ROADSIDE SAFETY HARDWARE IDENTIFICATION METHODS

Report to Congress

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LIST OF ABBREVIATIONS

1D	One-dimensional
2D	Two-dimensional
AASHTO	American Association of State Highway and Transportation Officials
EPC	Electronic Product Code
FAST Act	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
GPS	Global Positioning System
GRail	Idaho Guardrail Management System
HF	High Frequency
ID	Identification
ISO	International Organization for Standardization
ISPE	In-Service Performance Evaluation
LF	Low Frequency
LIDaR	Laser Imaging Detection and Ranging
MIMS	Materials Information Management System
RFID	Radio Frequency Identification
UHF	Ultra-High Frequency
UV	Ultraviolet

EXECUTIVE SUMMARY

Section 1429 of the Fixing America's Surface Transportation (FAST) Act requires the Secretary of Transportation to study identification methods that can improve the capability of transportation agencies to collect data about their roadside safety hardware, such as guardrail and end treatments. Transportation agencies use the collected data to evaluate the in-service performance of this safety hardware. This report submits the results of the study, which include:

- Determining available roadside safety hardware identification (ID) methods.
- Conducting an in-depth analysis of the ID methods.
- Evaluating the ID methods for their ability to convey information, withstand roadside conditions, and connect to existing agency systems.

Proper installation, maintenance, and evaluation of roadside safety hardware ensure that the hardware performs as designed and tested. Laboratory crash testing is only the first step in addressing the safety of roadside hardware. The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) encourage States to perform in-service performance evaluations (ISPE) to identify real-world performance of roadside hardware. Creating an inventory and monitoring the field performance of safety hardware provide in-service performance data that supplement data obtained from crash-testing the hardware. Transportation agencies can effectively improve their capability to monitor the field performance of safety hardware by using ID methods for ISPE programs or as part of overall agency asset management systems:

- The ISPE programs determine and document how the safety feature performs during a broad range of collision, operational, and maintenance situations for a typical site and traffic conditions.(1) The ISPE of roadside safety hardware provides additional information to practitioners on how hardware performs under various field conditions, which vary widely from the conditions under which the hardware is crash-tested.
- Asset management is a strategic and systematic process of operating, maintaining, and improving physical assets. Asset management allows analysis of collected data to aid in making decisions about maintenance, preservation, repair, rehabilitation, and replacement actions.(2)

This report documents the evaluation of ID methods and investigates how these ID methods may be integrated into a transportation agency's ISPE or asset management framework. Currently available ID methods were identified based on the FAST Act Section 1429 requirement, input from the expert panel, and review of literature and specifications. The FHWA identified and studied three primary ID methods:

- Barcodes, either one-dimensional (1D) or two-dimensional (2D).
- Radio frequency identification (RFID) devices, either active or passive.
- Serial numbers.

Approaches to tracking, and evaluating the performance of assets using these ID methods were also investigated, with a focus on roadside assets where that information was available.

Barcode and RFID systems include the tag identifier, readers or scanners to read the information, and middleware or software to store the information. System performance depends on line of sight, reading rate, reading distance, tag size, use of metal, and use near water. Serial numbers can be read and data entered manually. They can be stamped directly on roadside safety hardware or printed on a tag identifier. Practitioners in the highway industry were consulted about factors and characteristics that would impact their selection of ID methods. These factors covered a broad range of issues, including the components of the hardware to be identified, information security, placement and vandalism of ID tags, durability, and compatibility with existing systems. Evaluation of the ID methods took these factors into account and applied a grading system for various performance aspects. Approaches to gathering and using data from the devices were graded based on ease of use; available tag identifier options and technologies; and the ability to convey information, withstand roadside conditions, and connect to existing agency systems.

The transportation field and other industries have successfully used barcode, RFID, and serial number tag identifiers as an ID method. However, examples of use for safety hardware are very limited, and no full-scale ISPE programs were identified. There are currently four States with pilot ISPE programs that include a limited sample of guardrail terminals. While other experiments or research on ISPE has been conducted, very little progress has been made in this area. This could be due to the magnitude of implementing such a system in the field. The following factors should be evaluated when considering the use of hardware ID methods: connectivity to existing agency data systems, the number and categories of roadside hardware devices, the type of ID device, and the cost associated with the implementation of the ID devices and the supporting readers and software.

CHAPTER 1. BACKGROUND

Section 1429 of the FAST Act requires the Secretary of Transportation to study ID methods that transportation agencies can use to collect data about their roadside highway safety hardware. Transportation agencies can use these ID methods to evaluate the in-service performance of the roadside safety hardware and improve the data collected about the hardware. Section 1429 states the following:

> SEC. 1429. IDENTIFICATION OF ROADSIDE HIGHWAY SAFETY HARDWARE DEVICES.
>
> (a) STUDY.—The Secretary shall conduct a study on methods for identifying roadside highway safety hardware devices to improve the data collected on the devices, as necessary for in-service evaluation of the devices.
> (b) CONTENTS.—In conducting the study under subsection (a), the Secretary shall evaluate identification methods based on the ability of the method—
>> (1) to convey information on the devices, including manufacturing date, factory of origin, product brand, and model;
>> (2) to withstand roadside conditions; and
>> (3) to connect to State and regional inventories of similar devices.
>
> (c) IDENTIFICATION METHODS.—The identification methods to be studied under this section include stamped serial numbers, radio-frequency identification, and such other methods as the Secretary determines appropriate.
> (d) REPORT TO CONGRESS.—Not later than January 1, 2018, the Secretary shall submit to Congress a report on the results of the study under subsection (a).

This study is designed to satisfy the Section 1429 requirement. The study included a literature review, a review of the practices of transportation agencies and other industries, and input from an expert panel. The roadside safety hardware expert panel included manufacturers, installers, researchers from across the United States, and staff members from three State departments of transportation. The practitioners considered parameters that agencies could use to effectively select ID methods and improve their capability to implement ISPE or asset management programs.

This first chapter gives a brief background of roadside safety hardware, potential opportunities arising from identifying and documenting this hardware, and gaps in current methods of identifying and documenting information about roadside safety hardware.

ROADSIDE SAFETY HARDWARE

Roadside safety hardware is part of the highway infrastructure that functions to reduce crash severity. Roadway departures accounted for over half of the 35,092 traffic fatalities in the United States in 2015.[(3)] Roadside design provides for a clear, recoverable area where feasible, and where roadsides cannot be designed free of fixed objects, crashworthy roadside safety hardware is used to reduce risk. Despite improved design and crash testing of hardware, approximately 3 percent of U.S. traffic fatalities occur in vehicles where the most harmful event involved the hardware itself.*

Roadside Safety Hardware Definitions

The AASHTO *Roadside Design Guide* provides information on designing roadways to reduce crash risk and severity. Roadside barriers are designed to contain and redirect vehicles. Barriers are installed only in locations where there is potential for greater harm, such as crossing into oncoming traffic, rolling over on a steep slope, or hitting trees. When roadside assets are necessary, such as signs and luminaires, supports have safety design features to break away in a crash so that they pose minimal risk to motorists.

Before discussing and evaluating ID methods, it is important to understand the different types of roadside safety hardware and their functions. This section defines the following common hardware and gives some examples:

- Longitudinal barriers (guardrails).
- Barrier terminals (guardrail end treatments).
- Crash cushions.
- Breakaway hardware (signs, luminaires, etc.).

Longitudinal Barriers

The AASHTO *Roadside Design Guide* defines a *barrier* as:

> A device which provides a physical limitation through which a vehicle would not normally pass. It is intended to contain or redirect an errant vehicle.[1]

The term *barrier* in this report includes:

- **Roadside barrier**—"A longitudinal barrier used to shield roadside obstacles or non-traversable terrain features."
- **Median barrier**—"A longitudinal barrier used to prevent an errant vehicle from crossing the highway median."
- **Bridge railing**—"A longitudinal barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure."[1]

Figure 1 shows an example of longitudinal barrier.

* Based on data from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS) database. Roadside safety hardware includes all longitudinal barriers, barrier terminals, crash cushions, and traffic sign supports.

Figure 1. Photo. Example of longitudinal barrier.

Barrier Terminals

The AASHTO *Roadside Design Guide* defines a *terminal* as:

> …a crashworthy anchorage, a device used to anchor a flexible or semi-rigid barrier to the ground. Being crashworthy, terminals are normally used at the end of a barrier that is located within the clear zone or that is likely to be impacted by errant vehicles.(1)

Figure 2 shows an example of a barrier terminal.

Figure 2. Photo. Example of a barrier terminal.

Crash Cushions

The AASHTO *Roadside Design Guide* defines *crash cushions*, also known as impact attenuators, as:

> …typically attached to or placed in front of concrete barriers (median barriers, roadside barriers, or bridge railings) or other rigid fixed objects, such as bridge piers, to prevent an errant vehicle from impacting fixed objects by gradually decelerating the vehicle to a safe stop or by redirecting the vehicle away from the obstacle.(1)

Figure 3 shows an example of a crash cushion.

Figure 3. Photo. Example of a crash cushion.

Breakaway Hardware

The AASHTO *Roadside Design Guide* defines the term *breakaway* as:

> A design feature which allows a device such as a sign, luminaire, or traffic signal support to yield or separate upon impact. The release mechanism may be a slip plane, plastic hinges, fracture elements, or a combination of these.(1)

Breakaway hardware for this report includes supports for signs, luminaires, and traffic signals. Figure 4 shows an example of breakaway hardware, specifically a sign support.

Figure 4. Photo. Example of breakaway hardware.

Safety Hardware Performance

Crash testing of safety hardware is a vital first step in understanding how hardware will perform. However, crash testing is performed under ideal conditions, which are not always representative of every real-world condition across the entire roadway network. And while crash-testing parameters are set to test the limits of performance of hardware, some crashes may occur at higher speeds, different angles, or different vehicle parameters than the crash tests. The ISPE, continuous monitoring, and asset management allow agencies to gather more data about how safety hardware performs in practice.

In-Service Performance Evaluation

The AASHTO *Roadside Design Guide* states:

> …in-service evaluation is a very important step when assessing the impact performance of a new or extensively modified safety feature [or hardware]. The purpose of in-service evaluation is to determine and document the manner in which the safety feature [or hardware] performs within a broad range of collisions and real-world conditions, such as environmental, operational, and maintenance situations for typical site and traffic conditions.

The *Roadside Design Guide* lists the following factors that can cause differences between field performance and crash test results:

- Field impact conditions that are not included in crash test guidelines, such as non-tracking and side impacts.
- Site conditions, such as roadside slopes and ditches, that adversely affect vehicle kinematics before, during, or after impact with the safety device.
- Sensitivity to installation details, such as soil resistance or barrier flare configuration.(1)

The ISPEs allow transportation agencies to identify overall performance, potential weaknesses, and design problems of roadside safety hardware. The FHWA and AASHTO encourage agencies to evaluate in-service hardware and continuously monitor it to assess its field performance. However, agencies themselves determine how they monitor and assess in-field performance.

ISPEs may include the following elements:

- **An installation and maintenance checklist**—evaluate items related to construction, installation, and maintenance of the hardware.
- **Inventory**—examine the location and design details of the installation.
- **Crash monitoring**—examine the reported and non-reported crashes involving the installation.
- **In-depth investigation**—investigate the crashes that resulted in serious injury or a fatality by obtaining the police crash report, documenting the site, examining the involved vehicle, and making efforts to reconstruct the crash.

Continuous Monitoring

Even after the hardware has undergone a successful ISPE, the AASHTO *Manual for Assessing Safety Hardware* strongly recommends continuous monitoring. Continuous monitoring requires examining highway and traffic data, maintenance records, roadside feature inventory data, crash data, and other components for periodic analysis.(4)

Asset Management

Existing asset management practices used by transportation agencies may be an efficient means of accomplishing ISPE. Section 101(a)(2) of Title 23 of the United States Code defines *asset management* as:

> …a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost.(2)

The objective of asset management is to make decisions based on quality information and focused on engineering and business practices for resource allocation and utilization.(5)

Current requirements in asset management are for transportation agencies to develop asset management plans for pavement and bridges. However, expanding asset management to safety assets is an opportunity to obtain quality data for analysis in an ISPE program.

Data Collection

Quality data are key components of asset management and analyses such as ISPEs. The industry generally divides data collection techniques for asset management into three categories:

- Manual data collection.
- Automated collection.
- Remote collection.

Currently, these are the state-of-the-practice techniques for collecting information about roadway assets, including roadside safety hardware.

Manual Collection

Manual collection may use handheld computers, global positioning system (GPS) units, or pen-and-paper records. Data collectors may stop at a particular location and survey the condition and location of each asset, or they may conduct a driving survey.(6) The means of recording data may depend on the level of detail desired by the agency.

Automated Collection

Automated collection involves a vehicle equipped with technologies to identify and document transportation assets. The vehicle may be equipped with video cameras, a GPS unit, laser imaging detection and ranging (LIDaR), and computer hardware to capture, store, and process collected data.(6)

Remote Collection

Remote collection uses photo logs, video logs, and satellite images. With remote collection, the images are used in conjunction with ground information to describe the location, condition, attributes, and characteristics of the roadway asset.(6) The quality of the remote data collection may be dependent on existing records about the asset.

POTENTIAL OPPORTUNITIES

Identifying and documenting safety hardware can facilitate ISPE. As discussed previously, there are various methods to collect this information, including using barcodes, RFID, and serial numbers. For true facilitation of ISPE, transportation agencies must evaluate suitable ID methods that provide:

- Unique safety hardware tracking.
- Inception-to-salvage tracking.
- Robust data sets for analysis.
- Connectivity and real-time information.

This report provides information on determining how the three ID methods (barcodes, RFID, and serial numbers) might improve a transportation agency's capability to identify and document safety hardware.

Unique Safety Hardware Tracking

Traditional asset management practices typically look at the transportation system as a whole—tracking system conditions, needs, and performance; developing costs for maintaining and preserving existing assets; and determining when to undertake an action on an asset.[5] For safety hardware, an asset management system needs to be able to provide specific, unique information about the hardware. This information could describe the hardware (as a system), installed components, the manufacturer, the installer, or the location.

This information can be analyzed over time by many characteristics and can help transportation agencies develop performance profiles, which aid in decision making. The additional cost of these capabilities and the complexity of the databases and analysis procedures needed to use them must be considered as well. Methods need to match the capabilities and available funds of the agencies that would potentially use them.

Inception-to-Salvage Tracking

Another consideration is the capability to follow roadside safety hardware and components from their origination at a manufacturer's factory to their final disposition in a crash, system upgrade, or other reason for replacement. The concept and value of event-based tracking were heavily considered during this study, including the following:

- **Manufacturer information** could be useful to determine where specific safety hardware components are located if ISPEs found a problem with components manufactured during a certain time frame.
- **Installer information** could be used to determine where additional training is needed to improve installation practices of certain types of safety hardware and whether the training should be aimed at State, local, or contract personnel.
- **General maintenance information**, such as repairs needed following winter plowing, could be useful to track the durability and life-cycle costs of various safety hardware and may be useful to determine training needs.
- **Post-crash maintenance information** about repairing or replacing components or the safety hardware (as a system) could be used for the same purposes as general maintenance information. Post-crash maintenance information could also make the repair process more efficient.
- **Removal information** may be useful for agencies. Information could also include the new safety hardware or configuration used, and whether other work was completed that removed the need for the hardware.

Robust Data Sets

Another aspect considered in the evaluation of ID methods is the ability of an ID method to support robust data sets for use with ISPE and asset management analysis. Robust data may allow researchers to analyze safety hardware to determine which performs better under different roadside and crash conditions. The data could also speed up the ISPE process and provide more accurate data about installation and maintenance of safety hardware.

Connectivity and Real-Time Information

With the many cloud-based connectivity options available, the ability of an ID method to provide near-real-time safety hardware information is another important consideration in the evaluation.

Having information that can be accessed remotely and updated actively reduces labor, provides better quality information to associate with crash data, and may result in more timely analysis.

GAPS IN CURRENT PRACTICES

Gaps in the current processes used by transportation agencies to identify and document roadside safety hardware include the following:

- Current practices for roadway asset management document only location, usually on a regular inventory schedule (annual, every 5 years, etc.). Collecting this data is a significant undertaking, which is evident in the continued rise in transportation agencies using service providers to gather data through mobile means (such as vans equipped with LIDaR and navigational sensors). There were very few uses of asset management identified that include roadside hardware.
- Transportation agencies and service providers are not readily able to collect and/or record specific data about roadside safety hardware (i.e., installation date, installer, and number of repairs). If transportation agencies had a record of this information, they might be able to successfully integrate it into an ISPE or safety asset management program but might have difficulty keeping the database current.
- The accuracy and availability of such records may be heavily dependent on hardcopy documentation kept by various departments and would require additional information requests from manufacturers and installers. Transportation agencies, manufacturers, installers, and maintenance personnel may also lack a common data set.
- Access to these types of data is usually limited to the transportation agency, if not a specific division of the transportation agency. There are no documented examples of interorganizational electronic data sharing, such as installer to transportation agency.

This report addresses these gaps by investigating ID methods with the potential to improve data collection and storage necessary for ISPE.

HOW THIS REPORT IS ORGANIZED

This report summarizes findings in the following chapters:

- **Chapter 2: Current Safety Hardware ID Practices** gives selected examples of current ID methods and practices for roadway safety asset tracking and safety hardware identification.
- **Chapter 3: ID Methods Using Tag Identifiers** gives a detailed summary of the technical capabilities and limitations of tag identifiers. The summary includes the components of all studied tag identifier systems, a quantitative review of their technical abilities such as reading distance, and a cost overview.
- **Chapter 4: Selection of ID Methods** gives an overview of the considerations for future deployment, including security, tag placement and vandalism, durability under crash events and roadside conditions, and connectivity to existing systems.
- **Chapter 5: Evaluation of ID Methods** discusses the approach used to evaluate the various ID methods investigated in the study and the resulting grades for various quantitative and qualitative performance areas.

- **Chapter 6: Summary and Conclusions** provides conclusions based on the information gleaned during the project.

CHAPTER 2. SAFETY HARDWARE ID PRACTICES

At the time of this report, we found no transportation agencies having full-scale ISPE programs in place, although several pilot programs are underway. However, some transportation agencies do track specific roadway safety hardware or use asset management systems for roadway inventories that include roadside safety hardware. A few transportation agencies have also experimented with the investigated ID methods for a variety of purposes.

This chapter provides two examples of roadway safety hardware tracking and several examples of the investigated ID methods using tag identifiers; the latter includes examples from other industries to show the potential range of opportunities and limitations.

ROADWAY SAFETY ASSET TRACKING

In an effort to better understand how some transportation agencies currently identify and document roadside safety assets, this report includes a review of two current asset management practices from the literature: Idaho and Florida.

Idaho Guardrail Management System (GRail)

The Idaho Transportation Department has a video-logging system, called GRail, to identify guardrails on the National Highway System. The agency developed the GRail application system using Microsoft® Access Visual Basic.

A vehicle equipped with video-logging equipment, GPS, and the ability to log distance traveled collects data along a roadway at highway speeds and takes images of the roadside hardware. During processing, users compare the photo log to existing records and then update those existing records if needed. Agency staff also enter new guardrail installation information manually from project plans.[7]

Florida Guardrail System

In 2012, the Lehman Center for Transportation Research at Florida International University investigated the in-service performance of strong-post w-beam guardrail and cable median barrier systems.[8] The result was a Web-based system called the Florida Guardrail System.

The Florida Guardrail System's database includes the county and road where the guardrail is located, the begin/end milepost, the position of the guardrail, the guardrail characteristics and condition, any guardrail damage, and the guardrail component repair records. The database allows users to look at information for guardrail systems on all Florida State roadways. Staff members populate the database manually from field records. The database allows the Florida Department of Transportation to maintain and correct inventory records in a timely manner.

IDENTIFICATION METHODS USING TAG IDENTIFIERS

Three primary ID methods could aid transportation agencies' ISPE or asset management efforts:

- Barcodes (printed and tags).
- RFID (tags).
- Serial numbers (printed, stamped, and tags).

All three methods could be deployed through permanently attaching tags to hardware. Alternatively, barcodes and serial numbers could be printed on hardware, and serial numbers could be physically stamped into the material of the hardware. Typically, printing and stamping are completed during manufacture. Post-manufacture, transportation agencies and other industries are using physical tag identifier technology as an ID method.

Examples of Transportation Agencies Using Tag Identifiers

The following examples illustrate the potential of post-manufacture tag identifiers (barcodes, RFID, and serial numbers).

Georgia Department of Transportation

<u>Construction Materials</u>

The Georgia Department of Transportation (GDOT) explored the use of RFID tags for tracking construction materials that the GDOT Office of Materials and Research tests. The Office of Materials and Research tests as many as 30,000 samples of construction materials and keeps track of its inventory through a paper-based system.

The investigation used read-only, passive, ultra-high-frequency (UHF) tags, which were linked to GDOT's Materials Information Management System (MIMS). Once the RFID tag was linked to the MIMS, the system tracked the time of arrival at the laboratory, assignment for testing, delivery to the laboratory for testing, completion of testing, entry of test results into the MIMS, and submission for review and approval of testing. Both a handheld reader and a fixed reader were used for tagging and ID.

The project established the durability of the tags through testing by placing the tags under high-moisture conditions; immersing the tags in water, acid, and base solutions; placing the tags in a freezer for at least 24 hours; and placing the tags on top of a concrete cylinder during a compression test. Overall, the tags proved to be very durable under all conditions and provided consistent readings throughout the test. Research findings showed that RFID tags are a viable option for material tracking.

The tags were relatively cost efficient. The cost of each tag ranged from $0.20 for one-time-use tags to $2.75 for reusable tags. The RFID reading equipment had some issues reading the least-expensive tags and was sensitive to tag orientation and attachment to metal. The distance for readability ranged from 10 to 13 ft.[9]

Signs

In addition, GDOT explored the use of barcode labels for newly installed signs.[10] Implementation has been delayed due to problems with database integration and some hardware issues, but it is still being pursued. The proposed labels are to contain all the information describing the sign. The database will include the following data fields: height, width, size, fabrication date, warranty date, cost, substrate material, sheeting manufacturer, legend and background sheeting types, legend and background colors, sign location, GPS coordinates, sign designations, side of the road and lateral offset, and installation date.

Alaska Department of Transportation and Public Facilities

The Alaska Department of Transportation and Public Facilities and FHWA investigated the feasibility of using RFID technology in their work with the construction industry.[11] The investigation included a field evaluation of tracking price-pay items such as asphalt, base course, borrow, and riprap using RFID tags.

The existing tracking process required a computer-generated ticket that the truck driver carried to the dump point, where staff collected and processed the ticket information to create an accounts-payable item (payment) to the carrier or driver. To investigate the feasibility of using an automated tracking system, researchers installed 10 RFID tags on 10 different dump trucks. Tags were placed at the rear of each truck, and a tag reader was placed at the exit of the facility where materials were stored. The RFID tags kept track of the departure and return time of the trucks from the asphalt plant. Staff still manually entered the job identification number, the type of material being transported, and other information. Evaluation performance metrics for the RFID tags included accuracy, processing, and total time of each round trip by each truck. The RFID tags proved successful in tracking the dump trucks. There was a 16 percent error in data entry, but these were human errors in recording truck ID numbers and load type.

Arizona Department of Transportation

The Arizona Department of Transportation conducted a pilot implementation of a barcode inventory system for fixed assets.[12] In this investigation, a *fixed asset* was defined as an asset that is moveable, durable, and considered a capital asset, such as maintenance vehicles. The user can print a label using a computer and barcode printer, or can obtain preprinted labels. Barcodes can also have an embedded RFID tag.

The project had three implementation pilot strategies:

- Centralize fixed-asset inventory management.
- Implement software to replace the current inventory management system.
- Expand the implementation of the barcode tag ID methods.

The total implementation cost ranged from $11,155 to $12,425. The cost included software licenses, staff training, 20,000 barcode labels, 2-year software and hardware support, and two scanner units. The pilot estimated a reduction of 26 percent in man hours needed to collect asset data when compared to manual techniques. The primary benefits of the barcode system were portability, on-site data entry capability, accuracy, and better reporting.

Alabama Department of Transportation

In June 2008, the Alabama Department of Transportation issued a specification for highway signing and maintenance.(13) The specification outlines a sign inventory system to keep track of installation, replacement, and/or repair of the traffic sign. The internet-based inventory includes the following data:

- Sign ID number (barcode).
- Work order ID.
- Sign style and type (according to the *Manual on Uniform Traffic Control Devices*).
- Dimensions.
- Installation date.
- Sign sheeting type and manufacturer.
- Location (GPS).
- Digital photo.
- Post type.

In the inventory system, the contractor delivers the data to the transportation agency through computerized download and the internet. Information about when a contractor replaces, installs, or repairs a sign is posted within 48 hours of the work. The barcode label must be 2.5 inches wide and 0.75 inches high, and have manufacturer specifications of a 12-year readable service life.

Maryland State Highway Administration

The Maryland State Highway Administration investigated the use of RFID tags and barcodes for inventory tracking. Specifically, the agency wanted to determine the abilities of both barcodes and RFID to track material field samples at the Office of Materials Technology's laboratories. The objective of the study was to recommend an ID method.

Maryland officials recommended the use of barcodes for all labs at the Office of Materials Technology. One reason for the recommendation was the use of barcodes in other construction applications and in the automotive industry. In addition, the Maryland study determined that laboratories with a large number of samples and a wide range of involved parties could benefit from RFID.(14)

Examples of Other Industries Using Tag Identifiers

Other industries have used tag identifier technology as ID methods, and transportation agencies may find opportunities to use the methods in innovative ways. The following examples show the breadth of the technology's use.

Forest Service Tree Inventory

The Forest Service's Forest Inventory and Analysis Program conducted a national census to assess America's forests. At the time of the report, the program was using metal tags, which after several years are consumed by the trees or otherwise lost.

The Forest Service used passive UHF tags and tested two different kinds of readers. After an indoor test, the team selected 12 tags for outdoor testing. However, none of the 12 tags were readable from distances greater than 15 ft. in outdoor conditions. Researchers concluded that at a price of $0.45 per tag, the cost was too great for the Forest Service to purchase and use RFID tags. The research findings showed that if the cost of RFID technology continues to decline, RFID tags could be an attractive option for tree inventory.(15)

Emergency Relief Operations

Ozguven and Ozbay introduced a comprehensive feedback-based emergency management framework to maintain a safe amount of vital supplies such as medicine, food, fuel, and power.(16) Researchers noted the need for such a tracking system and database in the aftermath of Hurricane Sandy.

The effort estimated that although RFID tags are more expensive than barcodes, they may be more reliable. In addition, RFID tags can track the movement of supplies and minimize data entry and collection errors because they reduce information-processing time.

Construction

Construction Materials

In 2006, Song et al. presented an automated tracking system for construction materials that would identify and track materials at construction sites without adding to regular site operations.(17) Researchers studied off-the-shelf RFID tags and tag readers, and set up a testing region in an open field.

The team read and located tags accurately within the region 93 percent of the time. The findings listed compatibility with construction environments as one of the advantages of RFID tags. Passive tags worked well for construction, and the process did not require line-of-sight tracking, thus making tracking faster.

Pavement

In 2014, FHWA investigated the application of RFID tags on pavement.(18) The research evaluated the tracking of the placement of hot-mix asphalt and Portland cement concrete truckloads, pavement temperature and depth, and early detection of cracking in overlays. Two tags were encapsulated in a chlorinated polyvinyl chloride pipe and placed within the pavement:

- A passive UHF RFID tag.
- A surface acoustic wave RFID tag.

Surface acoustic wave RFID tags have longer read ranges and can measure temperature. Researchers placed the tags in the new pavement construction of three parking lots. For hot-mix asphalt, the field test resulted in a 60 to 80 percent read success after construction. For Portland cement concrete, however, none of the tags could be read 1 month after construction. The research findings concluded that RFID tags were an appropriate application for hot-mix asphalt applications but not Portland cement concrete applications.

Warehouse Management and Retail Logistics

The Southwest Jiaotong University in China investigated the application of RFID tags as a replacement for barcodes and their impacts on logistics.(19) The effort estimated that the warehouse and retail logistics industry can use RFID in transportation and distribution management, storage and warehouse management, and circulation processing management. The reasons for improvement in logistics are that RFID tags avoid human intervention and accelerate delivery, the tag is non-contact, and the industry can use the tags in lean production. Benefits also include increased productivity by reducing human error, achieving a dynamic supply chain data in real time, improved delivery logistics through control of transportation, and reduced data entry that improves information accuracy.

Freight Cargo

Transcore uses hardened outdoor RFID tags placed on individual railcars for tracking purposes. By using a static reader, Transcore can automatically collect data about the railcar's destination and inventory.

Electronic Utility Tracking and Verification

The Texas A&M Transportation Institute and Prairie View A&M University studied the feasibility of using RFID tags to manage utilities, outdoor advertising, and other highway infrastructure within the Texas Department of Transportation right-of-way.(20)

The project found the following advantages of using RFID tags:

- No line of sight is required when reading a tag.
- RFID tags can store large amounts of data in addition to a unique identifier.
- RFID tags are less sensitive to adverse conditions.
- Users can read many tags simultaneously.

Some disadvantages of RFID include improper placement of the tag, which may corrupt readings; cost; and security and privacy issues.

Active tags were able to perform on all tests: use for underground facilities, metallic and non-metallic pipes, different soil types, the distance of the reader from the ground, passive and active tags, and the readability of tags for overhead structures. For passive tags, as the distances below ground increased, readability decreased. The research findings showed that RFID technology is not adequate for widespread use for asset management because of the numerous assets that are present on the roadway, and the application of RFID tags would require a significant financial commitment. However, RFID tags showed promise for limited applications.(20)

CHAPTER SUMMARY

The transportation field and other industries have successfully used barcode, RFID, and serial number tag identifiers as an ID method. However, examples of use for safety hardware are very limited, and no full-scale ISPE programs were identified. These findings rely heavily on manufacturer information to further detail the capabilities of tag identifiers as an ID method.

The next chapter gives an overview of technologies that are used to tag roadway safety hardware, termed *tag identifiers*.

CHAPTER 3. ID METHODS USING TAG IDENTIFIERS

This chapter provides an overview of the specific tag identifier technologies, and their relative performance, used by transportation agencies to tag roadside safety hardware. This review focuses on the following three primary tag identifiers as ID methods:

- Barcodes, either 1D or 2D.
- RFID devices, either active or passive.
- Serial numbers.

There was no clear separation in the literature or practice between uses of barcodes and serial numbers as tag identifiers (often barcodes have both the printed matrix and serial number). Therefore, they are treated as the same method in this chapter. It is assumed that transportation agencies would deploy both barcode and serial number technologies post-manufacture by creating and attaching a tag using the same printing and installation process.

BARCODE AND SERIAL NUMBER TAGS

Barcode tag identifiers consist of printed lines, spaces, and shapes on a tag that users attach to the product or asset they want to track. Similarly, serial numbers are a group of alphanumeric characters that users print on a tag and attach to the product or asset they want to identify and document.

In considering barcodes and serial numbers, the construction of the tag is very similar, and often manufacturers print both barcodes and corresponding serial numbers along with any additional information a buyer might want on the tag (see figure 5). Barcode standards are provided by the GS1 system established by the Uniform Product Code Council, which has been in place since 2005.

Figure 5. Image. Combination barcode and serial number tag.

Barcode Components

The barcode ID method uses a system made up of the tag and the scanner/software.

Barcode Tags

There are two primary types of barcodes: 1D and 2D. The most common type is a 1D barcode, which consists of parallel lines and spaces (see figure 5). The 2D barcodes consist of a combination of dots and geometric shapes or a matrix (see figure 6). More than 44 different barcode formats (various ways to present the lines, spaces, and dots) are commercially available.

Figure 6. Image. 2D data matrix barcode.

Generally, 2D barcodes can hold more information (numeric and alphanumeric) than 1D barcodes. The maximum amount of storage on a 1D tag is 48 alphanumeric characters. The maximum amount of storage on a 2D tag is 4,296 alphanumeric characters.[21,22]

Barcode Scanners and Software

Similarly to RFID, a user must deploy a barcode scanner or device capable of scanning a (a cell phone or tablet, for example) to read the barcode (see

figure 7). The scanner decodes visual information and sends it to a user’s handheld device or computer, which has software to read and store the information. Most barcode scanners consist of three parts: an illumination system, sensor, and decoder. The scanner uses red light to illuminate the tag, and then a sensor detects the reflected light and generates an analog signal, sending it to the decoder.[23]

Figure 7. Photo. Barcode scanner.

Barcode Performance

The performance of barcode tags depends greatly on many factors, including:

- **Line of sight and read angle.** Line of sight is required for both 1D and 2D barcodes. Scanners can read 2D barcodes at some angles.(29)
- **Reading rates.** Read rates for barcodes are limited to one barcode per scan. Scanners also take longer to read a 2D barcode than a 1D barcode.(29)
- **Reading distance.** Reading distance varies, but generally scanners can read 1D barcodes at twice the distance of 2D barcodes.(29)
- **Tag size.** The distance that a scanner can read a barcode is directly dependent on tag size and scanner type.(24)

Barcode Costs

Users can print barcodes on any printable medium and use a cell phone or tablet to scan barcodes. Tags that can withstand harsh environmental conditions may cost considerably more. Information can be scanned directly into readily available office spreadsheet programs or can require complex software to code specific elements into agency databases. Formal systems with proprietary software can be costly. Therefore, barcode software acquisition costs range from $2,500 to $35,000 despite barcode labels themselves being inexpensive.(12) This cost excludes training, support, server software, and personal digital assistance (PDA) software.

Price is greatly impacted by the quantity, material, and size of tags ordered, along with the attachment mechanism. For example, for a 2-square-inch aluminum tag hardened for exterior conditions having a thickness of 12/1000 of an inch with adhesive, the price is $0.42 each for an order of 10,000 units, while changing the thickness to 20/1000 of an inch raises the unit price to

$1.40. These tags have a 30-year life expectancy in harsh environments. Polypropylene, polyester, or vinyl tags can cost as little as a few cents each but would not stand up to harsh environments.

RADIO FREQUENCY IDENTIFICATION TAGS

RFID Components

While the RFID ID method may seem like simply an ID tag, it is a system that includes three basic components—the tag, the reader, and middleware.[25]

RFID Tags

Figure 8 presents the standard design of an RFID tag. It includes two parts: an antenna for receiving and transmitting a signal, and an integrated semiconductor (microchip).

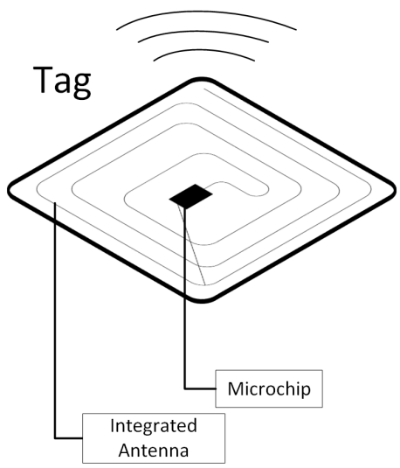

Figure 8. Image. Basic RFID tag.

<u>Types of RFID Tags</u>

There are three types of RFID tags:

- **Active RFID** tags have their own internal battery and, with this power source, are capable of sending continuous pings or signals.
- **Passive RFID** tags do not have an internal power source and must use a reader's energy waves to awaken and respond, relying entirely on the reader as a source of power.[25,26,27]
- **Semi-passive RFID** tags act similarly to passive tags and only transmit a signal when they are activated by a reader.[25]

The RFID industry has multiple standards and an established class system.[28] The Electronic Product Code standard specifies longevity and memory requirements. Additional information on the standards and classification is included in Appendix A.

No matter the type of RFID tag, they transmit data by three frequencies:

- **Low frequency (LF).** The LF tags are generally passive for short-range transmission and less costly.
- **High frequency (HF).** The HF tags are slightly more expensive, have longer reading ranges, and have higher reading speeds than LF tags.
- **Ultra-high frequency (UHF).** The UHF tags are the most commercial available of the three, their frequency is regulated by a worldwide standard, and they generally have a longer read range and higher reading speed than HF and LF tags.

The UHF tags are considered the most practical for unique-item tracking, offering a high reading range, speed, and rate. At practical application distances, UHF is strong enough to penetrate walls and other materials; however, long-range reading of UHF tags (thousands of feet and typically for active tags) requires line of sight similar to television antenna waves so that the signal is not blocked.[25]

Tag Memory

Manufacturers and standards specify that RFID tag memory can be accessed in three ways:

- **Read-only** tags have data that tag manufacturers permanently write in the tag memory that the end user cannot alter.
- **Read-write** tags have memory storage that the end user can alter. Manufacturers design these tags with various memory options and locking features. The supply chain management industry uses read-write tags on a regular basis so users can alter product information when required.
- **Write-once, read-many** tags allow the user to input custom information once, but they do not allow for revision. The user can then read the tags many times.[25]

RFID Readers

The RFID reader is a device that scans RFID tags and communicates the results to the bridging software known as middleware. The reader has its own antenna and communicates by broadcasting radio waves, awakening all tags operating in the same radio frequency. Some readers have additional abilities such as anti-collision, encryption and decryption, and transponder-reader authentication.

Readers can be handheld (figure 9), stationary, or mobile.[25]

Figure 9. Photo. Handheld RFID reader.

RFID Middleware

Middleware connects the readers and the data read from a tag to a database or enterprise software and/or information system. The middleware applies filtering, formatting, and logic to captured data. The middleware then provides access and data flow capabilities to/from back-end systems.[(25)] Middleware is often included within the reader.

RFID System Performance

The RFID tags have various potential technical limitations, including the reading rate, the reading distance, the impact of tag size, and use on metals and in wet conditions. These limitations are important for transportation agencies to understand so that they can use the correct tags for their purpose. This section discusses these possible limitations.

Line of Sight

The RFID technology generally does not require uninterrupted line of sight, though geological structures such as hills or mountains can obstruct the signal.

Reading Rate

The RFID readers can read multiple tags at the same time, up to 100 tags.[(29)]

Reading Distance

The RFID readers have limited range for reading and acquiring information from an RFID tag. This range varies with the type of tag. Users can read active RFID tags up to 656 ft. (200 m) away and passive RFID tags up to 82 ft. (25 m) away.[(36)] There is also emerging technology that allows for tags to be read up to 4 miles away.[(30)]

Tag Size

The size of RFID tags directly relates to the size of their antennas and their associated read range. The larger the antenna and tag, the farther away a tag can be read.[31]

Use on Metal

A common myth about RFID tags is that agencies cannot use them on metal. Non-improved RFID tags attached to metal objects have a history of problems. The metal reflects energy away from the tags and detunes the antenna. Manufacturers have addressed this concern by designing tags with spacers, often using the metal to reflect a greater amount of energy to the tag and increasing read range. In addition, efforts are underway to develop RFID tags using only the metal objects users attach them to as antennas.[32]

Use near Water

Similarly to use on metal, potential users often think that RFID devices are off limits for water. Submersion of an RFID tag distorts the RFID signal from the antenna as the water absorbs energy. Manufacturers have developed techniques to allow for RFID use underwater. By altering the antenna impedance, users can successfully read the tag.[32]

RFID Costs

The cost of an RFID tag (not the system including a reader and software) varies greatly depending on tag type and configuration. Generally, passive RFID tags are less expensive than active RFID tags.[33] Table 1 shows the various price ranges for passive and active RFID tags according to different sources.

Table 1. RFID tag costs per unit.

Source	Passive (UHF)	Active
Atlas RFID[34]	$0.15 to $5.00	$15 to $100
Impinj[35]	$0.50 to $2.00	None
Bridden[36]	$0.10 to $7.00	$4 to $30
RFID Journal[37]	$0.20 or more	$10 to $50

Tag costs are dependent on many things, including materials and manufacturing process as well as conditions for use (on metal or near water). The shape and application also impact price, and if the tag is a specialty tag, such as an eyelet, or is flexible enough to wrap around an object, the price is slightly higher. Price is directly related to the number of tags ordered; some prices drop almost 30 percent from an order of 100 tags to an order of 25,000 tags. There is also a relationship between durability and tag costs, especially for temperature extremes. A current price list based on quantity and durability is provided in Appendix B.

Maintenance cost should also be considered. The battery life for active tags ranges between 3 and 5 years. Some advancement in battery technology claims a 10-year life for active tags, but there is no easy way to determine when battery life has ended. This factor has implications for the cost of maintenance since transportation agencies will have to replace active RFID tags on a periodic basis. Transportation agencies should consider replacement costs if they choose to deploy active RFID tags.

Handheld readers with middleware pre-installed cost hundreds of dollars, while stationary readers can cost $1,000 or more.(27) Users can purchase UHF readers ranging from $500 to $3,000 depending on their added functionality.(37)

CHAPTER SUMMARY

Barcode and RFID systems include the tag identifier, readers or scanners to read the information, and middleware or software to store the information. System performance depends on line of sight, reading rate, reading distance, tag size, use of metal, and use near water. Serial numbers can be read and data entered manually. They can be stamped directly on roadside safety hardware or printed on a tag identifier. Since serial numbers are commonly used in combination with barcodes, they were treated as the same method in this chapter.

Once transportation agencies are familiar with the different tag identifier technologies as ID methods and their performance, the agencies can select the ID method that will work best for them. The next chapter describes several factors that transportation agencies may take into consideration while making this decision.

CHAPTER 4. SELECTION OF ID METHODS

After understanding the different ID methods, transportation agencies may consider several issues when selecting the appropriate ID methods for their network. This report identifies six primary performance issues regarding deployment of the ID methods identified:

- Identification of roadside hardware installations.
- Placement and physical vandalism.
- Durability under roadside conditions.
- Information security.
- Crash event durability.
- Connections to existing data systems.

Cost is also a factor for agencies to consider alongside performance.

IDENTIFICATION OF ROADSIDE HARDWARE INSTALLATIONS

There are two concepts that can be used to identify roadside safety hardware: hardware as a system of components and the individual components that make up that hardware. For example, a guardrail system would include railings, posts, block-outs, and end treatments. An individual component would include the end treatment alone (even end treatments could be further broken down into separate exchangeable components).

These concepts were developed assuming that manufacturers would not install tags. However, some manufacturers are already positioning themselves, or being required, to have the ability to identify their products.[38]

Based on the hardware as a system concept, transportation agencies would need to place only one tag for the entire hardware system or could even place the tag in the physical location of the system, not on the system components themselves. In the case of the individual components concept, agencies might have to install multiple tags at each location and sync or code those tags to the same unique ID number or numbers for each priority component of the hardware system. A third identification option blends the two by considering each piece of hardware as a parent of child components

Hardware as a System or Location Based

In the hardware as a system or location-based option, transportation agencies will tag hardware locations and include component and installation information in a documentation database. There will be one data key at each roadside safety hardware location. The agency will either be required to input manufacturer and installation information or provide manufacturers and installers access so that they may input this information. The documented information will provide the agencies with the ability to analyze both the hardware as a system and component data by location, installer, and manufacturer. This option relies heavily on the transportation agency and installers to correctly and diligently input information at the time of installation, at the time of repair and maintenance activities, and at the time of replacement.

Hardware Components

In the component-based option, transportation agencies will tag each priority component and require manufacturers or installers to tag new or replacement individual components of hardware. The agencies will be able to analyze the performance of individual components but may have difficulty understanding the performance of the series of components. This option will create multiple unique identifiers at each installation location, and when maintenance staff or an installer repairs or replaces a component, these new components will most likely have new unique identifiers. It is also important for transportation agencies to consider what to do with the tag of an obsolete component. Using a kill password to render an RFID useless or obliterating the barcode or serial number might help to prevent obsolete inventory from being included in a current database. This option relies heavily on the transportation agency to maintain and frequently update a detailed database, including a large number of components.

Parent Hardware as a System or Location Based with Child Components

A logical blending of the hardware as a system and hardware components tagging options is to view each piece of hardware as a parent of child components. For example, a guardrail parent hardware has an end treatment child component. This option would allow agencies to tag the parent hardware as a system or location and then attach child ID numbers to priority components. Transportation agencies can generate child component identifiers for existing installations and/or assimilate manufacturer identifiers under the parent hardware.

This option may also provide a mechanism for the transition from no identification and documentation by allowing the transportation agency to take small steps. Agencies would only have to identify existing parent hardware as systems while designing or moving toward the deployment of an identification and documentation program around new installation, maintenance, and repair. The documented information would provide the agencies with the ability to analyze both hardware as a system and hardware component data by location, installer, and manufacturer. This option would also allow for the industry to standardize manufacturer and installer information, making it uniform across all agency databases.

Scale of the Deployment of Hardware ID Method

It is important to consider the scale of implementation. For example, a typical urban freeway may have hundreds of installations of roadside safety hardware per mile. Even a rural local road is likely to have a few dozen. Based on the potentially large number of roadside safety hardware installations that an agency may have, a roadside safety hardware tagging effort may be a significant undertaking. Furthermore, agencies may find themselves with a mix of untagged components and tagged replacement components. Agencies that adopt the concept of hardware as a system may find locations with tags from newly manufactured components (with non-uniform and different ID information), and transportation agencies that adopt the concept of hardware by components may find it difficult to tag all existing installations.

PLACEMENT AND PHYSICAL VANDALISM

Manufacturers, installers, and/or transportation agencies must consider where to install the tag identifiers and whether placement would bring attention from potential vandals who might destroy or deface the tags. This is especially important to consider when determining whether transportation agencies should install serial numbers and/or barcodes. If vandals were to deface these types of tags and the destroyed/defaced tag was the only carrier of information, the transportation agency would lose all the information associated with the tag.

Although tag placement may affect the potential for vandalism, it will also impact the ability of the transportation agency's staff to read the tags, including using mobile data collection techniques. For example, if the installer places a tag in a location on the hardware where a component obstructs it from view, transportation agency staff would have to exit a vehicle to scan the tag.

To deal with these issues, transportation agencies could use the following placement options to combat vandalism:

- **Obscured placement.** Transportation agencies could require tags to be placed in obscure locations to reduce attention to them. This could possibly deter vandals from attempting to deface or remove the tag identifiers.
- **Limited conspicuity.** Based on discussion with experts and a demonstration at the Texas A&M University RFID laboratory, it is possible to disguise RFID tags under reflective sheeting or have them designed to mimic safety hardware components such as bolts and/or reflectors.
- **Stain-resistant and fire-resistant tags.** A review of commercially available barcode tags found both stain-resistant and proprietary fire-resistant tags that can resist temperatures up to 648°C (1,200°F).[39]

DURABILITY UNDER ROADSIDE CONDITIONS

A primary issue of concern is whether tag identifiers can withstand roadside conditions. Roadside conditions consist of many environmental, maintenance, and crash events that could impact tag operation and durability. Determining whether tag manufacturers had considered these types of conditions and had developed hardened tags was critical in evaluating the potential success of tag deployment.

The equipment specifications collected provide information for hardened/outdoor tags including 31 RFID tags and 36 barcode/serial number tags. Additional roadside conditions of interest should be considered such as maximum and minimum temperatures and common roadside chemicals.

Temperature Resistance

Understanding the expected regional temperatures that the tags will be exposed to will assist in determining the durability of available tags. Record temperatures in the United States range from −62°C (−80°F) in Alaska on January 23, 1971, to 57°C (134°F) in California on July 10, 1913.[40] High pavement temperatures may also impact temperatures at installations on roadside equipment.

Commercially available RFID tags can operate in extreme cold down to −50°C (−58°F) and extreme heat up to 300°C (572°F).[41] The ability to handle extreme temperatures varies greatly based on the encasement materials used for an RFID product. Plastics, resins, and metals have all performed well.

Commercially available barcode/serial number tags can operate in extreme cold down to −54°C (−65°F) and extreme heat up to 648°C (1,198°F).[42,43,44] For barcodes, not all manufacturers' specifications list a minimum operating temperature.

Water and Moisture Exposure

Transportation agencies must consider the impact of moisture for any tag option. Almost all roadside safety hardware is exposed to humidity and precipitation, including rain, snow and ice, as well as longitudinal barriers installed near waterways and drainage. Transportation agencies will need tags to withstand these conditions and periodic submersion from flooding and/or snow. Additionally, transportation agencies with facilities near coastlines should consider coastal spray and the need for saltwater resistance.

Water-resistant and submersion options are available for both RFID and barcode/serial number tags. For example, 28 of the available 31 durable RFID tag specifications list the product as submersible. For available barcode options, not all specifications indicated the ability for users to submerge tags but rather listed exterior exposure data to meet Federal Specification GG-P-455B from the mid-1960s for plates and foils. The Federal specification requires testing within a weatherometer but never indicates specific water resistance values or submersion, although the specification requires numerous chemical and organic solvent resistance values.[45] Moisture-resistant options are available for all conditions and for all tag types.

Ultraviolet Light Exposure

The sun will impact any installed tag through ultraviolet (UV) light. This exposure can cause certain materials to break down. Transportation agencies should consider UV-resistant tags to prevent degradation of visual-based tag information on barcodes/serial numbers, and degradation of the material for both RFID and barcodes/serial numbers.

Tags with significant UV resistance or imperviousness to UV exposure are commercially available. One barcode/serial number tag option includes a ceramic-fused stainless steel alloy with up to 100 years of UV resistance.[43] Tag options for RFID also include materials that are impervious to the impacts of UV light. However, transportation agencies should be aware that some tags do not have significant resistance to the impacts of UV light. Many RFID manufacturers claim their tags have excellent UV resistance but do not indicate how many years of resistance that covers. Some of the barcode/serial number tag specifications simply list a value for outdoor exposure length ranging from 1 to 10 years.[46]

Abrasive-Particle Exposure

In desert areas with high winds, transportation agencies should consider the potential for tags to suffer from abrasion due to particulate impact.

Abrasion-resistant options are available specifically for barcode/serial number tags with specific brush and abrasion wheel testing results. Some barcode/serial number manufacturers claim unparalleled abrasion resistance.[46] In contrast, most RFID tag specifications do not specifically address abrasion resistance. This could be primarily due to tags not having information printed on the outside of the RFID tag. Any abrasion concerns for RFID-only tags would ultimately be about particulates penetrating the encasement material.

Roadside Chemical Exposure

Common chemicals found near safety hardware include de-icing and anti-icing chemicals, herbicides, and petroleum-based chemicals such as diesel fuel and motor oil. Transportation agencies should consider using tags installed on roadside safety hardware that are resistant to saltwater, various herbicides, magnesium chloride, calcium chloride, diesel fuel, and motor oils.[47,48,49]

Chemical-resistant barcode and RFID tags are commercially available. These chemicals include solvents, acids, alcohols, ammonia, bleach, brake fluid, caustics, cleaners, engine coolant, chlorides, Freon, fuels (diesel, jet, and gasoline), heptane, hexane, hydrocarbons, ketones, oil, saltwater, sodium hydroxide, transmission fluid, xylene, and xylol.

Staining and Smearing

Transportation agencies should deploy tags that are resistant to staining and smearing, especially for visual-based tags such as barcodes and serial numbers. Tags should also resist overspray from paints and pavement maintenance activities. Since RFID tags do not rely on visual performance, staining and smearing are of no consequence unless combined with a barcode surface tag.

Many barcode/serial number tag options have staining and smearing resistance. One particular manufacturer coats barcode/serial number tags in Teflon, making the tags resistant to cleaning, pickling, painting, and powder coating.[50]

INFORMATION SECURITY

Agencies need to consider whether to put detailed hardware information on the tag identifier or use the identifier as a data key to access the information in the database. There are two primary ways tag readers convey information:

- **By the back end.** The tag reader uses middleware (often via an internet connection) to access the database or network server and provide the information about the hardware.
- **By the front end only.** The tag reader simply conveys the information on the tag.

Types of Security Threats

Similarly, security threats can include back-end and front-end security threats.

Back End

Back-end security threats include unauthorized access to the database or network server. This could be via an unauthorized tag reader or user via an internet connection to the information database. Unauthorized readers, hackers, and vandals have the highest potential to create back-end security threats.

Front End

Front-end security concerns include:

- **Unauthorized access to the tags and their information.** Unauthorized readers, hackers, and vandals could potentially target vulnerable tags. Both RFID and barcode tags have a critical vulnerability to a rogue reader. Rogue readers can access an RFID by simply reading what is on the tag with the correct frequency, and scanners can determine the barcode data if using the correct scanner for that barcode type.
- **Rogue tags and cloned tags.** For all studied tagging options, there is the potential for rogue tags (in addition to a rogue reader/scanner) and cloned tags. Vandals, equipment manufacturer competitors, and installers could place rogue tags on roadside hardware, introducing new information and/or cloning existing tags to disrupt the asset management process.
- **Side channel attacks.** Though most likely of negligible risk, side channel attacks can occur when rogue hardware captures security information during communications from an authorized reader and tag. Side channel attacks can access both kill passwords and data passwords.[(51)]

Security Options

Transportation agencies have three primary security options:

- No security.
- Back-end database and internet access security.
- Front-end (tag-based) security.

No Security

In this case, the transportation agency would deploy no security options, allowing tag identifiers to be both read-only and read-writable without access authorization protocols. This option allows multiple organizations easy access to read and write hardware and event information on either the tag or the transportation agency's database.

This option creates the potential for abuse from private citizens and/or vandals, allowing unwanted users to access, read, and input information. This security option would also prevent any capability for the transportation agency to track the ID of database users. Transportation agencies could limit their exposure by installing tags holding only a data key or ID number and requiring users to know the address of the agency's database to access information.

Back-End Database and Internet Access Security

In perhaps the most secure option, the transportation agency would deploy back-end database access security, allowing only authorized readers direct access via middleware to the database using current, proven security practices. For example, a secure socket layer is a standard security technology for establishing an encrypted link between a server and browser, or reader in this case.[52] If the transportation agency provides access to users via the internet or enterprise software with internet interface, the agency could deploy username and password security.

Authorized users would then access specific hardware information using the hardware's unique identifier by scan, read, or manual entry. This option would allow the transportation agencies to assign multiple levels of access, roles, and permissions to the database. In addition, transportation agencies could track both database inquiries and any information entered into the database according to the user, time, and date the information was inputted.

This option would also allow for using read-only tags, a recommended security best practice along with excluding confidential information on any tag.[51] This option is also potentially tag agnostic, only requiring a data key/ID number.

Front-End (Tag-Based) Security

For RFID technology, Gen2 RFID Standards provide for the ability to lock the information on the tag, but it is unclear if there are any direct access permission protocols to prevent an unauthorized reader from reading the information on an RFID tag. There are multiple built-in features including a lock memory and kill password:

- The *lock memory password* essentially creates an authorization to lock the memory on the RFID. For example, once an agency installs an RFID tag and places information about the component, it can create a password necessary to change the information on the tag.[53]
- The *kill password*, regularly used in retail applications, allows retailers to render an RFID useless, including access to customer information. A kill password could be useful in a roadside setting to delete tags on hardware taken out of service.

Additionally, transportation agencies could deploy encrypted serial numbers on the tags, but this may complicate data flow and would require a management process for the encryption key.[51] For barcodes, one option is for agencies to encrypt 2D barcodes since research suggests this strategy as a transit ticket security solution.[54]

CRASH EVENT DURABILITY

Members of the expert panel noted the potential need for tags to be able to withstand direct vehicle impact. It is difficult to determine the importance of this need without knowing where transportation agencies and the industry will place tags, presumably by a future standard, and how the tags will be attached. If transportation agencies place tags on hardware where they could potentially receive a direct impact from a vehicle, the force and scraping of the vehicle across a tag could compromise the integrity of both visual readability for barcodes/serial numbers and RFID chip operation. If transportation agencies place tags on secondary components, such as a strong post for a guardrail system, the means of attachment becomes vital so that the force from vehicle impact does not dislodge the tag from the roadside safety hardware.

Commercially Available Options Having Impact Resistance

Some manufacturers test tags for impact and pressure. One RFID manufacturer tested tags by dropping an 18-kg weight from a height of 2 m, which provides some impact resistance data but does not replicate the impacts expected in a vehicle crash, and the tag still functioned after more than 25 drop tests. The manufacturer also pressure-tested the same tag under 30,000 pounds per square inch for 30 days.[55]

Commercially Available Options for Attaching Tags

The way an agency attaches tags could be just as important as direct impact during a crash event. There are many potential ways transportation agencies, manufacturers, and installers can attach tags, including adhesives, cable ties (or a similar system), embedment, rivets, screws, tethers (or a similar system), and welds. However, if the force of the vehicular impact dislodges a tag, it is important for transportation agencies to be able to locate the dislodged tag. Due to line-of-sight restrictions with barcode/serial number tags, this type of tag would have to be located manually. If the agency were to use an RFID reader with a tag locator mode, agency staff could use the reader to locate a dislodged RFID tag.[56]

CONNECTIONS TO EXISTING DATA SYSTEMS

One of the overarching evaluation categories is the ability for tag identifiers as an ID method to connect and exchange information with existing asset management databases and software. An important characteristic transportation agencies should be concerned with involves associating unique identifiers with existing unique assets. One of the major components of an RFID and/or barcode system is the middleware that affords the connection to an existing server database or enterprise software. There should be no barriers to connectivity via middleware. Typically, middleware is pre-installed on the reader and can be set up to connect to existing systems. Costs may be associated with installation, operations, maintenance, and training with using the system, but these costs should be minimal.

CHAPTER SUMMARY

When selecting hardware ID methods, transportation agencies will need to decide whether to tag the system or the individual components; how detailed the information on the tag will be and how to secure the information; where on the roadside hardware the tag will be placed to balance usefulness, durability, and potential vandalism; and the middleware needed to connect the unique assets with existing agency data systems. The next chapter describes the evaluation approach for the various ID methods that transportation agencies could use for identifying roadway safety hardware.

CHAPTER 5. EVALUATION OF ID METHODS

Based on the identified ID methods discussed, an evaluation matrix was created to compare the performance of each in various areas. A grading system was used to create the evaluation matrix. Grades were based primarily on a review of literature, and a review of manufacturer specifications. Participation in various demonstrations, and input from the expert panel through consensus also informed the grading.

The performance areas are listed in this chapter and describe the background and reasoning behind the grading provided for each ID method. An evaluation matrix summarizes the grading to facilitate the selection of an ID method based on each performance area.

Transportation agencies can use the evaluation matrix in this chapter to select their preferred ID method. Each method has strengths and weaknesses. Selecting a preferred ID method is greatly dependent on the agency's needs. Beyond the evaluation matrix, it is important to quantify the cost and scale of implementation of the ID method to determine feasibility.

EVALUATION APPROACH

As previously discussed, the three primary ID methods are:

- 1D or 2D barcodes (printed on the hardware and as tag identifiers).
- Passive or active RFID (as tag identifiers).
- Serial numbers (printed, stamped, and in combination with barcode tag identifiers).

These primary methods all have various attributes that may or may not impact an overall rating. Methods were graded based on their best commercially available option for that attribute.

Performance Areas Evaluated

This chapter summarizes information about how the ID methods were evaluated, along with the results of the evaluation. The ID methods are evaluated for their ability to:

- Convey data.
- Withstand roadside conditions.
- Connect to existing systems.

The issues for method selection, discussed in the previous chapter, informed the evaluation of the ID methods for each of these three aspects. Cost is also a factor for agencies to consider alongside performance. It was not evaluated separately because the cost varies significantly based on the desired performance and quantity. The following performance areas address these three aspects:

- Convey data:
    - Information storage capacity.
    - Read distance.

- Read rate.
- Line of sight and angled reading.
- Automation and mobile reading.
- Read/write options.
- Event trigger options.

- Ability to withstand roadway conditions:
    - General roadside durability.
    - Vandalism-related durability.
    - Maintenance activities.
    - Crash event durability.
- Ability to connect to existing systems:
    - Connectivity.
    - Equipment needs.
    - Software needs.
    - Information security.

Grading

A five-level grading system was used:

- Poor—the method provides minimal or no performance.
- Fair—the method provides low performance.
- Good—the method provides acceptable performance.
- Very good—the method provides above-acceptable performance but has some disadvantages.
- Excellent—the method provides above-acceptable performance and has only minimal disadvantages.

An *excellent* grade suggests the highest capability, while a *poor* grade suggests minimal capability in the corresponding performance area.

EVALUATION RESULTS

Each of the performance areas are discussed in the following sections with some detail regarding how the various ID methods performed. The evaluation results for all methods by performance area are presented in the evaluation matrix (table 2). The table is useful to easily compare the capabilities of each ID method.

Table 2. Evaluation of ID methods for all performance areas.

Performance Area	Barcodes		RFID		Serial Number
	1D	2D	Passive	Active	
Information storage capacity	Fair	Good	Very good	Excellent	Poor
Read distance	Good	Fair	Very good	Excellent	Poor
Read rate	Good	Good	Excellent	Excellent	Poor
Line of sight and angled reading	Fair	Good	Excellent	Excellent	Poor
Automation and mobile reading	Good	Good	Very good	Excellent	Poor
Read/write options	Good	Good	Excellent	Excellent	Fair
Event trigger options	Poor	Poor	Very good	Very good	Poor
General roadside durability	Excellent	Excellent	Excellent	Excellent	Excellent
Vandalism-related durability	Good	Good	Excellent	Very good	Fair
Maintenance activities	Very good	Very good	Excellent	Fair	Very good
Crash event durability	Very good	Very good	Excellent	Excellent	Poor
Connectivity	Very good	Excellent	Excellent	Excellent	Good
Equipment needs	Very good	Good	Fair	Fair	Excellent
Software needs	Very good	Very good	Very good	Very good	Excellent
Information security	Excellent	Excellent	Excellent	Very good	Excellent

Information Storage Capacity

The information storage capacity performance area primarily considers the number of printed characters or matrices and electronic data. Typically, one character is 8 bits.

The 1D barcodes allow up to 48 characters or approximately 384 bits, and 2D bar codes allow up to 4,296 characters or approximately 34 KB. Passive RFID allows up to 64 KB, and active RFID allows up to 128 KB. Serial numbers have no electronic data storage on the tag, and the tag size determines the available area for printed information.

Read Distance

The read distance performance area considers the maximum distance a user can read information from a selected ID method without considering line-of-sight requirements.

The 1D barcode tag identifiers generally have reading distances of less than 15 ft. (5 m), and the reading distance depends on tag size and scanner settings. The 2D barcode tag identifiers have maximum scanning distances that are approximately half the distance of 1D barcode tag identifiers. Passive RFID tag identifiers have reading distances that approach 100 ft. (33 m). Active RFID tag identifiers have reading distances that approach 300 ft. (100 m) due to beacon-like signals from internal power sources. Serial number identifiers have reading distances limited to the human eye or photo magnification, and the reading distance depends on the size of the tag.

Read Rate

The read rate performance area evaluates the number of tags that users can read over a given period of time, excluding distance but including line-of-sight considerations.

The 1D barcode scanners can read one tag per scan and are limited by line of sight and a successful scan. The 2D barcode scanners can read one tag per scan and are limited by line of sight and a successful scan; 2D barcodes generally take a longer time to scan. Both passive and active RFID tags can be read in many multiples per scan, up to 100 tags at once, with appropriate middleware. Serial number identifiers are limited to a single manual read and limited by line of sight.

Line of Sight and Angled Reading

The line-of-sight and angled reading performance area evaluates the method's line-of-sight requirements for scanning and reading tags without consideration for reading distance.

The 1D barcode tag identifiers require direct line of sight and proper alignment of tag and scanner lasers. The 2D barcode tag identifiers can be read at an angle but still require partial line of sight. Passive and active RFID tag identifiers can be read within the reader's generated magnetic field and do not require direct line of sight. Serial number identifiers must be read manually, and line of sight is required.

Automation and Mobile Reading

The automation and mobile reading performance area evaluates the ability of users to read ID tags automatically with consideration for mobile tags or readers and reading distance.

The 1D barcode tag identifiers require the barcode and scanner to be aligned. The 2D barcode tag identifiers offer some allowance for misalignment with angled scanning, but the tag has to be fairly close to the scanner. Passive RFID tag identifiers can be read automatically and while the reader or tag is moving. Active RFID tag identifiers can be read automatically while the reader or tag is moving; with the beacon function, they can be used to capture all tags within a radius of the reader. Serial number identifiers are limited to human interaction.

Read/Write Options

The read/write options performance area evaluates the available choices for reading and placing information on the selected ID method and does not include consideration for use with a connected database, only what information users can read from or add to the physical tag.

The 1D barcode tag identifiers are print (write) once, read only; some basic barcode types have character limitations. The 2D barcode tag identifiers are print (write) once, read only. Passive and active RFID tag identifiers are available in read-only; write-once, read-only; read/write; read/write with locking; and kill options. Serial number identifiers are write once, read only (non-electronic).

Event Trigger Options

The event trigger options performance area evaluates the ability of users to associate tags with additional electronic sensors, such as an accelerometer, without consideration for reading distance.

The 1D and 2D barcode tag identifiers have no event trigger options. Passive and active RFID tag identifiers have event trigger options but require reading of the tag. Serial number identifiers have no event trigger options outside physical damage.

General Roadside Durability

The general roadside durability performance area evaluates the ability of commercially available ID methods to withstand roadside conditions, such as temperature; exposure to moisture, wind, and abrasion; ultraviolet degradation; and roadside chemicals as described in a review of roadside conditions and manufacturer specifications. This evaluation does not include the need for maintenance or vandalism/crash event durability.

All ID methods and tag identifiers have options available to withstand all common roadside conditions.

Vandalism-Related Durability

The vandalism-related durability performance area evaluates the potential threat of vandalism including removing a tag, defacing a tag, or attempting to destroy an installed tag.

The 1D and 2D barcode tag identifiers can be found with stain-resistant properties, but barcodes could be obstructed or physically damaged. Passive RFID tag identifiers have impact-resistant properties (encasements) available and can be disguised as a hardware component or obstructed by reflective tape. Active RFID tag identifiers are not permanent since batteries need to be replaced periodically; the tag identifiers are also bulky, potentially limiting concealment options. Stain-resistant serial number identifiers are available, but tags could be obstructed or physically damaged; for example, stamped serial numbers could be filed off.

Maintenance Activities

The maintenance activities performance area evaluates the need for maintenance after installation and considers the best available attachment methods, plus resistance to staining and smearing.

The 1D and 2D barcode tag identifiers are stain resistant but may need cleaning before scanning. Passive RFID tag identifiers have no maintenance requirements if operating within specifications. Active RFID tags need to be replaced every 3 to 5 years due to battery life. There have been some advancements in battery life, with some manufacturers claiming a 10-year battery life. There is no easy way for a transportation agency to determine when battery life has ended. Like barcodes, serial number identifiers are stain resistant but may need cleaning before reading.

Crash Event Durability

The crash event durability performance area evaluates performance during and after a crash event, including forced dislodging of tags from roadside safety hardware.

The 1D and 2D barcode tag identifiers are available with resistance to abrasion, but crash events could damage the surface, rendering it unreadable, and there is no recovery option outside manually locating dislodged tags. Passive RFID tag identifiers are available with impact resistance, and dislodged tags can be found with readers and a proximity scan. Active RFID tag identifiers are available with rugged encasement; dislodged tags can be found with a proximity reader, and beacon tags can send out an active signal to help locate them. Serial number tag identifiers are available with resistance to abrasion, but crash events could damage the surface, rendering it unreadable; there are no recovery options outside manually locating dislodged tags.

Connectivity

The connectivity performance area evaluates the ability to connect with existing systems.

The 1D barcode tag identifiers have maximum character limitations that could prevent the use of existing asset identifiers; however, 1D barcodes can be read electronically, and users can connect scanners to the server database. Similarly, 2D barcode tag identifiers and both passive and active RFID tag identifiers can be read electronically, and users can connect scanners/readers to the server database. Serial number tag identifiers require manual input into a connected server database interface.

Equipment Needs

The equipment needs performance area evaluates the need for equipment to access the information on a tag. The evaluation method does not consider tools required to install tags.

The 1D and 2D barcode tag identifiers require a separate scanner although many available cell phone applications can read barcodes. The 1D barcodes also allow for the ID number to be printed (on a combined tag) under the barcode. Barcodes in general also require an interface for database connectivity. Passive and active RFID tag identifiers require a separate reader and an interface for database connectivity. Serial number tag identifiers have no immediate equipment requirement but require an interface (laptop) for database connectivity.

Software Needs

The software needs performance area evaluates the need for software for users to operate the ID method beyond onboard reader software and existing asset management software.

The 1D and 2D barcode tag identifiers require a server connection. Passive and active RFID tag identifiers require middleware for a server connection. Serial number identifiers require no software, but software may be needed to input and/or access data.

Information Security

The information security performance area evaluates how secure safety hardware information is once placed on the tag or when transportation agencies use a tag to connect to a back-end server database. This performance area does not evaluate physical tag security (discussed separately as vandalism).

The 1D and 2D barcode tag identifiers can be read by any scanner set to a specific barcode type, but users can encrypt identifiers, and back-end security may be necessary to prevent unauthorized access. Passive and active RFID tag identifiers can be read by any RFID reader (at greater distances for active RFID tags), but users can encrypt identifiers in the back end and/or lock writable memory blocks. If active RFID tags are used for greater storage, information exposure is a concern because tags can be geo-located using GPS. Serial number identifiers can be read by anyone, but without connectivity, security threats are isolated to the back-end interface where back-end security may be necessary to prevent unauthorized access.

CHAPTER SUMMARY

The ID methods were evaluated and graded for their ability to convey data, withstand roadside conditions, and connect to existing systems. The results of the evaluation allow transportation agencies to determine which ID method is best suited to their purpose. The evaluation showed the investigated ID methods to be adaptable to a transportation agency's needs, once these needs are identified. The next chapter summarizes the findings included in this report.

CHAPTER 6. SUMMARY AND CONCLUSIONS

The objective of this report was to identify available ID methods to improve the data collected on roadside safety hardware to use for ISPEs and evaluate those methods. The study found that there are mainly three types of ID methods that are feasible and available for use. Each ID method has advantages and disadvantages when considering their ability to convey information, withstand roadside conditions, and connect to existing agency asset management systems or other databases. The evaluation resulted in a performance matrix of the evaluation of ID methods (located in chapter 5), which transportation agencies can use to select their preferred ID method based on their site-specific needs and available resources.

Transportation agencies have made recent strides in tracking and managing their assets, and several examples related to roadside safety hardware are documented in this report. Several transportation agencies are using tag identifiers in a limited or exploratory capacity. None were identified as being used for ISPEs, although there are examples of uses to track some roadside assets, primarily signs. As asset management becomes more routine for transportation agencies, it is likely these ID methods will begin to be used for roadway assets, especially if costs continue to diminish and capabilities continue to expand. Vehicle-to-infrastructure communication may also play a large role in making this type of data more readily available.

The currently available ID methods—1D and 2D barcodes, passive and active RFID, and serial numbers—were analyzed based on input from industry experts and through review of literature and specifications. This report provides detailed information on the capabilities of each method and how they work within an information system. In addition, practitioners provided insights on several factors that transportation agencies need to consider when planning to use the ID methods. Each method has benefits and limitations.

The evaluation of the three primary ID methods consisted of grading each method in 15 performance areas. The performance areas were developed to include the ID methods' ability to convey information, withstand roadside conditions, and connect to existing systems. Transportation agencies and the roadside safety hardware industry can use the grades for the tag identifiers in those areas most important to their needs—along with cost information for the tags, readers, and middleware needed—as a starting point in developing or improving their inventory and safety hardware tracking capabilities.

It is critical for transportation agencies to maintain quality data on these assets from inception to salvage. Identifying and maintaining a database of roadside hardware using any of the ID methods identified in this report can facilitate asset management and in-service performance efforts. Barcodes, RFID, and serial numbers are all potentially useful ID methods of identifying and documenting safety hardware. Beyond this report, it is important to define the scale and therefore the cost of implementation of the hardware ID method, which may determine overall feasibility. It may be most feasible to begin with a subset of roadside safety hardware but develop the system with future full-scale implementation in mind.

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APPENDIX A. STANDARDS FOR RFID TAGS

ELECTRONIC PRODUCT CODE STANDARD

The RFID industry has multiple standards and an established class system. The industry also subdivides standards according to interface protocol, data content, conformance, and applications.(1) The Electronic Product Code (EPC) standard specifies longevity and memory requirements. Memory requirements include:

- 96-bit EPC/number.
- 32- to 64-bit tag identifier.
- 32-bit kill password.
- 32-bit access password.
- Manufacturer-dependent user memory as high as 64 KB.(2)

The concept of a kill password and access password may be confusing. The protocol does not provide for a mechanism to prevent the reading of a Gen2 tag but has the ability to lock information using an access password and to render a tag inoperable using a kill password. A kill password will either render the tag unreadable or change the state of the tag—for example, changing the state of a retail tag from "inventory" to "purchased."(3)

The International Organization for Standardization (ISO) has created multiple standards for tracking cattle, air interface protocols, payment systems, vicinity cards, and performance testing.(1)

The Auto-ID Center developed the EPC and related technologies using UHF RFID. The Auto-ID Center desired a global RFID system based on an open standard due to the inherent need for the ability to track goods from one country to the next. The center developed a numbering system and network infrastructure using ISO air interface protocols but, instead of using the ISO UHF protocol, developed its own due to the complexity of the existing ISO protocol. The Auto-ID protocol, with some procedures now accepted as an ISO standard (Gen2), originally proposed six classes of UHF RFID tags:

- **Class 0**—a read-only passive tag with non-programmable memory.
- **Class 1**—a write-once, read-many passive tag.
- **Class 2**—a read-write passive tag with up to 65 KB of read-write memory.
- **Class 3**—a semi-passive tag with up to 65 KB read-write memory; a Class 2 tag with a built-in battery to support increased read range.
- **Class 4**—an active tag that uses a built-in battery to run the microchip's circuitry and to power a transmitter that broadcasts a signal to a reader.
- **Class 5**—an active RFID tag that can communicate with other Class 5 tags and/or other hardware.(1)

The industry adopted the EPC Radio Frequency Identity Protocols Generation-2 UHF RFID standard in 2004. This standard specifies the requirements for all classes of Gen2, which are backward compatible with first-generation tag standards. The 2004 standard applies to all tag classes but particularly to Class 2 tags. The EPC standard specifies longevity and memory requirements.

U.S. DEPARTMENT OF DEFENSE RFID STANDARD

Known as the DoD-96 Identifier, this U.S. Department of Defense specification provides instruction for a 96-bit identifier format using EPCglobal Gen2 tag standards.[(4)] It is primarily used for supply chain management.

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APPENDIX B. COST MATRIX OF RFID TAGS

Costs for RFID tags by quantity and durability are provided in table A-1.

Table A-1. Cost matrix by quantity and durability.

Tag Model	Cost for 1–100	Cost for 500	Cost for 1K	Cost for 5K	Cost for 10K	Cost for 25K	Max Temp. C	Notes
ARMORED 300C	$13.70	$13.20	$12.70	$12.45	$12.20	$12.20	300	Stainless steel
BT-1HT	$9.70	$8.70	$8.20	$7.95	$7.45	$7.20	300	Ceramic filler
BT-3HT	$9.70	$8.70	$8.20	$7.95	$7.45	$7.20	300	N/A
HD-101	$7.70	$6.90	$6.77	$5.98	$5.90	$5.14	200	Flexible wrap
RS-102	$6.21	$6.14	$5.30	$5.17	$5.14	$4.60	200	Impact tested
ST-1	$7.04	$6.84	$5.73	$5.43	$5.37	$5.00	250	Eyelet over bolt
STI	$9.50	$8.50	$8.00	$7.75	$7.25	$7.00	200	Drill tap and turn
TMT-3	$5.38	$4.78	$4.13	$3.83	$3.80	$3.70	200	N/A
WOW-1 WELDABLE	$7.20	$6.45	$6.20	$5.85	$5.50	$5.20	200	Weldable
Average	$8.46	$7.80	$7.25	$6.93	$6.67	$6.36	N/A	N/A

N/A = not applicable.