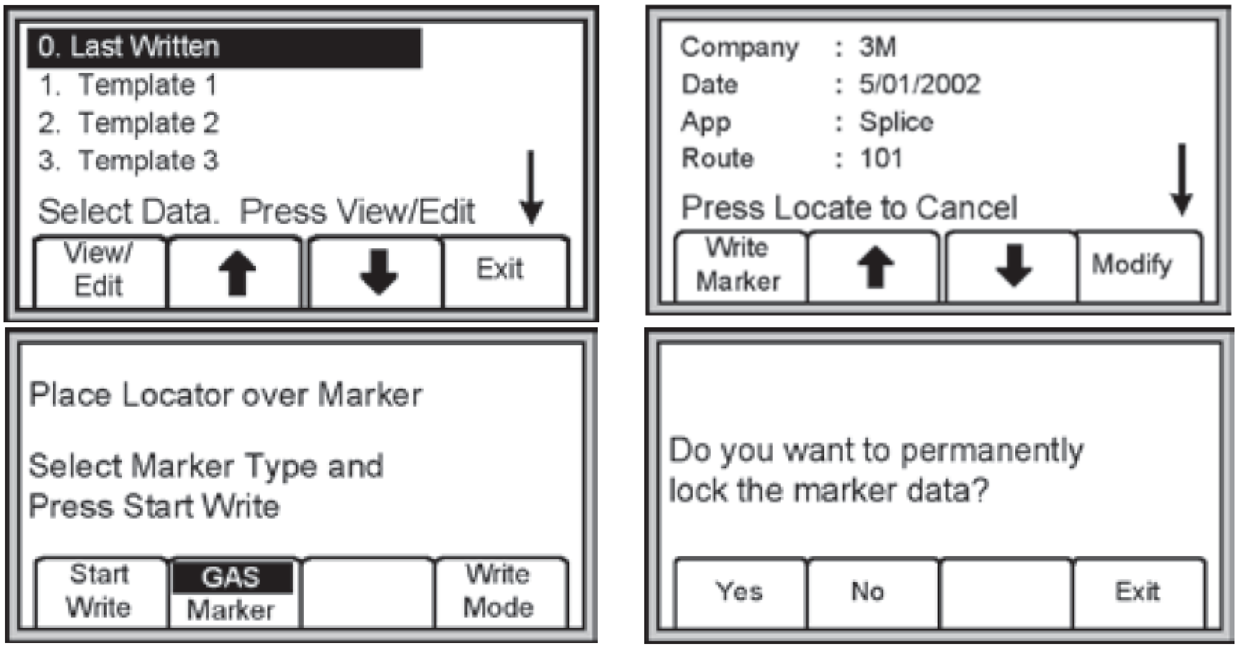


Figure 39. Steps for Programming 3M Markers (3M Dynatel 1420 Operators Manual).

Individual fields of the tag can be modified by the locator even after the marker ball is buried in the ground (and marker data are not locked).

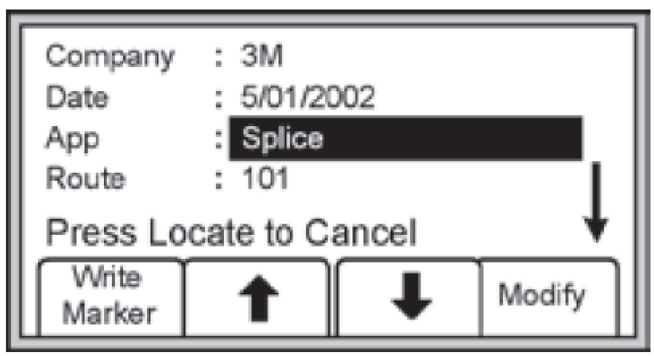


Figure 40. Editing Fields of 3M Markers (3M Dynatel 1420 Operators Manual).

To program multiple balls (up to 10) with the same programmable part, a special stand is available from 3M. A special Writer device (that looks quite similar to the locator device) must be used in order to program multiple balls.

Reading Marker Tags

Once the tags (balls and near-surface markers) are buried, they can be read using the 3M Locator device. The locator device stores the information of up to 100 tags that it reads. After the marker balls are read, the information from the ball can be seen on the LCD display device. The device displays the fixed ID number and the programmable information on the tag. It is necessary for the locator to have the same schema that was used to program the marker ball to be loaded on the locator in order to read the data properly.

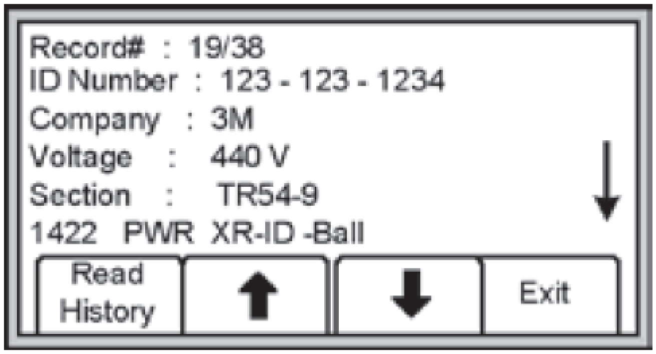


Figure 41. Reading Marker Information (3M Dynatel 1420 Operators Manual).

The 3M locator system and the markers are a proprietary solution for a well-managed single entity that can keep track of their assets (locators, templates, etc). The system does not provide integration with other vendors or other software systems. It is not possible to view additional data on the locator device that is associated to the marker and stored in a separate database. This is because the locators are not Wi-Fi enabled, and LCD screens are not general enough to display data in various formats that may be coming in from a different database. All future extensions and expansions of the system are limited by a single company, 3M.

Implementation of Schema Using Specialty Technology (RF Code)

Initial Setup

Since RF Code uses custom proprietary technology, RFID tags can only be read by RF Code readers designed to read at a particular non-standard frequency. The tags cannot be read by other readers from other manufacturers. RF Code provides several types of readers. We used the mobile M220 reader. This reader allows the reading of up to 25 unknown tags, that is, tags that have not been pre-programmed into the reader. Once the reader is setup to read tags of a particular frequency based on tag type, it is ready. The reader documentation indicates that it can read from 0 to 100 meters. The reader can read the information of a maximum of 25 tags, after which the data have to be downloaded to a computer.

Creating Configuration Tag Files

For each tag, an XML configuration file has to be created. The configuration file is created by entering the tag details in the form on the website provided by RF Code (http://www.rfcode.com/Resources/Support/MobileTrak-Tag-Spec-File-Generator.html). From the website, the file can be mailed to any email address. For the tag number 0012691 (utility schema), the XML configuration file is shown in Figure 42.

```
  <?xml version="1.0" encoding="UTF-8" ?>
- <mobiletrak version="1.0">
  - <assets>
    - <asset name="Williams,Gas,6,10,PVC,100" desc="Company, Type, Size, Depth, Material, PSI">
        <tag id="00012691" taggroupid="Locate" />
      </asset>
    </assets>
    <taggroups readerfamily="M" />
    <zones />
  </mobiletrak>
```


Figure 42. XML File for Underground Utilities.

For the tag number 0012692 (advertising schema), the XML configuration file is shown in Figure 43.


```
  <?xml version="1.0" encoding="UTF-8" ?>
- <mobiletrak version="1.0">
  - <assets>
    - <asset name="ClearChannel,4,2,1600,2" desc="Company,Type,Material,Size,Faces">
        <tag id="00012692" taggroupid="Locate" />
      </asset>
    </assets>
    <taggroups readerfamily="M" />
    <zones />
  </mobiletrak>
```


Figure 43. XML File for Aboveground Advertising Sign.

For the tag number 0012693 (monumentation schema), the XML configuration file is shown in Figure 44.


```
  <?xml version="1.0" encoding="UTF-8" ?>
- <mobiletrak version="1.0">
  - <assets>
    - <asset name="PropertyCorner,2012069" desc="Type, StampingNumber">
        <tag id="00012693" taggroupid="Locate" />
      </asset>
    </assets>
    <taggroups readerfamily="M" />
    <zones />
  </mobiletrak>
```


Figure 44. XML File for Aboveground Monumentation.

Using the Configuration File for Tags

A computer is setup with the Mobile Trak Lite application from RF Code. The configuration XML files, generated above, are loaded into the application. This enables the application to display the configuration information associated with the tag when the tag reader is connected to the computer.

Viewing the Tag Information Read by Reader

The M220 reader is started and taken into the field where the tags are read. After reading the tags, it is attached to the computer on which the Mobile Trak Lite application is running. The configuration files of the tags read must be loaded into this Mobile Trak Lite application, as described in the previous step. Once the tag information is downloaded from the reader into the application, the information can be viewed in a general layout, where information of multiple tags can be seen at once (see Table 22).

Table 22. Viewing RF Code Tag Information.

Asset Name	Asset Location	Signal Strength
Abe Yarborough		
Bay Raymond		-50
Corel Ray		-60
Chad Horns		-64
Chris Hood		-68
Frank Harris		-74
Jonathan Luce		-57
Judy Klan		-77
Katie Cole	IRID 125	-84
Karen Woods		-75
Hugh Mason		-55
Ron Giseeyh		-89
Status: Online	**Amount: 15 of 25**	**File: configuration.wrl**

By clicking on one tag and selecting the details option, the details of the tag can be viewed, as seen in Figure 45.

Figure 45. Viewing RF Code Tag Detail Information (Mobile Trak Lite User Manual).

The active specialty tags from RF Code are a proprietary solution. The system does not provide integration with other vendors or other software systems. The readers provided by the company are not meant for interactive use where one tag is read and data associated with the tag is retrieved from another database. Their readers are designed primarily for asset management and real-time monitoring, where the reader is fixed at a location and it monitors the tags within a certain radius based on the signal strength of the tags and the receiver. This receiver is then attached to a computer that runs RF Code proprietary software. When a tag is tampered or moved, then based on the configuration, the software can trigger an alarm.

CONCLUSIONS

In this section we have reviewed the various software integration schemas for the three main type of RFID technologies—passive (Gen2), proprietary passive (3M), and proprietary active (RF Code). The passive (Gen2) tags provide the most versatility in terms of programming and vendor choice. The coding and reading of the tags is based on well-known international standards. However, most Gen2 tags currently available are not packaged for underground conditions and exposure to harsh environments. The 3M solution is a good solution, but is based only on the proprietary information of one company. The active technology specialty tag solution from RF Code provides longer read distances. However, their custom application has to be used and integration with third party software and solutions is questionable because there is no current approved standard for the entire range of active tag manufacturers.

CHAPTER 7: COST/BENEFIT EVALUATION AND SUMMARY OF RFID TECHNOLOGIES

COST/BENEFIT EVALUATION OF RFID TECHNOLOGIES

Based on the previous results, RFID system candidates will be identified that best meet TxDOT's needs. For each strategy identified in the last subtask, the researchers will conduct a cost/benefit evaluation. This cost/benefit evaluation will focus upon technology issues, in comparison to the economic implications assessment that focuses upon broader implementation issues within TxDOT. The evaluation will further assist researchers and TxDOT in identifying the best implementation decisions. A real options method will be used to perform an economic evaluation of the different RFID systems. The profit of the option will indicate which RFID system is best, and what will be recommended.

To determine the profit of the systems, the costs of different types of RFID systems from different vendors were evaluated and are shown in Table 23. Initial costs of the system represent the cost of a mobile reader, as tags are assessed as an incremental cost separately. As seen in Table 23, non-standard systems lead to additional costs because there are no market forces to drive down cost, and there are no other vendors to go to if the proprietary company raises prices. As seen in Table 23, 3M is the only vendor for their system, so their costs are increased to account for any proprietary costs. Table 23 also displays the different costs during the different stages of implementing the RFID systems. These costs were derived by adding the initial cost and the incremental cost of the appropriate number of tags. For the development phase, this number is 20 tags; the trial phase utilizes 100 tags, and the implementation phase uses 1000 tags. The number of tags in the implementation phase for the RF Code system is doubled, because of the need to replace the batteries during the period of the economic analysis. In addition, a proprietary cost is included for the non-standard RFID systems.

Table 23. Costs for Different RFID Systems.

System	ISO/EPC Standard	Initial Cost	Tag Cost	Proprietary Cost	R&D Cost	Trial Cost	Implement Cost
RF Code	Yes	$ 1,793	10		$ 1,993	$ 2,793	$ 21,793
3M	No	$ 1,380	5	$ 4,140	$ 5,620	$ 6,020	$ 10,520
Smartmark	No	$ 1,600	0.1	$ 4,800	$ 1,602	$ 1,610	$ 6,500
Confidex	No	$ 910	0.1	$ 2,730	$ 912	$ 920	$ 3,740
Motorola	Yes	$ 2,725	0.1		$ 2,727	$ 2,735	$ 2,825
Intermec	Yes	$ 1,970	0.1		$ 1,972	$ 1,980	$ 2,070

Cost/Benefit Evaluation Process

Model

The period before implementation can be divided into three phases: Development Phase, Trial Phase, and Implementation Phase. Figure 46 shows the three phases.

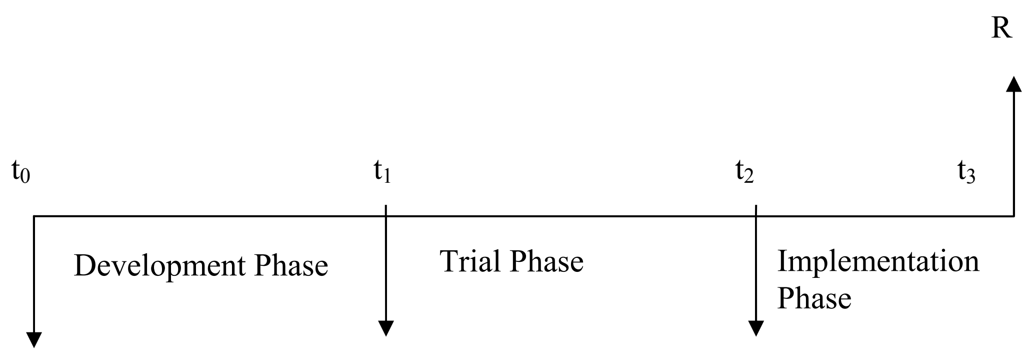


Figure 46. Three Phases of the Project.

Based on the initial cost model, a compound real option model will be used to evaluate the different types of RFID systems identified for this project. For the project, the investment is known as D at the beginning, X for testing the property of the system in real environment at the end of year t1, and M for comprehensive implementation at the end of year t2. At the end of year t3, there will be return of R. Depending on these investments and revenue, the initial value of the project can be estimated for different types of RFID systems, marked as V0.

Due to the selection of a compound real option model, the Geske Equation will be utilized to calculate the value of the project implementation.

$$V_f = V_0 e^{-r(t_3 - t_1)} MN(k, h; \rho) - M e^{-r(t_3 - t_1)} MN(k - \Delta\sqrt{t_2 - t_1}, h - \Delta\sqrt{t_3 - t_1}; \rho) - X e^{-r(t_2 - t_1)} N(k - \Delta\sqrt{t_2 - t_1})$$

Where:
r = riskless interest rate;
δ = discount rate;
Δ = volatility of the rate of change of the commercial venture;
V0 = present value of the commercial venture;
MN (a, b; ρ) is multivariate normal distribution, where a and b are its upper and lower limitation of the function and ρ is the correlation coefficient; and
N (x) is standard normal distribution.

$$\rho = \sqrt{\frac{t_2 - t_1}{t_3 - t_1}};$$

$$h = \frac{\ln(V/M) + \Delta^2 \times (t_3 - t_1)/2}{\Delta \times \sqrt{t_3 - t_1}};$$

$$k = \frac{\ln(V/V_c) + \Delta^2 \times (t_2 - t_1)/2}{\Delta \times \sqrt{t_2 - t_1}};$$

$$V_c = \max(C(V, X, t_2) - M, 0).$$

The B-S-M model for single real options will be used to determine Vc.

$$C(t) = V_0 N(d_1) - Xe^{-rt} N(d_2) \text{ Where}$$

$$d_1 = \frac{\ln(V_0 / X) + (r + \Delta^2 / 2) \times t}{\Delta T^{1/2}};$$

$$d_2 = d_1 - \Delta T^{1/2};$$

t is the option's time to maturity or expiration, N(di) is the standard normal distribution function, and I is the index of d, the substitute variable.

Simulation

Matlab was used to simulate the model using the following values of the parameters: r=6 percent, δ=0, Δ=27 percent. These values are conservative estimates found in a case study similar to this project executed by School of Economics and Business Management at Tsinghua University. The period for analysis is 10 years, so the values t0 = 0, t1=2, t2=8, and t3=10 years are used. The benefit of system performance was evaluated and assigned weighting values for each criterion from the benchmarking test results. For underground performance, the systems were evaluated by material type, buried tag depth, vertical distance, and horizontal distance. For aboveground performance, the systems were evaluated by vertical tag height, vertical antenna height, and horizontal distance. The return of the systems including the weight of their performance, shown in Table 24, Table 25, and Table 26, will determine the value of real options of the alternatives. The present value of real options through the 10 years is assumed as $10,000, and the investments are equivalent for underground, aboveground, and both of them together. Using the weightings in Table 24, Table 25, and Table 26, the present value for each system can be determined for systems that operate underground less than 24 inches deep, underground greater than 24 inches deep, and aboveground, respectively. This analysis is needed because of the acute change in performance around 24 inches. Table 27 summarizes the value for each system in each of the different parameters.

Table 24. Performance for Underground Depths (0 to 24 Inches).

	RF Code	3M	Motorola	Smartmark	Confidex	Intermec
Underground	10	9	6.25	4	4	3
Material Type	10	10	8	5	5	4
Tag Depth	10	10	4	2	2	1
Vertical Distance	10	8	7	5	5	4
Horizontal Distance	10	8	6	4	4	3
Underground Value	$ 100,000	$ 90,000	$ 62,500	$ 40,000	$ 40,000	$ 30,000

Table 25. Performance for Underground Depth (Beyond 24 Inches).

	RF Code	3M	Motorola	Smartmark	Confidex	Intermec
Underground	10	9	1	1	1	1
Material Type	10	10	2	2	2	2
Tag Depth	10	10	0	0	0	0
Vertical Distance	10	8	2	2	2	2
Horizontal Distance	10	8	0	0	0	0
Underground Value	$ 100,000	$ 90,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000

Table 26. Performance for Aboveground Assets.

	RF Code	3M	Motorola	Smartmark	Confidex	Intermec
Aboveground	10	0	0	0	0	0
Vertical Tag Height	10	0	0	0	0	0
Vertical Antenna Height	10	0	0	0	0	0
Horizontal Distance	10	0	0	0	0	0
Aboveground Value	$ 100,000	$ -	$ -	$ -	$ -	$ -

Table 27. Summary of Present Options Based on Performance Value.

	RF Code	3M	Motorola	Smartmark	Confidex	Intermec
Value Underground up to 24"	$ 100,000	$ 90,000	$ 62,500	$ 40,000	$ 40,000	$ 30,000
Value Underground Greater than 24"	$ 100,000	$ 90,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000
Value Aboveground	$ 100,000	$ -	$ -	$ -	$ -	$ -
Total Value	$ 300,000	$ 180,000	$ 72,500	$ 50,000	$ 50,000	$ 40,000

Results and Analysis

After running the model, the values for profit after implementation belowground up to 24 inches are shown in Table 28. Profit is the value of the options not including the initial investment. For the of RF Code system, there is also a maintenance cost included at the end of 10th year to replace batteries of active tags and reset them. This cost is estimated at $20 per tag underground given the work needed to access the tags. Numbers in parenthesis represent negative dollar amounts.

Table 28. Profit for Underground Technologies (0 to 24 Inches).

	Motorola	3M	Confidex	Smartmark	Intermec	RF Code
Profit	$ 19,915	$ 17,146	$ 15,427	$ 13,176	$ 7,289	$ (3,697)

As seen in Table 28, underground technologies located up to 24 inches for aboveground implementation have the Motorola system being the most profitable with $19,915. The RF Code is the only system that is shown to have a loss and not a profit at the end of 10th year. The values for profit after implementation of technologies belowground beyond 24 inches are shown in Table 29.

Table 29. Profit for Underground Technologies (Beyond 24 Inches).

	3M	Confidex	Smartmark	Intermec	RF Code	Motorola
Profit	$ 17,146	$ 1,478	$ (1,000)	$ (2,406)	$ (3,697)	$ (5,450)

As seen in Table 29, for underground technologies located beyond 24 inches, 3M had the greatest profit at $17,146. Confidex showed a small profit of $1,478, while all other systems showed a loss. RF Code is the only system that has the ability to work aboveground in the selected parameters; therefore, it is the only one that has the ability to make a profit. The profit of $16,303 for RF Code after the 10th year is found in Table 30.

Table 30. Profit for Aboveground Technologies.

	RF Code
Profit	$ 16,303

Based on poor results seen by the individual systems working both underground and aboveground, a benefit evaluation of combinations of systems as specific alternatives was analyzed. The three alternatives chosen by their profitability in the individual regions were RF Code and Motorola, RF Code and 3M, and RF Code and Confidex. The results of the profit found for implementing RF Code aboveground and another system underground up to 24 inches in the 10th year are shown in Table 31.

Table 31. Profit for Combination Systems (Underground, 0-24 in., and Aboveground).

Systems	RF Code + Motorola	RF Code + 3M	RF Code + Confidex
Profit	$ 36,732	$ 33,573	$ 32,300

From Table 31, the largest profit is found by implementing Motorola for the system underground up to 24 inches and RF Code for the system aboveground. The profit realized with this combination is $36,732. The combination of RF Code for aboveground and 3M for underground up to 24 inches has the second largest profit of $33,573. The alternative of RF Code aboveground and Confidex underground up to 24 inches has the smallest profit with $32,300. The results of the profit found for implementing RF Code aboveground and another system underground beyond 24 inches in the 10th year are shown in Table 32.

Table 32. Profit for Alternatives Systems (Underground >24 in. and Aboveground).

Systems	RF Code + 3M	RF Code + Confidex	RF Code + Motorola
Profit	$ 33,573	$ 17,802	$ 11,234

As shown in Table 32, the alternative with RF Code aboveground and 3M underground beyond 24 inches had the largest profit with $33,573. The system with the second highest profit is the alternative with RF Code aboveground and Confidex belowground beyond 24 inches with $17,802. Finally, the combination of RF Code aboveground and Motorola underground beyond 24 inches realized the smallest profit with $11,234. All combinations made a profit of more than $10,000 at the end of 10th year.

CONCLUSIONS

The different RFID systems were evaluated economically using a real options model that took performance of the system into account. The study period of this model included three phases: Development, Trial, and Implementation. The initial costs of the systems were determined using the costs of RFID tags and mobile readers. The economic model also accounted for the different costs at the three phases. Using Matlab, the model was simulated to find the profit of each system.

By analyzing the profits of the different RFID systems, the conclusion was reached that the best type of implementation would be one that involved a combination of two different RFID systems. One combination could be used for underground up to 24 inches and aboveground while another combination could be used for underground beyond 24 inches and aboveground. When considering a system for working aboveground and underground up to 24 inches, the combination of RF Code working aboveground and Motorola working underground up to 24 inches would be the most economic system to recommend. It is assessed as having a profit of $36,732. This large profit is due to the standardized frequency used and good working performance, which drives down costs and increases the benefit. For a system for aboveground and underground beyond 24 inches, the best combination is the one that has RF Code working aboveground and 3M working underground beyond 24 inches. This combination had the largest profit at $33,573.

Based on the economic and performance analysis, the alternative of Motorola and RF Code working together with capabilities aboveground and up to 24 inches underground is the recommendation. This is because it had a greater profit versus any system that operated both underground and past 24 inches deep, or any of the systems working in the three situations alone. This analysis could be adjusted and rerun based on changing values of different capabilities, but in the current state it gave an answer that provided the best option. The value of real options allowed us to assess that the option of Motorola and RF Code was the most economic across the many alternatives for implementation.

SUMMARY OF RFID TECHNOLOGY EVALUATION FINDINGS

The benchmark tests demonstrated that RFID active tags performed well, demonstrating high read rates in aboveground and underground environments for all parameters tested. RFID passive tags did not perform as well as the active tags, though they demonstrated success at shorter ranges (less than 8 ft) in the aboveground tests and had very limited performance (less than 1.25 ft) in the underground testing. Generally, as the distance belowground increased, the passive RFID readability decreased and as the distance from the reader to the ground decreased the readability increased.

The operational data suggest that there are two promising technologies, namely, 3M (passive) and RF Code (active). While each technology has its limitations, it will be important for TxDOT to prioritize the applications for which RFID will be utilized as well as the cost associated with implementation.

Moreover, of the three main types of RFID technologies—passive (Gen2), proprietary passive (3M), and proprietary active (RF Code)—the passive (Gen2) tags provide the most versatility in terms of programming and vendor choice. The coding and reading of the tags is based on well-known national and international standards. However, most Gen2 tags currently available are not packaged for underground conditions and exposure to harsh environments. The 3M solution is a good solution, but is based only on the proprietary information of one company. The active specialty tag from RF Code provides longer distance readings. However, the tags need their batteries replaced every few years (based on tag type—current maximum life of battery was around four years for one type of tag they sell). In addition, only their application and readers from RF Code must be used to read the data and leads to a single vendor situation.

In evaluating the economics of the passive and active RFID systems, results indicate the most cost effective implementation would be one that involved a combination of two different RFID systems. One combination could be used for underground up to 24 inches and aboveground while another combination could be used for underground beyond 24 inches and aboveground. The most economic option was determined to be Motorola (an International Organization for Standardization standard passive RFID System) and RF Code (an ISO non-standard active RFID System) working together with capabilities aboveground and up to 24 inches underground is the recommendation.

CHAPTER 8: FEASIBILITY ASSESSMENT

Using the information gathered through the literature review, survey, webinar, evaluation of technologies, and other activities, the research team assessed the feasibility of using RFID for numerous applications of ROW management. The primary focus of the assessment was on the three primary applications: utilities, outdoor advertising, and survey monumentation. Where appropriate, limited feasibility assessments were conducted for other applications. This chapter presents the results of the feasibility analysis.

GENERAL FEASIBILITY ISSUES

The feasibility analysis focused primarily on the issues related to specific applications of RFID in the ROW. However, there are some overarching considerations associated with RFID in the ROW that apply across all applications. These considerations are listed below:

- RFID technologies are not widely used by other transportation agencies in the ROW. The most similar applications to ROW management tend to be at airports and some use by private utility owners to mark their own assets. As a result, TxDOT would be a leader in implementing the technology. While being a leader can have many advantages, it also means a steeper learning curve for the agency.
- Because of the extensive network of assets and the costs associated with marking the assets using RFID, implementation of the RFID technology will likely be incremental and it will be some period of time before the benefits of using RFID could be realized.
- To realize the benefits relative to the costs, the use of RFID would need to be limited to a small area or it needs to be widely used on a large area. There is likely little benefit to using RFID on a spotty basis over a wide area. Furthermore, as mentioned in the previous bullet, to realize a benefit, RFID would need to be fully implemented over a relatively short period of time.
- There are advancements in other technological areas that may provide a more effective means of managing many of the ROW assets. Examples of other technologies include GIS systems and mobile access to computerized databases.

Impact of RFID Technologies on Feasibility

As mentioned in a previous chapter, there are two types of RFID technologies—active and passive. Table 33 identifies some of the characteristics of the two technologies that may impact the manner in which RFID is implemented for ROW management.

Table 33. Feasibility Attributes of RFID Technologies.

RFID Type	Power	Reading Distance
Active	Internal (battery) – requires battery replacement 5 year (approximate) intervals	> 5 ft
Passive	External	< 5 ft

For example, any application of RFID to underground utilities would require the use of a passive tag, as it would not be feasible to dig up an active tag approximately every five years to replace the battery. Any ROW management activity that would require the asset information to be read from more than 5 ft away would require an active tag. However, the agency would need to replace the battery on such a tag at periodic intervals. The battery replacement demands are likely to require greater maintenance than the typical access to the information provided by the RFID tag. As such, it is not likely that active tags would be used for ROW management activities.

FEASIBILITY OF SPECIFIC APPLICATIONS

The research team conducted individual feasibility assessments of RFID for the following applications: underground utilities, aboveground utilities, outdoor advertising, survey monumentation, no-mow areas, traffic signs/signals, and TxDOT owned assets. For the assessment of each application, the team considered one or more of the following factors in determining the feasibility for that particular application: TxDOT needs, implementation details, approximate implementation costs, benefits, alternative technologies, and other factors as appropriate. In some cases, the impacts of one aspect of the feasibility assessment were such that it limited the overall feasibility of the application.

Underground Utilities

The basic concept of RFID implementation for underground utilities is that an RFID tag is placed on or near the utility at regular intervals. In practice, the tags have been spaced every 25 to 50 ft and at specific locations such as a tee, elbow, change in elevation, or valve. Depending upon the technology used, the tag would do one of the following: use a unique frequency to identify only the type of utility (no information about owner, depth, size, or other characteristics), a unique identification number that can be cross-referenced to an external database, or specific information about the utility that is embedded in the RFID tag.

Cost Assessment

There are approximately 80,000 centerline miles of highway in the TxDOT system. To estimate the minimum cost of implementing RFID technology to mark the underground system, the researchers assumed that there was one utility paralleling each centerline mile (a conservative estimate) and that RFID tags were buried every 50 ft along the utility (another conservative estimate). The most common marker used today is a proprietary product. Multiple versions are available, with costs that range from $8 per marker to over $20 per marker depending upon the level of RFID technology employed. Assuming the lowest cost of $8 to purchase the lowest technology RFID marker (provides only an indication of the type of utility, but no additional information about the utility), the material costs of the markers themselves would be over $67 million. This does not include the cost of installing the markers. In order to properly locate the marker, the depth and lateral position of the utility must be identified every 50 ft. A hole is then dug and the marker is placed in the hole. Estimating a cost of $20 per hole, the total installation cost of the markers would be over $160 million. Combined with the material costs, the research team estimates that it would cost over $200 million to mark the underground utilities in the TxDOT ROW and potentially much more depending upon the total number of utilities. In comparison to a retroactive installation, the RFID markers can be installed at little additional installation costs when installed at the time the utility is placed in the ground.

One of the challenges associated with the costs of implementing RFID technologies is who would fund the installation. The utilities are mostly privately owned. While TxDOT could initiate legislation to require RFID technology for underground utilities, such an effort would likely be met with resistance from the affected parties unless TxDOT were to fund the installation with TxDOT funds. The expectation of such resistance is based on the fact that RFID technologies are used by utility owners on a very limited basis at the present time.

Implementation Timeframe

For RFID marking of underground utilities to be effective, users would need to have some level of confidence that all, or at least most, of the underground utilities in the ROW are marked. However, because of the cost and demands of retroactive installation, it would likely be an extended period of time (potentially more than a decade) before all utilities would be marked and the benefits of using RFID technology could be realized. During the transition period, inconsistent use of RFID technology would require continued use of status quo location techniques and create potential concern over the inability to use RFID for its intended purposes.

Underground Utility Benefits

The anticipated benefits associated with using RFID to identify underground utilities is that the technology would provide more accurate information about the type and location of assets located below the ground. Depending upon the options selected for implementation, the information could range from identifying only the approximate location and type of utility (gas, electrical, water, wastewater, etc.) to specific information about the type, depth, and owner of the asset. The advantage of RFID is that this information would be available without having to dig test holes to identify location and type. Furthermore, the information is buried with or above the utility so that it cannot be destroyed or moved over time. Such information could potentially be very useful in reducing the occurrence of events in which an asset is cut or damaged by work in the ROW. Another benefit is the potential savings in costs and time when locating utilities.

Underground Utilities Challenges

In comparison to the benefits, there are numerous challenges associated with the implementation of RFID for underground utilities. These challenges generally fall into several categories: time required for implementation, proprietary nature of some of the technology, durability and obsolescence of the technology.

- **Time required for implementation.** See the preceding section on implementation timeframe, which identifies the extended time required to place RFID markers with sufficient underground utilities to make it practical to use RFID detection tools.
- **Proprietary nature of some of the technology.** The more technical of the off-the-shelf RFID utility marker products utilize proprietary technologies. These are the technologies that provide the ability to include specific information about the utility

(such as depth, type, owner, etc.). If TxDOT wanted to use RFID technology to provide detailed information about the underground assets, then they would have to pursue one of the following options:

- ♦ Commit to long-term (2-50 year) use of a proprietary product.
- ♦ Commit resources to the development of RFID utility marker products that are in the public domain and that can be manufactured on a low-bid contract basis.

- **Durability.** Testing conducted as part of this research effort indicated that the off-the-shelf RFID products are very durable. However, the use of the technology for marking underground utilities is relatively new and the ability to use the technology over a period of 20 to 50 years is unproven.
- **Obsolescence of the technology.** Technology advances at a rapid rate. In many cases, electronic technology can become obsolete within 5 to 10 years of its initial implementation. Because the underground RFID marker cannot be easily updated or replaced, the technology could become obsolete well before the end of the need of the life for the asset. From an underground utilities standpoint, this has two implications for the use of RFID:
    - ♦ Will the sensor technology needed to identify buried RFID markers be available in 10 to 20 years?
    - ♦ Will a new technology provide a more feasible means of identifying underground utilities? Such a technology may not be buried with the asset, but may provide for on-site delivery of database information. Such information may be richer in detail than that associated with an RFID marker.

Underground Utilities Feasibility

Given the factors described in this section, statewide implementation of RFID technology for managing underground assets is not recommended for the following reasons:

- It is expensive.
- There is a long installation transition period before the benefits would begin to be realized.
- The most detailed implementation option would likely involve the use of proprietary products.
- Alternative technologies may provide more effective means of delivering the same or related information about the underground utilities.

In comparison to statewide implementation of the technology, a limited implementation of RFID underground utility markers could be feasible and prove to be beneficial. A utility relocation project in advance of road construction would provide the optimal environment for such implementation. Such an implementation scenario provides the following benefits:

- The project is limited to a finite area, limiting the extent to which the technology is used.
- The utility relocation project has a short timeframe so that the benefits are realized within a reasonable time period.
- A large number of utilities are typically moved, and some of the utility relocation is done in a sequential manner. By marking the utilities as they are moved, it makes them

more easily identified by the other utility contractors working in the same area. It also makes utility identification easier during the actual road construction project.

- The ability to track relocated utilities during the relocation project and during the actual roadway construction can save significant time and resources.
- The benefits of the technology are realized over a reasonable period of time (likely less than five years). Such a timeframe ensures the maximum benefits for the funds expended.

This type of application of RFID technology has been successfully utilized by the Virginia Department of Transportation, as described in the summary of the webinar at the end of Chapter 3.

Outdoor Advertising

The basic concept of RFID implementation for outdoor advertising is that an RFID tag would be placed on one of the supporting structures for the sign. This tag would provide information about the outdoor advertising sign such as the owner, dimensions, permit information, size, etc. In this application, either of the two RFID technologies could be used and each has specific benefits, as described below:

- Active tag: An active tag would provide the ability to gather information about the sign from a distance. Since these signs are located off the ROW, this allows access to the information without having to get the property owner's permission to be on the property. However, active tag is powered by a battery, which would need to be replaced at periodic intervals.
- Passive tag: A passive tag would require the user to be within approximately 5 ft of the tag. In this situation, use of a passive tag would be essentially the same as putting an information plaque on the supporting structure, as the user would have to be almost as close to the tag as they would have to be to an informational plaque.

Outdoor Advertising Benefits

One of the benefits of RFID application for outdoor advertising is the ability to obtain the information from the vehicle or roadside. As indicated in the outdoor advertising testing described in Chapter 5, the range of an active tag varies, ranging from 115 to over 350 ft for the specific type of RFID tag evaluated. This range would provide the ability to read the tag from the roadside. The test further indicated that the tag could be read at speeds in the range of 35-45 mph in some of the applications.

Outdoor Advertising Challenges

Based on discussions with TxDOT personnel in the ROW division, the information about outdoor advertising that could be provided by an RFID tag is little more than the information that is already available from a database or that can be observed in the field. The benefits associated with the application are not sufficient to offset the costs of installation and battery maintenance.

Outdoor Advertising Feasibility

Based on the information gathered by the researchers and input received from TxDOT staff, the feasibility of using RFID applications to manage outdoor advertising is very low.

Survey Monumentation

The concept of RFID technology implementation for survey monumentation would be to bury an RFID tag in a survey monument at the time that the monument is fabricated in the field. A generic RFID tag can be used that would provide a unique identification code (number) for the monument. This number could be cross-referenced to a database to access information about the monument. Furthermore, the RFID tag could serve as an aid in locating monuments that are covered by a thin layer of dirt or grass.

In such an application, the RFID tags would be passive and would be embedded in the concrete monument near the surface. The implementation would be low costs, as a generic RFID tag is inexpensive. There are two major benefits to the use of RFID tags in survey monuments:

- The identification number provided by the RFID tag would make it easier to identify the monument characteristics for surveyors.
- The RFID could make it easier for surveyors to find the monument. Surveyors typically know the general location of a monument, but may not be able to see it when it is covered by dirt or grass. By moving a sensor over the anticipated location, a surveyor may be able to detect the presence of the monument.

There are some challenges associated with this application, including the following:

- The application would require an external database that would be available to surveyors and that is linked to the RFID number.
- As is the case with underground utilities, it would be many years before a significant number of survey monuments would have embedded RFID tags. This means that the application would have limited value for an extended period.
- The research team was not able conduct a test of the performance of generic RFID tags embedded in concrete. As a result, the performance of generic tags embedded in concrete is uncertain. Furthermore, the lifespan of such an application is unknown.

Based on its potential, the research team recommends a limited field evaluation of this application. An implementation project would be the ideal mechanism for such an evaluation. The application should be limited to a corridor with a manageable number of monuments that will all be constructed within a short timeframe. Each monument should be embedded with several types of generic RFID tags. Surveyors can then assess the ability to read and use the information from the monuments using these tags.

Aboveground Utilities

Aboveground utilities typically include electrical power, cable, and other communications utilities that are located longitudinally within the ROW, but can also include point features such as a meter or utility cabinet/pedestal (switching box, transformer cabinet, etc.). In general, the use of RFID for aboveground utilities is similar to that for underground utilities, with the following differences:

- The location and type of aboveground utilities can be visually identified. This eliminates one of the major advantages of using RFID in the underground application—the ability to identify an asset that cannot be seen. As a result, the benefits to be realized from this application are more limited.
- It would be easier and less expensive to install RFID markers on aboveground utilities.
- The application of RFID to aboveground utilities does little to reduce the likelihood of a catastrophic event (such as cutting or damaging an underground utility) as the aboveground utility can be readily identified.
- The aboveground utility can be marked with a code or description that can be read by someone without requiring the specific sensor instruments associated with RFID technology.

For the reasons listed above, when combined with the information associated with underground utilities, the research team found little benefit to implementing RFID technology for aboveground utilities.

SUMMARY OF FEASIBILITY ASSESSMENT

Based on the findings of the feasibility assessment described in this chapter, the research team believes that there is limited application of RFID technologies for ROW management. However, the team did identify two applications that should be considered for limited implementation as described below. The benefits associated with either or both of these could be better defined through an implementation project that would better evaluate the particulars of implementation, as such factors were beyond the scope of this feasibility assessment. The recommended implementation applications include:

- use of RFID markers to identify underground utilities that are relocated or moved as part of a utility relocation project that precedes a roadway construction project and
- use of RFID tags embedded in survey monuments.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

The objective of this project was to assess the feasibility of using RFID technologies to manage various assets, particularly utilities located in the ROW as well as other assets for which the TxDOT ROW Division is responsible for managing. In particular, the research focused on three main asset applications: utilities, outdoor advertising, and survey monumentation. In addition to the three focus areas of RFID application, the research team also identified the following applications where RFID technology may have some potential usefulness: no-mow areas, traffic signs/signals, and TxDOT owned assets. The research team conducted the research activities listed below to identify applicable technologies, prior uses of such technologies, the advantages and limitations of various applications, and an overall assessment of each application:

- review of applicable literature on RFID technologies,
- identification of recent applications of RFID technologies for ROW assets,
- evaluation of RFID performance for ROW applications,
- evaluation of RFID costs and benefits, and
- assessment of RFID feasibility.

Actual field evaluations of the performance of RFID technology in various ROW management functions was beyond the scope of this project.

SUMMARY OF ACTIVITIES

As part of this project, the research team conducted the following activities in an effort to assess the feasibility of using RFID technology to better manage assets located in the highway ROW.

- Identification of current practices, including:
  - general RFID technology,
  - current use of RFID technology in utility identification,
  - international practices for RFID use in utility management,
  - surveys of agencies and other stakeholders, and
  - webinar on RFID use for utility relocation by a state transportation agency;
- Evaluation of RFID performance in underground and outdoor advertising test environments;
- Development of a software integration schema;
- Cost/benefit evaluation of RFID technologies; and
- Feasibility assessment of specific RFID applications for ROW management.

SUMMARY OF FINDINGS

As a result of the various activities conducted through this project, the research team developed the following findings:

- RFID technology is a relatively mature technology that continues to improve. It is widely used in a wide variety of applications in many different sectors.
- RFID technologies have been adapted to underground utility management by several manufacturers. These manufacturers' products can be installed at the time of utility

installation or retroactively to indicate the presence of the underground utilities. Different products provide different levels of identification. These include:
    - A marker that emits a specific frequency. Frequencies are assigned to specific types of utilities. This provides the ability for someone to determine that a particular type of utility is located underground at that location. No additional information is provided.
    - A marker that provides specific information that is programmed into the RFID marker at the time of installation. This type of marker is a proprietary product that requires a proprietary sensor to program and read the RFID marker.
- There is an extensive system of assets in the TxDOT ROW. It would require an extensive time to mark a sufficient portion of the assets with RFID for such a system to provide benefits.
- It would be expensive to retroactively install RFID for underground utilities. However, if not retroactively installed, then the status quo methods of identifying underground utilities would also have to continue to be used, providing little benefit to the use of RFID.
- Other state transportation agencies are not using RFID technologies for ROW management on a widespread basis.
- One state DOT has successfully used RFID technology for marking underground utilities as part of a utility relocation project that precedes a roadway construction project. This application provides the most likely means of implementing RFID for underground utilities in a manner that would be cost beneficial.
- Other information delivery methods or technologies (not assessed as part of this project) could provide a more effective means of obtaining some information about ROW assets.

RECOMMENDATIONS

Based on the findings generated from the activities of this project, the team offers the following conclusions and recommendations regarding the use of RFID technologies for managing assets in the ROW:

- RFID technology does not appear to present a widespread opportunity for significant improvements in TxDOT ROW asset management for the following reasons:
    - TxDOT assets are extensive.
        - To be useful, the majority of assets would need to be marked with RFID technologies.
        - Implementing RFID on a widespread basis would require a significant financial commitment.
    - Other technologies (existing and developing) may present alternative means of accomplishing similar management objectives.
- RFID does present an opportunity for TxDOT if utilized in limited applications.
    - The RFID applications that demonstrate the greatest feasibility include:
        - using markers during utility relocation and
        - using tags to identify survey monuments.
- Other applications have limited value:
    - outdoor advertising – no added value, and

    - widespread utility marking – increased costs with limited payback until system is largely marked.
- TxDOT should fund implementation projects to assess the effectiveness of RFID applications. These projects should address the following:
    - Use of RFID technology to mark utilities during relocation as part of a construction project. This would likely be a relatively large implementation project.
        - Use RFID utility marker balls to identify utilities as part of a utility relocation project and the succeeding construction.
        - Assess the effectiveness and cost savings.
    - Use of RFID technology to mark survey monumentation. This would likely be a relatively small implementation project to:
        - install survey monuments in a corridor where significant surveying will take place and
        - assess effectiveness over an extended period.

FUTURE ACTIVITY

The scope of this project was to assess the feasibility of using RFID technologies to manage ROW assets. As such, the research team did not conduct actual field evaluations of any particular application of RFID for ROW management applications. The findings of this research found limited feasibility for RFID applications, identifying only two potential applications that could result in benefits to TxDOT. The research team recommended limited implementation evaluations of RFID applications for utility relocation associated with a construction project and for survey monument identification in a selected highway corridor. Such implementation projects should be selected based on the following:

- The scope of application needs to be wide enough to assess effectiveness, but not so wide that it presents unmanageable challenges.
- The evaluation should be over a fairly compact area of application.
- The evaluation should be phased over time so that the benefits can be evaluated in an appropriate manner.

CHAPTER 10: REFERENCES

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APPENDIX A:
STATE TRANSPORTATION AGENCY SURVEY

The following presents the survey language that was distributed to members of the AASHTO Committee on Right-of-Way and Utilities in the first survey administered as part of this project.

TO: Members of the AASHTO Subcommittee on Right of Way and Utilities

The Texas Transportation Institute is conducting a research project for TxDOT on the feasibility of using RFID (radio frequency identification device) technologies to identify, assess, and/or manage various assets that may be located in or near the highway right-of-way. As part of this research, we are conducting a brief email survey to identify current and planned ROW applications of RFID technologies among transportation agencies. We would be grateful if you could take a few minutes to complete this survey. Participation is voluntary. Simply place an X next to the selected response and/or type your comments below the question and return the email to gene-h@tamu.edu. Feel free to contact me if you have any questions or comments. Thank you for your participation. For those that may not be familiar with the concept of RFID use in the ROW, there is a short description of the concept at the end of the survey, along with my contact information. We would appreciate a response within two weeks if possible.

In addition to the survey, one of the research project efforts will be a web conference on the use of RFID technologies in the ROW. That web conference will take place in early July. If you or a member or your organization would like to participate in the web conference, please respond to this message with the name and email address of the individual(s) that would like to participate.

<u>Survey Questions</u>

Please answer the following questions with an X and any explanation (if appropriate).

1. Does your agency currently use RFID technologies for agency assets located in the ROW (i.e., ROW markers, traffic signs, other infrastructure elements, etc.)?

   ___ Yes (please skip questions 4 and 5)
   ___ No (please skip question 3)
   ___ Other (please explain)

2. Does your agency currently require or recommend the use of RFID technologies for others' assets located in your ROW (i.e., utilities, outdoor advertising, etc.)?

   ___ Yes (please skip questions 4 and 5)
   ___ No (please skip question 3)
   ___ Other (please explain)

3. If your agency addresses RFID use, please indicate the applications for which your agency has formal rules, regulations, or specifications that relate to the use of RFID technologies for managing assets in or near the roadway ROW:

___ Underground utilities
___ Aboveground utilities
___ Outdoor advertising
___ Agency assets (bridges, signs, culverts, signals, counters, etc.)
___ Other (please explain)

4. If your agency does not use or monitor RFID, why?

___ The agency has evaluated and determined that it would not be desirable to implement. What was the main reason for not implementing? Please indicate whether the findings of these evaluations are available for review.
___ The agency has not evaluated or addressed the potential application.
___ The agency is waiting for the technology to mature and/or have greater use.
___ Other (please explain)

5. If your agency does not currently use RFID technology for ROW applications, is it considering doing so in the future?

___ Yes
___ No

6. Does your agency know if others (such as utility companies) that use RFID technologies for their assets located in your roadway ROW?

___ The agency knows such technology is used, but does not track or monitor the information associated with use.
___ Not aware of such use

7. Are you aware of other agencies (local agencies in your state or local/state agencies elsewhere) that use RFID technologies for managing ROW assets?

___ Yes (please list the agency names)
___ No

<u>Description of RFID Use in the Highway ROW</u>

Radio frequency identification device (RFID) technology provides the capability to store a unique ID number and basic attribute information, which can be retrieved wirelessly when the device (or RFID tag) detects a radio signal from a remote reader. RFID technology is currently used in many applications including inventory management and highway toll tags. The use of RFID technology offers the potential to improve the ability to manage right-of-way (ROW) functions and identify/track/manage assets located within the ROW. This research project is a feasibility study of how RFID technology can be used to support various ROW functions. This project will identify RFID technologies and the potential of those technologies to support ROW activities such as identifying utilities, outdoor advertising, infrastructure, and ROW markers.

APPENDIX B: UTILITY COMPANY AND PUBLIC AGENCY SURVEY

The following presents the survey language that was distributed to utility companies and public agencies in the second survey administered as part of this project.

TO: Utility Companies and Public Agencies Responsible for Utilities

The Texas Transportation Institute is conducting a research project for TxDOT on the feasibility of using RFID (radio frequency identification device) technologies to identify, assess, and/or manage various assets that may be located in or near the highway right-of-way (ROW). One of the applications of RFID technology is using RFID tags to identify and/or track utilities and otherwise manage these assets. As part of this research, we are conducting a brief email survey to identify current and planned applications of RFID technologies among utility companies/agencies. We would be grateful if you could take a few minutes to complete this survey. Participation is voluntary. Simply place an X next to the selected response and/or type your comments below the question and return the email to gene-h@tamu.edu. Feel free to contact me if you have any questions or comments. Thank you for your participation. For those that may not be familiar with the concept of RFID use in the ROW, there is a short description of the concept at the end of the survey, along with my contact information. We would appreciate a response within two weeks if possible.

In addition to the survey, one of the research project efforts will be a web conference on the use of RFID technologies in the ROW. That web conference will take place in early August. If you or a member or your company/organization would like to participate in the web conference, please respond to this message with the name and email address of the individual(s) that would like to participate.

<u>Survey Questions</u>

Please answer the following questions with an X and any explanation (if appropriate).

1. What type of utilities is your company or agency responsible for?

   ___ Water
   ___ Wastewater
   ___ Electricity or power
   ___ Cable TV
   ___ Gas
   ___ Telephone or Communications (including fiber optic)
   ___ Other (please identify) _________________

2. Does your company or agency currently use RFID technologies for utility locating/tracking and asset management?

   ___Yes
   ___ No
   ___ Other (please explain)

3. If your company or agency does not use RFID technology for managing utility installations, why?

   ___ We have evaluated it and determined that it would not be desirable to implement. What was the main reason for not implementing? Please indicate whether the findings of these evaluations are available for review.
   ___ We have not evaluated or addressed the potential application.
   ___ We are waiting for the technology to mature and/or have greater use.
   ___ Other (please explain)

4. If your company or agency does not currently use RFID technology for ROW applications, is it considering doing so in the future?

   ___Yes
   ___ No

5. Are you aware of other companies or agencies that use RFID technologies for utility locating/tracking or asset management?

   ___ Yes (please list the names)
   ___ No

<u>Description of RFID Use in the Highway ROW</u>

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