Furthered Implementation of Long-Range RFID Technology in Highway Asset Management

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Committee

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Abstract

Radio Frequency Identification (RFID) technology is used in various industries as for mobilizing data through transmission of radio waves to and from RFID tags. In turn the data can be received from the tags through an RFID reader for the user to view. RFID technology has been researched at Virginia Tech to find applicable systems to assist the highway asset management programs of the Virginia Department of Transportation (VDOT). The highway asset inspection data is useful to VDOT and field inspectors but it is not stored on-site where it is most useful; RFID technology could be the solution to accessing the data on-site (Fedrowitz 2007). The previous research found and tested two applicable systems, a long-range and short-range system.

This research further analyzes the long-range RFID system, which uses a reader to pull tag ID numbers from a distance and display them on a tablet PC connected to the system. The following objectives were used to create and evaluate a long-range RFID toolkit ideal for implementation into VDOT’s highway asset management programs: (1) establish an interface between the system and inspection data, (2) perform a market analysis to purchase an optimal wireless internet card as a part of the RFID-Data interface, (3) evaluate performance of the toolkit in predicted implementation scenarios, (4) explore possible use of long-range RFID system in conjunction with the short-range RFID system, (5) perform a total cost analysis of the entire toolkit, and (6) provide VDOT with a comprehensive report on the long-range RFID toolkit.

Results of this research are the following: (1) an interface was created through a retrieval program that links tag ID numbers corresponding to highway inspection data and supplemental materials helpful to the user posted online, (2) there is a wireless card on the market that works efficiently with the retrieval program, (3) there were noticeable negative differences between past and present tests with the RFID system in the static and dynamic tag reading distances, yet the retrieval program was still able to read tag ID numbers dynamically and display the corresponding data posted online to the user, (4) the asset location program of the short-range system could share results with the long-range retrieval program, (5) toolkit implementation is expensive because of the cost and quantity figures for the tags, and (6) an exhaustive report on the toolkit was prepared for VDOT.
~ Acknowledgements ~

I would first like to thank God and praise him for giving me the strength, perseverance, and endurance at the most difficult times when concluding my research and graduate studies seemed out of reach.

My friends and family, especially my parents, have shown everlasting love and support to get me over the personal and academic hurdles to complete my degree and always see the bigger and better things in my future.

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1 – Introduction

1.1 – Background

RFID Technology: How It Works

Radio Frequency Identification (RFID) is a technology presently being used and ever-evolving as an available means of mobilizing and manipulating data to the user’s customary advantage for improved management efficiency. The primary ingredient for any effective RFID system is the tag, the focal point for the user, as the tag is the source of mobility. Using a similar methodology as bar codes, RFID tags are small devices (see Figure 1) that can hold data or information which is then reported via radio waves when activated by a reading device, such as a scanner or reader shown in Figure 2. As a result, RFID does not require line-of-sight between the tag and reader like a bar coding system using light waves (CII 2001, SAT Corporation 2003).

Figure 1: Various RFID Tags

Figure 2: Short-Range RFID Reader
The tag itself holds a circuit chip and antenna enclosed in a type of casing that prevents exposure to any damaging environments. The reader uses an antenna, either integrated or external, to produce a radio-frequency magnetic field which serves as a carrier of power to the RFID tag from the reader. When the tag is in range of the magnetic field, the integrated circuit in the tag is energized and the memory contents of the tag are transmitted to the reader. The reader decodes the data for storage, viewing, and transmission to a computer (Fedrowitz 2007). RFID tags can be classified as passive or active. With a passive system, the tag is stimulated and powered by the magnetic field emanating from the reader; these systems are usually short range (0–1 meter) and have an indefinite life. With the active system, the transponder is stimulated by the reader but powered by an internal battery. Active systems maintain a longer read range (up to about 30 meters), but have batteries maintaining anywhere from a three to ten-year life span. Unlike the passive system that uses a short-range reader shown in Figure 2, the active system often uses a different type of reader combined with an assortment of external antennae (see Figure 3) to advantageously use the ability to read the tag from a distance. RFID systems can also be classified as read-only and read-write systems. With the read-only system, information content cannot be altered, storage capability is limited (1 to 16 bytes), and there is a rapid data transfer rate (CII 2001). The read-write system can not only be read but it also has the capabilities to be written to. The memory capacity of the tags varies from 64 bytes to 32 kilobytes (Jaselskis and El-Misalami 2003).

Figure 3: Long-Range RFID System Hardware
RFID Technology: Application Examples

Since 1979, RFID technology has been used in many different applications which include but are not limited to: personnel identification, material identification, tolls and fees, equipment maintenance, law enforcement, asset location and tracking, and animal tracking (Jaselskis et al. 1995). As more and more become aware of RFID technology and understand its potential uses, it is being implemented in new fields for varying applications. RFID tags, unlike bar code labels, are not easily damaged and can survive harsh conditions such as fluids, dust, chemicals, flames, and shock. This durability enables RFID tags to be used in all kinds of applications (CII 2001). Various industries are looking toward better ways to manage their inventory in a more efficient manner and expedite progress of deliverables. RFID systems have become popular with big retailers who want to use them to track stock and automate operations. Although each company has its individual motives for utilizing RFID technology, three guiding business benefits that are driving companies and industries to invest in RFID systems are: efficiency, security, and marketing. Because of benefits like these, industries such as construction and transportation are researching and implementing RFID technology to improve data storage applications and satisfy business needs (Kinsella 2005). With the enormous size of inventory needed to be transported to construction sites, materials can be tracked using RFID tags with individual pieces each having their location and quantity updated at various points of reference. RFID tags can be loaded with maintenance records, special tools data, and warranty status information as well, which is a huge advantage over manually reading stamped tags and hand-lettered codes (Sawyer 2004). According to Kang et al. (2007) RFID technology opens the possibility of automating the entire tool management process. In an experiment, participants were instructed to place seven tools attached with RFID tags into a storage box containing other tools. Out of 30 trials, the RFID reader successfully identified all seven tags 26 times within two minutes. More impressively, the reader missed only four tools out of 210 tools tested, and the reader produced similar results with the storage box lid open and closed (Kang et al. 2007). “There is definitely a role for RFID in construction,” says Sawyer (2004), “it is a matter of working through the pilots and figuring out the best application. The opportunities for
increasing efficiency will not depend so much on standards development, as on the adopters’ creative thinking.”

Steps are being taken to improve the highway infrastructure, and the use of RFID technology could lengthen the strides of these steps. In one study a road sign asset management system was proposed in which the road sign’s location, type, size, height, and condition are noted and encoded onto passive RFID tags placed on the sign (Kain and MacGowan 2007). The readers would be located in official vehicles to query the signs and to encode sign condition. An additional part of this study says that another good use for RFID tags would be to manage the other roadside assets such as control box inventory (Kain and MacGowan 2007). Bridge inspectors can make use of RFID technology and use it advantageously. The inspections currently use paper-based reports to access historical information of bridge components and to visually locate specific components of interest. This can often be very cumbersome for a variety of reasons, while the use of RFID technology can eliminate or decrease the complexity that causes problems. RFID technology provides an opportunity to: make historical information readily available with the bridge components in a distributed fashion, update information stored with the component when work is performed, and to locate bridge components effectively (Akinci 2007). In other words, the bridge and its components are tagged with RFID and can be considered “intelligent”. Signs and bridges are only a small fraction of interstate highway assets that would benefit from the RFID technology. Similar information for dozens of other highway assets could be useful if available on-site, such as the history of certain items in terms of when they were installed, when they were replaced, how often they are damaged, and so forth.

1.2 – Point of Departure

Highway Asset Management

In an effort to provide the traveling public of the Commonwealth of Virginia a cost effective, high quality transportation infrastructure at a desired level of performance, the Virginia Department of Transportation (VDOT) has adopted an innovative highway asset management program with an initiative known as Performance-Based Road
Maintenance (PBRM); VDOT has contracted with a private concern for the management of certain assets located within the right of way for an entire geographical area (CHAMPS 2007). According to Piñero (2003) PBRM “specifies a desired outcome rather than a material or method and promises to be an excellent tool to improve government efficiency in maintaining transportation networks”. VDOT has maintenance contractors working on improving the quality of Virginia’s interstate highways through PBRM; however, without proper monitoring, it could likely yield adverse outcomes (Piñero 2003). In order to monitor progress and efficiency of the maintenance contracts, Virginia Tech assesses the condition of the assets within selected segments of interstate highways included in a section contracted for maintenance. Table 1 shows the typical information summarized for one segment of a highway (one-tenth of a mile in length from mile marker to subsequent mile marker) that crews collect during inspection. In the figure, the particular segment’s main information is shown, such as location and direction; the middle column uses numeric codes to designate whether the pertaining asset item in the first column has failed inspection, passed inspection, not inspected or not been found; the third column shows the particular comment code that explains why the asset item failed due to established criterion if it has done so during inspection. The number of segments to be inspected and their location is chosen by Virginia Tech through a random sampling with a 95% confidence level that the segments to be inspected will represent the contract section sufficiently. Depending on how the sampling progresses and the size of the contract section, the final number of segments can be in the lower hundreds to over a thousand. The random sampling, of course, can only be done after a baseline inspection is done where every segment is inspected to see what asset items are present and their condition prior to performed maintenance. The inspection data is then compiled and compared to the baseline inspection; this comparison data is very useful to VDOT because it shows how the maintenance and rehabilitation of the interstate highways are progressing. All of the data collected by the inspection crews is analyzed and prepared by Virginia Tech in a partnership with VDOT, called the Center for Highway Asset Maintenance ProgramS (CHAMPS), which was established to provide independent assessments and technical leadership to support innovations in maintenance and construction.
The mission of CHAMPS is to provide an ongoing support to VDOT on matters related to the privatization of the interstate maintenance activities, innovation, and research in maintenance and construction contracting. Since the partnership was established, Virginia Tech has continually researched and implemented new methods and technologies to enhance the process and results of the partnership. While the data collected through the inspections performed is useful to VDOT and field inspectors “the problem is that the data is not stored on-site where it is most useful; RFID technology could be the solution to storing data on-site where VDOT and field inspectors could read previously stored data and write to the tag to update data” (Fedrowitz 2007).

### Previous Research

Walter Fedrowitz, a previous graduate student in the Myers-Lawson School of Construction at Virginia Tech, had been working with RFID technology to set a foundation for its potential valuable usage to CHAMPS, which he was a valued member of as well. His research explored the market analysis of RFID technology to find a
system that is greatly applicable to highway asset management. According to Fedrowitz (2007), “the RFID characteristics that produced the greatest challenges to find were tags that could be mounted to metal surfaces, had large memory capacities, and had long-range reading capabilities. During the market research and analysis stage it was concluded that finding a long-range read/write system that matched all the necessary characteristics, including being capable of mounting to metal, was going to be challenging”. Fedrowitz concluded that both long-range and short-range products were available on the market, each with their own advantages and disadvantages. The long-range RFID tags could be read from much farther distances than the short-range tags, but the short-range tags could hold more information than the long-range tags because of their higher memory capacity. Table 2 and Table 3 show the specifications and characteristics for potential long-range products, as well as rankings of different factors for each product. Table 4 and Table 5 show the specifications and characteristics for potential short-range products, as well as rankings of different factors for each product.

Table 2: Specifications and Characteristics for Long-Range Systems
(Fedrowitz 2007)

<table>
<thead>
<tr>
<th>Factors</th>
<th>Transcore</th>
<th>AAID</th>
<th>Motorola</th>
<th>AXCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory Capacity</td>
<td>120 bit</td>
<td>None, unique ID # only</td>
<td>90 bit</td>
<td>None, unique ID # only</td>
</tr>
<tr>
<td>Read Range</td>
<td>12'-35'</td>
<td>600'</td>
<td>4'-7'</td>
<td>100'</td>
</tr>
<tr>
<td>Mount to Metal</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>System Cost</td>
<td>$6,500</td>
<td>$6,111</td>
<td>$2,709</td>
<td>$1,196</td>
</tr>
<tr>
<td>Tag Size</td>
<td>3.7 x 2.4 x 0.6 in</td>
<td>3.4 x 2.8 x 0.3 in</td>
<td>6 x 6 x 0.5 in</td>
<td>4.1 x 2.2 x 0.5 in</td>
</tr>
<tr>
<td>Operating Frequency</td>
<td>915 MHz</td>
<td>433.92 MHz</td>
<td>628 MHz</td>
<td>126 KHZ</td>
</tr>
<tr>
<td>Tag Durability</td>
<td>Waterproof, very large temperature range</td>
<td>Waterproof, large temperature range</td>
<td>All weather, durable</td>
<td>Large temperature range</td>
</tr>
<tr>
<td>Software Compatibility</td>
<td>Programming help needed</td>
<td>easy installation CD, Windows interface</td>
<td>No installation, “quick start”</td>
<td>Quick start, Basic Installation</td>
</tr>
</tbody>
</table>
Table 3: Long-Range System Rankings (Fedrowitz 2007)

<table>
<thead>
<tr>
<th>Factors</th>
<th>Transcend</th>
<th>AAIID</th>
<th>Motorola</th>
<th>AXCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory Capacity</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Read Range</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Mount to Metal</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Cost</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Tag Size</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Tag Durability</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Software Compatibility</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>19</strong></td>
<td><strong>28</strong></td>
<td><strong>22</strong></td>
<td><strong>23</strong></td>
</tr>
</tbody>
</table>

Table 4: Specifications and Characteristics for Short-Range Systems (Fedrowitz 2007)

<table>
<thead>
<tr>
<th>Factors</th>
<th>Dynasys</th>
<th>SAT Corporation</th>
<th>HID Corporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory Capacity</td>
<td>2000 bits</td>
<td>1080 bits</td>
<td>16k bits</td>
</tr>
<tr>
<td>Read Range</td>
<td>2 to 3 in</td>
<td>2 to 3 in</td>
<td>1 in</td>
</tr>
<tr>
<td>Mount to Metal</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>System Cost</td>
<td>$2,700</td>
<td>$2,709</td>
<td>$320</td>
</tr>
<tr>
<td>Tag Size</td>
<td>0.9 DIA x 0.1 in</td>
<td>0.15 DIA x 1.2 in</td>
<td>1.3 DIA x 0.1 in</td>
</tr>
<tr>
<td>Operating Frequency</td>
<td>13.56 MHz</td>
<td>134.2 KHz</td>
<td>13.56 MHz</td>
</tr>
<tr>
<td>Tag Durability</td>
<td>waterproof, large temperature range</td>
<td>waterproof, glass/plastic casing</td>
<td>waterproof, large temperature range</td>
</tr>
<tr>
<td>Software Compatibility</td>
<td>Windows operating system, handheld</td>
<td>Windows operating system, handheld</td>
<td>Software development kit, Windows GUI</td>
</tr>
</tbody>
</table>

Table 5: Short-Range System Rankings (Fedrowitz 2007)

<table>
<thead>
<tr>
<th>Factors</th>
<th>Dynasys</th>
<th>SAT Corp</th>
<th>HID Corp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory Capacity</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Read Range</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Mount to Metal</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cost</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Tag Size</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Tag Durability</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Software Compatibility</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30</strong></td>
<td><strong>20</strong></td>
<td><strong>28</strong></td>
</tr>
</tbody>
</table>
The “mount to metal” factor was particularly significant due to the fact that the RFID tags would most likely be mounted to the metal mile marker signs that specify the starting point of a crew’s work in a chosen highway segment. The long-range and short-range products from the two companies with the highest total ranking for the key factors were chosen, AAID and Dynasys. After a long-range and short-range product was chosen, Fedrowitz began testing the following five functions of the products to get a sense at what they were capable of:

a) Ability of an RFID reader to read a tag attached to a metal mile marker sign  
b) Speed an RFID reader can be traveling and consistently read a tag  
c) Size of memory on the tag and type of information that can be stored on the tag  
d) Time required to write to a tag and to read a tag  
e) Ease of reading/writing to a tag

The short-range tag was not looked at for the speed at which the reader could accurately read the tag from a moving vehicle because of the close proximity (measured in inches) needed by the user. The long-range tag was not looked at for memory storage because there is no additional memory capacity in addition to the unique identification number on the long-range tag. Fedrowitz (2007, p. 2) briefly concluded his results as follows:

“It was determined that the long-range system can consistently read up to 115 feet from a tag mounted to a mile marker sign under static conditions (vehicle not moving). In addition, the maximum dynamic read range of the long-range system traveling at 10 mph was also 115 feet. The short-range system can read an RFID tag mounted one centimeter away from metal at a distance of two inches. At a highway speed of sixty to sixty five mph, the long-range system was not very consistent and is capable of reading a tag at a maximum distance only twenty five feet. The short-range system has a storage capacity of 2000 bits and, based on information confirmed by a computer programmer, the baseline asset information
collected for forty asset items should fit on the short-range passive RFID tag. For both the short-range and long-range systems, the time required to read from an RFID tag was less than two seconds, which is very efficient. The long-range RFID system was very easy to learn how to operate and was convenient to use. The handheld short-range system was very convenient to use because of the mobility of the system.”

Future research suggested by Fedrowitz involves developing toolkits to meet the potential applications and to test the systems once operational. Such toolkits could wirelessly reference the baseline inspection database using the unique ID number of a tag read by the long-range system. Another potential application for future research is the short-range system that stores baseline asset information on an RFID tag mounted to a mile marker sign. For this application, a program would be written that will store data on an RFID tag using code to compress and uncompress asset item condition information. Using code rather than the actual information uses less memory on the short-range tag, and the code will interface with a program loaded into the reader that translates for the user on-site. A total of approximately 320 bits would be needed for storing asset and condition code on an RFID tag. The remaining memory capacity would be used to store failure codes for the forty asset items.
2 – Objectives

2.1 – Scope

First and foremost, the research presented strives for results that ultimately benefit the CHAMPS partnership through discovery of the applicable RFID technology. Though results may be used to advance other fields that adopt RFID technology, the research methodology used is solely focused on improving the highway asset management process. Secondly, in order to extract as much knowledge about the capabilities of an RFID system in highway asset management, the research presented is limited to the long-range RFID system established in the previous research done at Virginia Tech. The short-range RFID system is taken into account for a system that combines the long-range and short-range RFID system capabilities and applications for practical use.

2.2 – Objectives

The goal of this research is to further investigate the use of long-range RFID technology in highway asset management by continuing the research efforts that Walter Fedrowitz has done thus far at Virginia Tech. Fedrowitz has been able to find a suitable long-range RFID system whose functions are capable of advancing the efforts of VDOT in their highway asset management endeavors. Ultimately, a toolkit for the long-range RFID system is to be created that provides the necessary equipment and programs to potential users with minimal interface disturbance; this will be partly discovered by testing real-time applications of the long-range RFID system to CHAMPS practices. The objectives for this research to develop a long-range RFID toolkit are the following:

1) Establish an interface between the long-range RFID system and CHAMPS data.
2) Perform a market analysis to purchase an optimal wireless internet card to be evaluated in field conditions as a part of the RFID-Data interface.
3) Evaluate performance of long-range RFID toolkit in predicted implementation scenarios.
4) Explore possible use of long-range RFID system in conjunction with short-range RFID system.

5) Perform a total cost analysis of the entire long-range RFID toolkit created for various contract type and size.

6) Provide VDOT with a report showing the practices and advantages of using the long-range RFID toolkit on-site.

The toolkit to be created for the long-range RFID system not only exclusively includes the equipment needed for use of the system, but also any created programs that perform the interface between the data to be retrieved and the system. Part of the toolkit development requires the programming skills of Steve Spillane of Anderson & Associates, Inc., who played an important role in the initial RFID research performed by Fedrowitz.

2.3 – Methodology & Implementation

**Objective #1: Establish an interface between the long-range RFID system and CHAMPS data.**

The most imperative objective of this research is to find a way to connect the long-range RFID tags to the data since the tags can be retrieved by the system in the field. The inspection data is not only used and viewed by inspection crews through a portable tablet PC but also posted to an internet server, so the most logical and optimal interface is to create an RFID tag retrieval program that connects the long-range RFID system to the inspection data files posted online with a wireless internet connection. The AAID long-range RFID system, shown in Figure 4, uses software installed on a tablet PC to display a tag’s ID number when connected to a reader using an antenna to pull tags that are within reading range.
The primary function of the retrieval program, shown with Table 6 and Figure 5, is to display the online data corresponding to the tag ID numbers that the reader pulls from the field. The retrieval program must be able to handle reading multiple tags within the reader’s range and display the data for the segments corresponding to the multiple tags at the user’s choice. Another function of the retrieval program is to provide links to supplemental materials that benefit the knowledge of the user. For example, if the user is out in the field looking at a highway ramp and would like a sketch of the ramp then a link to a document containing ramp sketches would be provided once the tag for that ramp segment is read by the retrieval program. In a similar fashion, if the user is standing in front of an asset and would like to see the passing criterion then a link to a document containing such information would be provided once the tag representing the highway segment containing that asset is read by the retrieval program. Creating this retrieval program to provide instant access to highway inspection data for particular segments, while also providing supplemental materials, can increase accuracy and efficiency of highway asset inspections and analysis. The retrieval program and its functionality will only be useful if the tablet PC has a solid internet connection by means of a wireless broadband internet card.
Figure 5: Retrieval Program Function
Table 6: Retrieval Program Function Legend

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID Tag with ID#</td>
<td>A</td>
</tr>
<tr>
<td>Reader with Antenna</td>
<td>B</td>
</tr>
<tr>
<td>Tablet PC</td>
<td>C</td>
</tr>
<tr>
<td>Wireless Card</td>
<td>D</td>
</tr>
<tr>
<td>Server</td>
<td>E</td>
</tr>
<tr>
<td>Information Accessed:</td>
<td></td>
</tr>
<tr>
<td>Segment Data</td>
<td>F.1</td>
</tr>
<tr>
<td>Ramp Sketch</td>
<td>F.2</td>
</tr>
<tr>
<td>Passing Criterion</td>
<td>F.3</td>
</tr>
<tr>
<td>Short-Range Locator</td>
<td>F.4</td>
</tr>
</tbody>
</table>

**Objective #2: Perform a market analysis to purchase an optimal wireless internet card to be evaluated in field conditions as a part of the RFID-Data interface.**

To ensure that the interface between the retrieval program and online data work to full potential, an internet connection needs to be available at anywhere a highway segment with a corresponding RFID tag is located. The wireless broadband internet cards from the major retailers are looked at with a number of factors to consider for each model. Some of the major factors to consider include the service range available by the provider, the type of connection to the tablet PC, and the data transfer rate. After the factors have been established, the models receive total scores based on values that are assigned to each factor with the more important factors’ scores receiving a multiplier. Using this scoring system, a model’s total score is greatly increased if it scores well with an important factor that a wireless card should have for use with highway asset management. The model with the highest score is purchased and evaluated with respect to the interface involved with the rest of the long-rang RFID toolkit in predicted implementation scenarios.
Objective #3: Evaluate performance of long-range RFID toolkit in predicted implementation scenarios.

Once the retrieval program is created and a wireless card is included to complete the toolkit with the AAID long-range RFID system, testing of the toolkit is performed. The testing itself is performed on the Virginia Tech Transportation Institute (VTTI) Smart Road in Blacksburg, Virginia, which simulates a realistic two lane interstate and shoulder setting where the long-range RFID tags are mounted to metal mile markers. The toolkit contains a 6” antenna and a RAEK antenna (shown in Figure 6) that can be used with the reader, with the RAEK antenna shown to give a slight advantage in reading range in previous testing.

The first phase of testing includes a reiteration of the static and dynamic testing of the long-range RFID system performed by Fedrowitz during the pilot study. The static testing involves testing the reader’s ability to pick up an RFID tag on a mile marker at a distance in feet of 5, 10, 25, 50, 100, as well as recording the maximum distance a tag can be picked up by the reader. The dynamic testing involves using the reader to poll for an RFID tag on a mile marker while the reader is traveling at speeds of 10, 20, 30, and 60 miles per hour, and recording the distance away from the mile marker the tag is picked up. As seen in Figure 4, the tags are located on the back of the mile markers that face oncoming traffic. The static testing is done facing the mile markers and increasing to the incremental distances moving in reverse away from the mile marker against normal traffic flow. The dynamic testing is done facing the mile markers as well, and the distance the reader is away from the mile marker is recorded when picking up the tag’s ID number while approaching at the incremental speeds.

The second phase of testing involves all facets of the retrieval program as a part of the toolkit using real data and supplemental materials. This includes the ability to read multiple tags and display the corresponding data with links to supplemental materials while traveling at the variable speeds used with the first phase of testing. An important aspect of the retrieval program evaluation is the effort required by the user to handle not only the retrieval program but the rest of the hardware included in the toolkit in a typical dynamic scenario for highway asset management. The evaluation also includes looking
at the durability of the long-range RFID tags over an extended period of time as they are limited in battery life and exposed to different weather extremes.

Figure 6: 6” and RAEK Antennae

Objective #4: Explore possible use of long-range RFID system in conjunction with short-range RFID system.

The short-range RFID system (see Figure 7) discussed in the previous research has been further researched by Cecilia Arrington at Virginia Tech for further value and application to VDOT’s highway asset management practice.

Figure 7: Dynasys Short-Range RFID System
Within Arrington’s research a location program was created that allows the user to store and locate asset quantities into quadrants of a highway segment model, shown with F.4 of Figure 5. With this program the user knows the quantity and general location of an asset by dividing the 1/10th of a mile segment into four equal parts and inputting the asset quantities when the segment is first inspected. If the user needs to locate an asset for inspection or general observance their length of search area is reduced from 528 feet to 132 feet; this greatly decreases time on-site, increasing overall efficiency as well (Arrington 2009). The long-range RFID toolkit is looked at for possible inclusion of the short-range RFID system and more specifically the location program to add overall value to the toolkit and user advantage.

**Objective #5: Perform a total cost analysis of the entire long-range RFID toolkit created for various contract type and size.**

After the toolkit is developed and all necessary pieces of hardware and software have been included, an analysis is performed to assess costs for purchasing the toolkit. This cost analysis encompasses most of the major interstates in the state of Virginia through 14 of VDOT’s highway asset management contracts for different regions. Figure 8 shows the location of the interstates for each contract except for the PPTA I-895 contract. The different elements of the total cost analysis include expenses for the required number of tags as well as the long-range RFID system hardware and software. The number of tags required is based upon the number of mainline (both directions of travel, i.e. northbound and southbound) and ramp segments that can be inspected under contractual mile marker ranges, and includes a factor for extra tags or replacing tags that may become damaged or lost prior to mile marker placement. The total cost analysis does not include expenses for man hours in the initial application of the tags to the mile markers. While there is a total cost for implementing the toolkit for all 14 contracts, each contract has its own individual cost which will help VDOT further assess the viability of incorporating the toolkit into their highway asset management practice.
Figure 8: VDOT Highway Asset Management Contracts
Objective #6: Provide VDOT with a report showing the practices and advantages of using the long-range RFID toolkit on-site.

The research presented here along with the following results, conclusions, and recommendations serve as an exhaustive report on the capabilities and applications of an available RFID technology found most applicable to VDOT’s highway asset management practice. This report, while it contains positive and negative feedback on the presented RFID technology, does not serve to sway the decision of VDOT to implement the technology into their business needs; it rather serves to provide the necessary information and details for VDOT to make such a decision soundly.
3 – Results

**Objective #1: Establish an interface between the long-range RFID system and CHAMPS data.**

The creation of the retrieval program called upon the assistance of Steve Spillane, a software programmer of Anderson & Associates, Inc. Spillane’s work found that creating the tag to data interface required the customization of the functions of the reader (circled in Figure 9) in the AAID long-range RFID system.

![Figure 9: AAID Long-Range RFID Reader](image)

Originally the user of the AAID long-range RFID software on the tablet PC launches the reader to pull the tag ID number, with the aid of the antenna, and sends the tag ID number(s) back to the software display on the tablet PC for the user to view (see Figure 10).

![Figure 10: AAID Long-Range RFID Software Display](image)
The retrieval program is customized to control the tag reading function of the reader and uses this function control as a center point to operate the rest of the retrieval program functions. Spillane created the retrieval program in Microsoft Access format since the inspection programs and data for the CHAMPS field crews are used and submitted in Microsoft Access format as well. The retrieval program references a Microsoft Access data file that contains the highway asset data, corresponding RFID tag ID numbers, and the links to the supplemental materials for a highway segment represented by a tag. Once the tags have been placed in the field, the corresponding segment data that each tag represents is stored in the data file which is then posted online to a server. Figures 11 and 12 show two tables in the data file, SiteMain and SiteFiles, which are updated with proper information for the retrieval program to reference. SiteMain holds the asset data for each segment represented by segment numbers. These segment numbers are assigned to the tag ID numbers, and the retrieval program will display the asset data for that segment when its tag ID number is read from the field.

SiteFiles holds the description (fDescription column) and link (fURL column) for the supplemental materials being provided for each segment. The description will show up in the retrieval program and acts as a link for the website of the document; the user can input as many document links as they wish for a segment number.
Figure 12: Retrieval Program Data File – SiteFiles Table

Once the data file has been updated and posted to the online server, the user can run the program out in the field as they are searching for long-range RFID tags corresponding to the data in the data file. Figure 13 shows what the retrieval program displays for the user when it is launched. The “AutPoll Start” button activates the reader to search for any available tags within range just as the auto poll function in the original AAID software. Any tag ID numbers for tags within reading range appear in the top table of Figure 13 along with the time stamp of when the reader last read the tag, just like the original AAID software display shown in Figure 10.

Figure 13: Retrieval Program Display
The user can select any tag ID number from the table and the segment data represented by the tag is displayed along with the link(s) for supplemental materials assigned to the segment. For example, in Figure 12 the user provided a link to the GIS data for segment 61006 in the data table, and Figure 14 shows the link provided and launched in the retrieval program display. If the user knows the number for a highway segment and also knows they are out of range for reading the tag corresponding to that segment, they can change the “Search Type” to “Segment Number” and input the segment number instead and the data is displayed once they select the “Fetch Data” button (see Figure 15).

Figure 14: Retrieval Program Display – Supplemental Material
Overall, the retrieval program that has been created is an ideal program for the primary functions it needs to have. The program can read multiple tags at once and display the data necessary for the user while also providing external links to the supplemental materials desired. The retrieval program’s true usefulness is dependent upon the quality of the wireless internet card and how well it functions dynamically, both of which will be discussed in the results from the next two objectives.

Objective #2: Perform a market analysis to purchase an optimal wireless internet card to be evaluated in field conditions as a part of the RFID-Data interface.

In searching for an optimal wireless card three major providers and their wireless card models were researched: AT&T, Verizon, and Sprint. Each dealer provided a variety of models to choose from, each with advantages and disadvantages when compared. The factors considered in the service provider and model comparison (presented in Table 7) were: broadband service coverage, PC connection type,
information transfer rate, contract and service price, antenna type, and positive attributes such as an LED status indicator and available memory storage.

**Model Evaluation Factors**

The provider with the better broadband service coverage was determined by comparing maps of Virginia showing where the providers’ broadband internet service was made available. The coverage provided by AT&T and Sprint seemed about equal, however Verizon’s coverage was much better; this was especially true for regions under highway asset management contracts by VDOT that are more rural in nature and thus have an overall lower reception quality for wireless communication. Figure 16 gives an example of this contrast in broadband internet coverage for southwest Virginia for which the Bristol and Salem contract are partial to.

![Figure 16: Southwest Virginia Broadband Internet – Provider (Coverage Color)](image)

All of the models evaluated required either a USB port or a type of wireless card port for the computer to be used, the tablet PC in this case. The USB port is universal for almost all computers manufactured and used in today’s home and business, however the wireless card ports can vary in the size, type, and nomenclature established in the specifications for different computers. According to the Personal Computer Memory Card International Association (PCMCIA) website, the wireless card is commonly...
referred to as a “PC Card”, which is a shortened version of the former name “PCMCIA Card”. Three types of PC Cards are made available: Type I, Type II, and Type III. All three types have the same pin connection and dimensions for length and width, but differ in thickness; a thinner card can be used in a thicker slot, but a thicker card can not be used in a thinner slot. The tablet PC uses a Type II PCMCIA Card, but can also use a Type I since the wireless card port is thick enough for both types to fit. Some of the wireless card models labeled their interface type as “CardBus” which is a 32-bit PC Card and works at a higher speed than the 16-bit version. Typically, any device manufactured before the second half of 1997 will almost certainly not have a CardBus capable slot, according to the PCMCIA website. Other wireless card models had an interface called “ExpressCard 34/54”. This interface is similar to the PC Card but is shorter in height and width, and could not be used with the tablet PC unless an adapter is provided.

Each provider listed a range of data transfer rates, or the typical minimum and maximum speed, when the wireless card has obtained a secure internet connection. A data transfer rate range was given for both downloading and uploading data for almost all models in units of megabytes per second.

All three providers charged a monthly service fee of $60 to use the data plan. All three data plans had an allowance of five gigabytes (5 GB) of data transfer before additional charges would occur. To give perspective, Sprint mentions that with 5 GB over 1.7 million single page emails without attachments, over 10,000 low-resolution photos, and over 1,200 three minute songs can be transferred. In terms of contract pricing models were compared using the two year contract price available online, which varied anywhere from around $100 to $150. While refurbished models were available and cheaper, only brand new versions of each model were looked at to ensure the utmost quality when purchased.

All wireless cards function with an antenna, whether or not the antenna was integrated internally or externally varied from model to model. Some also included an additional input where an external antenna could be attached by the user to boost the signal range of the card. Likewise, some of the models contained a slot for a memory card so as to give the user the advantage of a thumb drive storage device along with the wireless capability. A status LED was present on all models evaluated which tells the
user when or when they are not connected; this is helpful in simplifying the computer interface with the user.

**Model Scoring and Choice**

Each model was ranked among the others in Table 8 for each factor being evaluated, along with certain factors being weighted higher than others through multipliers of 0.5 - 3. The broadband internet service was ranked on a scale of 1-3, with Verizon receiving three points for having the best overall coverage. The broadband internet service score also was multiplied by a factor of three, the highest multiplier, since the capability to connect to the internet from any interstate in Virginia is the most important capability to have.

Models scored the highest on a scale of 0-4 with a multiplier factor of two if they used a USB connection. The USB connection is the most popular, it can be used with any PC if the user decided not to use the tablet PC, and the user does not have to worry about the type of PC Card connection. The USB models are smaller, more mobile, and have the most simplistic and automatic installation and usage with its “plug-and-play” interface. Models would receive one point if they were an ExpressCard 34/54 that came with a PC Card adapter, but no points were allotted if the adapter was not included.

Models by AT&T scored the highest on a range of 1-4 with a multiplier factor of 1 for the data transfer rates since they had higher maximum download and upload speeds. Sprint’s models scored the lowest since they had the lowest maximum download and upload speeds.

Price-wise, a model received three points if the two-year contract price was $100 or less, two points if $125 or less, and one point if $150 or less, with a multiplier factor of one. The monthly service charge was not factored into the product scoring because all three providers offered the same price for the same amount of allowable data usage. This non-factor case was also the same for models having status LEDs.

If the models had an available input to attach an external antenna they received two points instead of one, with a multiplier factor of one. If the models could expand their memory with an available card slot they received one point, but received two points
if the available card slot allowed for cards with higher storage capacities. The available storage expansion while useful is also a luxury, so the multiplier factor was only 0.5.

In the end, after all scores for each factor were added together Verizon’s USB760 Modem was the winning model. This outcome was due to the fact that the USB760 Modem is a USB type wireless card under the best broadband coverage among the three providers evaluated. It was also one of the cheapest models evaluated with expandable memory. Once the USB760 Modem was purchased and received it was inserted into the tablet PC’s USB port and it immediately brought up a set-up wizard. After some initial set-up questions and installation that took about four to five minutes the device was ready to use and connected to the internet. The next time it was inserted the start-up screen came to display and it was connected within a minute from initial insert (see Figure 17).

![USB760 Modem Broadband Wireless Card by Verizon](image)

**Figure 17: USB760 Modem Broadband Wireless Card by Verizon**
Table 7: Wireless Internet Card Information Comparison

<table>
<thead>
<tr>
<th>Network</th>
<th>Broadband Ranking*</th>
<th>Model</th>
<th>PC Connection</th>
<th>Max Transfer Rate</th>
<th>2-YR Contract Price</th>
<th>Service Price</th>
<th>Antenna</th>
<th>Status LED</th>
<th>Expandable Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T</td>
<td>2nd</td>
<td>USBConnect Mercury</td>
<td>USB</td>
<td>0.7-1.7 Mbps d/l, 0.5-1.2 Mbps u/l</td>
<td>$100.00</td>
<td>$60.00</td>
<td>Integrated</td>
<td>Yes</td>
<td>32 GB</td>
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<tr>
<td></td>
<td></td>
<td>Sierra Wireless AirCard 881</td>
<td>Type II PC Card</td>
<td>3.6 Mbps</td>
<td>$149.99</td>
<td></td>
<td>Integrated</td>
<td>Yes</td>
<td>--</td>
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<tr>
<td></td>
<td></td>
<td>USBConnect Quicksilver</td>
<td>USB</td>
<td>0.7-1.7 Mbps d/l, 0.5-1.2 Mbps u/l</td>
<td>$100.00</td>
<td></td>
<td>Integrated</td>
<td>Yes</td>
<td>32 GB</td>
</tr>
<tr>
<td>Verizon</td>
<td>1st</td>
<td>USB760 Modem</td>
<td>USB</td>
<td>0.6-1.4 Mbps d/l, 0.5-0.8 Mbps u/l</td>
<td>$99.99</td>
<td></td>
<td>Int. &amp; ext. port</td>
<td>Yes</td>
<td>Up to 8 MB</td>
</tr>
<tr>
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<td></td>
<td>PC5750 PC Card</td>
<td>Type II PC Card</td>
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<td>$99.99</td>
<td>$59.99</td>
<td>Hinged port</td>
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<tr>
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<td>$119.99</td>
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<td>Flip-up port</td>
<td>Yes</td>
<td>--</td>
</tr>
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<td></td>
<td>AirCard 595</td>
<td>Type II PC Card</td>
<td>0.6-1.4 Mbps d/l, 0.5-0.8 Mbps u/l</td>
<td>$149.99</td>
<td></td>
<td>Ext. &amp; ext. port</td>
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<tr>
<td></td>
<td></td>
<td>V740 ExpressCard</td>
<td>ExpressCard 34/54</td>
<td>0.6-1.4 Mbps d/l, 0.5-0.8 Mbps u/l</td>
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<tr>
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<td>Compass 597</td>
<td>USB</td>
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<td>$99.99</td>
<td>$59.99</td>
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<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Merlin EX720</td>
<td>ExpressCard 34/54 (PC Card Adapter included)</td>
<td>0.6-1.4 Mbps d/l, 0.35-0.5 Mbps u/l</td>
<td>$149.99</td>
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<td>Flip-up port</td>
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<td>AirCard 597E</td>
<td>ExpressCard 34/54 (PC Card Adapter included)</td>
<td>0.6-1.4 Mbps d/l, 0.35-0.5 Mbps u/l</td>
<td>$149.99</td>
<td></td>
<td>Int. &amp; ext. port</td>
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<td></td>
<td>Aircard 595</td>
<td>Type II PC Card</td>
<td>0.6-1.4 Mbps d/l, 0.35-0.5 Mbps u/l</td>
<td>$119.99</td>
<td></td>
<td>Int. &amp; ext. port</td>
<td>Yes</td>
<td>--</td>
</tr>
</tbody>
</table>

* Based on coverage map provided

Table 8: Wireless Internet Card Scoring

<table>
<thead>
<tr>
<th>Network</th>
<th>Broadband Ranking</th>
<th>Model</th>
<th>PC Connection</th>
<th>Max Transfer Rate</th>
<th>2-YR Contract Price</th>
<th>Service Price</th>
<th>Antenna</th>
<th>Status LED</th>
<th>Expandable Memory</th>
<th>TOTAL (w/ Multiplier)</th>
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<td></td>
<td></td>
<td>Sierra Wireless AirCard 881</td>
<td>3</td>
<td>4</td>
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<td>0</td>
<td>1</td>
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</table>
Objective #3: Evaluate performance of long-range RFID toolkit in predicted implementation scenarios.

Testing - Phase 1

During the first phase of testing at the Smart Road, the ability and limits of the long-range RFID reader were tested statically and dynamically just as they were tested by Fedrowitz during the pilot study. Statically, the reader was placed at various distances facing the front of a mile marker that had a long-range RFID tag attached to the back. The reader was held four feet off of the ground at distances of 5, 10, 25, 50, and 100 feet away from the mile marker along the shoulder of the road. The reader was tested using a six inch antenna and a RAEK antenna (see Figure 6) and it was concluded that the reader could pick up the long-range RFID tag on the back of the mile marker with both antennae at all of the various distances except for 100 feet. At 50 feet the reader was not consistent in reading the tag ID number with either antenna. It was also concluded that the maximum distance the reader could pick up the tag at with the six inch antenna was about 68 feet, and a few feet further with the RAEK antenna. The reader would sometimes lose the signal of the tag while relocating to the next distance, and once static again it would take a few seconds to pick the tag back up. Dynamically, the reader was attached to the side of a vehicle closest to the shoulder and was tested to see at what distance from the front of the mile marker it would read the tag while going 10, 20, 30, and 60 mph. Several iterations at each speed revealed that while traveling 10 mph the tag was still being read around the mark of 50 feet, but at 20 and 30 mph the tag was only getting picked up by the reader around the mark of 25 feet. This distance decreased to anywhere from 15 feet in front of the mile marker to 15 feet passed the mile marker while traveling at 60 mph. These results were almost identical when using either the six inch antenna or the RAEK antenna.

It is interesting to note in this first phase of testing that the maximum static reading distance found by Fedrowitz was about twice the distance away when performing the same experiment. Similarly, the dynamic reading distance at 10 mph found by Fedrowitz was more than twice the distance away when performing the same experiment. At highway speeds of 60-65 mph, Fedrowitz found reading distances at 25 feet while
some of the experiment trials performed presently did not have a tag reading until passing the mile marker. These dramatic differences suggest an unknown variable that may lie within part of the long-range RFID system. The battery used by Fedrowitz to power the reader has since been replaced with a different battery, and while these batteries carry the same specifications they both were used many times and it could be the event that Fedrowitz was providing more power to the reader than the reader is receiving presently. The unknown variable may also lie between the reader and the RFID tag, as there may be more signal interference in the spring months for these present experiments and less signal interference during the fall months when Fedrowitz performed the same experiments. The tags have also been replaced since then and while they are the same model it is uncertain what differences in performance may arise. These mixed results between previous and present testing could be a sign that the long-range RFID system is inconsistent or possibly damaged, however the RFID tags are still being picked up statically and dynamically.

**Testing - Phase 2**

The second phase of testing was essentially a repeat performance of the dynamic testing in the first phase, except the retrieval program was used instead of the AAID software. The retrieval program data file was created and posted on the server by Spillane, as explained in the first objective’s results with Figures 11 and 12, which connected 19 RFID tag ID numbers to 19 segments of data and supplemental material files posted online. The 19 tags were then attached to the back of their corresponding segment mile markers, which was the entire set of mile markers and ranges from 0.0-1.8 on the Smart Road. The USB760 Modem wireless card was connected, the retrieval program was launched, and the vehicle with the reader began driving passed all of the mile markers at 10, 20, 30, and 60 mph in the same fashion as the first phase of testing. Testing with speeds less than 60 mph was performed close to or completely on the shoulder in order to simulate how the toolkit would be used in real time with highway traffic.

All of the tags were picked up by the retrieval program at speeds of 10, 20, and 30 mph, while three of the tags were not picked up non-consecutively at 60 mph. The
dynamic reading distances for all four speeds remained fairly consistent. At times the retrieval program would pick up a tag farther away than expected; this among other factors was possibly due to the actual distance to the tag being less than the length of road to the tag due to road curvature, or the way the mile marker was sitting or leaning in the ground increasing or impeding the signal connection. A positive outcome of picking up almost all the tags (which were displayed in the top table of the display shown in Figure 13) is that the tag ID numbers did not leave if the tag was out of range, and the user could recall the data for that segment again. However, this table displaying the tag ID numbers is only so big that once four tags have been read the user has to scroll down in order to see the next tag that gets picked up by the retrieval program.

The USB760 Modem wireless card stayed connected to the internet during the entire second phase of testing. The Smart Road is located in a rural setting in the mountains and the strength of connection was never at full capacity, but it still remained functional and kept the internet connection steadily. One issue that can be especially problematic for using the toolkit at speeds over 10 mph is having links to supplemental materials that are password protected. While the username and password are known for these materials, the tablet PC uses an on-screen keyboard that the user has to type with using the tablet PC’s pen; it can be very burdensome time-wise for the user. This problem only gets worse when the protected material is large in size and takes time to load completely. In certain lighting during the day the tablet PC screen resolution can make the display hard to see as well.

**Long-Range RFID Tag Durability**

Operationally, the AAID long-range RFID tags are supposed to have a life of three to five years in terms of the battery capacity. It was found that in the spring of 2009 most of the tags Fedrowitz had been using in the fall of 2007 were no longer able to be picked up by the reader. New tags were purchased and used for the present testing, yet some of the old tags would still get picked up by the reader in the second phase of testing as well. This inconsistency can become an issue in planning when to replace the tags out on the highway so that all data can remain accessible.
Physically, the tags seem very durable from an observational standpoint. There is no physical damage present on tags that have been subject to two winters and one summer containing multiple occasions of heavy precipitation along with single and triple digit temperatures. It is still unclear as to what degree of operational punishment the tags take during these harsh weather patterns as some of the tags from the fall of 2007 are still active. The double sided red adhesive pad (shown in Figure 3) is extremely strong minutes after it has been applied to the tag and the mile marker. Trying to presently remove tags that were installed in the fall of 2007 usually results in breaking the tag and not the adhesive; this is not true for all of the older tags, as some have fallen off or come loose using some applied force. The use of small plastic bags and epoxy (see Figure 18) was tested in order to provide a way of putting the tag on the mile marker without permanently attaching it. If the tag needs to be replaced it can simply be removed from the plastic bag and replaced with a new one. After implementing this strategy on a mile marker at the Smart Road, the long-range RFID system had trouble reading the enclosed tag and after two weeks the bag had fallen off of the sign. It seems that the adhesive pads are the best way to go since they are strong and durable and most likely the tag can be damaged when removed if it is no longer active.

![Figure 18: Long-Range RFID Tag in Plastic Bag](image)

The different pieces of the toolkit apparatus (see Figure 19) can be cumbersome for the user when all pieces of hardware involved need to remain connected. There is a
USB cable that is connected to the tablet PC at one end and to the Ethernet cable at the other end. The Ethernet cable connects to the reader at one end and shares its connection at the USB cord with two wires connected to the power source, which is a 12 volt battery. These two wires use “alligator clips” attached to the positive and negative poles of the battery, and these clips can easily detach if the wires to the clips are pulled on. Including the wireless card, there are a total of four cables or wires and six connections (circled in Figure 19) that need to stay in tact for the long-range-RFID toolkit to remain functional. Use of the RAEK antenna creates an additional cable and connection to deal with as well. The six inch antenna has no cable and there were no issues with its connection to the reader. The past and present experiments have used red duct tape to secure the reader and antenna to the vehicle being used.

The close proximity with the two USB ports on the tablet PC and the width dimension of the USB760 Modem wireless card create an extremely tight fit when the USB cable and the wireless card are plugged in to start the retrieval program. Often times this tightness would cause one or the other to disconnect. Another issue with the USB cable is whether or not it is connected to the correct USB port designated by the retrieval program. The user can easily change which port the retrieval program designates for the USB cable, but if it is connected to the wrong USB port the tablet PC goes haywire and the retrieval program is uncontrollable.
Figure 19: Long-Range RFID Toolkit Hardware and Connections
Objective #4: Explore possible use of long-range RFID system in conjunction with short-range RFID system.

While both the long-range and short-range RFID systems share the same technology, their tags and the data they possess along with the retrieval process are far too unique to combine the primary functions of both systems, which come from different vendors. Instead the combination of the long-range retrieval program with the short-range location program was created and both systems can function through the same tablet PC.

With the short-range RFID system, the user inputs the quantity and location of assets into the location program (see Figure 20). Like the long-range RFID retrieval program, the short-range RFID location program is in Microsoft Access format.

**Figure 20: Short-Range RFID Location Program Input Display (Arrington 2009)**

Once the user is done inputting quantity and location data for assets within a particular segment, the data is exported to an XML file so that it can function with the short-range RFID reader and be able to be written to and read from the short-range RFID tags (see Figure 7) and displayed as shown in Figure 21.
As the user inputs the data into the short-range location program, the data is stored in a Microsoft Access table labeled “SiteAssets”, which is where the long-range retrieval program can relate. SiteAssets is another table in the retrieval program that functions with the previously discussed SiteFiles and SiteMain tables (see Figure 22).

If the retrieval program pulls a long-range RFID tag with an ID number corresponding to a segment that was also assigned a short-range tag with the location data logged then the SiteAssets data from the short-range location program can be placed in the data file for the long-range retrieval program. Now the location program display will appear in the retrieval program display (see Figure 23), which is a function of the retrieval program created by Spillane.
Objective #5: Perform a total cost analysis of the entire long-range RFID toolkit created for various contract type and size.

The projected expenses for implementing the long-range RFID toolkit in each of the 14 different contracted sections of Virginia’s interstates mandated by VDOT are presented in Table 9. The number of tags needed for the mainline (non-ramp) segments is based upon the range of mile markers covered by the contract. With each segment being 1/10th of a mile and having a matching highway segment in the opposite direction, the number of tags needed for segments is equal to: Total miles * 10 Segments per mile * 2 Directions. Added to this total are the number of ramps in each contract’s interstate highway(s) which each receive a tag; the total number of ramps for each contract comes from list of ramps picked up during the baseline inspection. It is possible that not every ramp for each contract is included in the total, as there may have been exemptions due to items such as construction zones preventing baseline inspection of certain sections of interstate highway. Some contracts contain segments that are inspected yet not assigned to mile markers, such as memorials or special facilities, so they are not included in the segment total. The totals for segments and ramps serve as a close approximation for the number of tags needed for each contract. The long-range RFID tags from AAID, or AA-T800 tags, cost $33.50 per tag. An extra 5% was added to the total number of tags to account for replacement tags and/or extra tags in the event that some are damaged before or during placement on the mile markers and also in case the total needed for segments
and/or ramps were higher than anticipated. Using the total number of tags, plus the extra 5%, the proper amount of adhesive was calculated using a retail estimate of $1,115 for 12 rolls of 36 yards (432 yards or 1296 feet) of the double sided adhesive. $1,115 for 1296 feet equates to $0.86 per foot of adhesive. The width of the adhesive is ¾” so each tag would need two 3” long strips. The $0.86 per foot of adhesive would then cover two tags, or $0.48 per tag, which is cheaper than AAID’s cost of $0.60 per tag for the similar adhesive pads they provide.

The cost figures used for the software, cables, reader, antennae, and power supply come from a cost sheet supplied by the AAID sales department; these cost figures for the system items are for one system only. Depending upon how much the system is used if implemented, a new power supply may need to be purchased from time to time as well as certain hardware items when damaged from wear and tear. It is assumed that the users will provide their own tablet PCs or laptops in the field and, as previously mentioned, the cost for labor in placing the tags on the mile markers is not included in the total cost analysis.

**Objective #6: Provide VDOT with a report showing the practices and advantages of using the long-range RFID toolkit on-site.**

The long-range RFID toolkit has been presented in this report in all applicable areas for assisting VDOT’s highway asset management programs; from its earliest stages as an idea to research available RFID technology to the acquisition and analysis of the necessary pieces for an effective toolkit to the following final conclusions and recommendations for the toolkit.
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Subtotal Cost: $910,563.50

Subtotal Cost: $45,528.18

Subtotal Cost: $13,699.22

Subtotal Cost: $35.00

Subtotal Cost: $554.00

Subtotal Cost: $60.00

TOTAL COMBINED COST: $970,439.90

Table 9: Total Cost Analysis for Long-Range RFID Toolkit
4 – Conclusions & Recommendations

4.1 – Conclusions

All of the objectives sought have been met with the research presented. The results give way to certain attributes the long-range RFID toolkit possesses that can be interpreted as positive and negative towards assisting VDOT’s highway asset management programs, the soul purpose of this research.

The long-range retrieval program created by Spillane properly grasps control of the tag reading function of the long-range RFID system and displays the correct data when wirelessly connected to the data placed online. The retrieval program, as Spillane commented in verbal discussion, “performs the correct functions but is still in a very elementary format” from a user-friendly standpoint. The data file and program are very stringent with correct data for a successful interface, such as the correct USB port ID number or any other technical aspect for the user other than the three basic input tables of the data file; the user can experience multiple issues if they are not well versed in the workings of Microsoft Access. The retrieval program was not tested with multiple data files, and the data file tested was posted to the server of Anderson & Associates, Inc. with the server ID located within the inner workings of the retrieval program code. This reliance upon Anderson & Associates, Inc. and Spillane takes away from total independence for the user of the toolkit; if there was an error in the data (i.e. wrong tag ID number corresponding to a segment number) it would not be a quick fix out in the field.

The USB760 Modem wireless card by Verizon worked as well as advertised and lived up to the top scoring it received in the wireless card evaluation table. The ability to maintain a constant internet connection was successful throughout the field testing.

Noticeable differences with the static and dynamic results of the long-range RFID system achieved by Fedrowitz take away from the integrity of the toolkit. Although the long-range RFID tags were still able to be read consistently, the decrease in the read distances by about 50% is a cause for concern as it impedes the efficiency of the toolkit and the tasks being performed by the user, especially at highway speeds of 60 mph. Further testing of individual pieces of the toolkit, such as tag and reader orientation
effectiveness, would benefit the toolkit by eliminating unknown variables and establishing better consistency. Dynamic testing of the retrieval program proved successful as segment data was displayed and supplemental materials were downloaded and displayed at all vehicle speeds tested. The lack of space for multiple tag ID numbers to be displayed and password authorization can attest to the previously mentioned user-friendliness issue of the retrieval program. Problems arise when dealing with the clumsiness of the toolkit apparatus as the connections for the different parts, including the attachment of the reader to the vehicle, are unstable. Some kind of utility box or tray for stabilizing the equipment and a strong attachment mechanism for the reader that does not damage the vehicle would benefit the toolkit immensely. The inability for some of the tags to maintain their life span according to specification is another cause for concern and adds to the inefficiency of the toolkit; with so many tags being placed in the field it would require a very sporadic replacement schedule. However, the long-range tags have proven to be physically strong in extreme weather conditions.

The long-range and short-range RFID systems found a commonality with the location program created for the short-range RFID system by Spillane, as the quantity and location of assets were able to be displayed in the long-range retrieval program as well. Achieving this combination is not instantaneous as the user would need to input the location data collected into the retrieval program data file and have it posted to the server before made available on display. Inputting the location data into the retrieval program data file also requires the user to search for the common segment numbers that the corresponding long-range and short-range tags share. Data may have been collected for segments by the short-range RFID system that the long-range RFID system had not collected yet either.

The long-range RFID toolkit seems very expensive from an overall perspective of the quantities involved with implementing it into all of VDOT’s contracts. Looking at each contract cost individually compared to the others it would be most logical at this stage to implement the toolkit into the PPTA I-895 contract as a pilot project, which would cost less than $10,000 as compared to the Richmond North contract near $150,000. Of course, it may be just as effective to implement the toolkit into only a few
miles of interstate for any upcoming annual inspection and test the level of usefulness and efficiency created.

The overall objective of this research was to benefit the CHAMPS partnership centering VDOT’s highway asset management programs through further research of an applicable RFID technology. This objective has been achieved by providing a plethora of information from all areas of long-range RFID technology that will serve VDOT well in their decision making for implementation.

4.2 – Future Research Recommendations

It is recommended that future areas of research focus on improving the highway asset management practices of VDOT by increasing the knowledge of the long-range RFID toolkit presented and looking into other state of the art technologies that mobilize data. In terms of the long-range RFID toolkit, improvement areas exist in the inconsistencies found between similar experiments that should have resulted in more congruent data. The elimination of unknown variables should be targeted with the possible creation of a manual to troubleshoot common pitfalls for new users of the long-range RFID toolkit; it is important to maintain the integrity and reliability of the toolkit with its capabilities constantly at their highest level of performance. The availability of a broadband internet connection is imperative for the use of the toolkit, and should be tested on all interstate highways of Virginia. The mobilization of data comes in many forms of technology, and the use of GPS as one of these applicable technologies should be further researched. GPS coordinates could substitute for the long-range RFID tag ID numbers so that the retrieval program would be using a GPS system instead of a reader to pull the desired data. Using a different technology this way could cut back on hardware and other related costs while still improving highway asset management efficiency.
5 – References


Appendix A – Final Exam: CIB W78 Conference Paper
ABSTRACT: Radio Frequency Identification (RFID) technology mobilizes data through radio wave transmission with RFID tags. Two RFID systems, short-range and long-range, showed potential in assisting highway asset management programs of the Virginia Department of Transportation (VDOT) by providing access to condition data in the field; both systems were previously analyzed for tag retrieval and data storage. In this research, the short-range system is further analyzed to: evaluate affordable tag security methods, assist in highway asset location visualization, evaluate tag performance in weather conditions, and explore optimal tag attachment to highway mile markers. The long-range RFID system is further analyzed to: establish a wireless broadband-based system-data interface, perform a market analysis for an optimal wireless internet card for the interface, evaluate performance in predicted implementation scenarios, explore a combination of both RFID systems, and perform a system cost analysis. Results yield an overall positive impact on highway asset management using RFID technology.

1 INTRODUCTION
1.1 RFID technology
Radio Frequency Identification (RFID) technology is used as an available means of mobilizing and manipulating data for improving efficiency. The primary ingredient for any effective RFID system is the tag, which is the source of mobility. RFID tags are small devices that can hold data or information which is then reported via radio waves when activated by a reader device. As a result, RFID does not require line-of-sight between the tag and reader like a bar coding system using light waves (CII 2001). The tag itself holds a circuit chip and antenna enclosed in a type of casing that prevents exposure. The reader uses an antenna, either integrated or external, to produce a radio-frequency magnetic field which serves as a carrier of power to the RFID tag from the reader. When the tag is in range of the magnetic field, the integrated circuit in the tag is energized and the memory contents of the tag are transmitted to the reader. The reader decodes the data for storage, viewing, and transmission to a computer (CII 2001, Jaselskis et al. 1995). RFID tags can be classified as passive or active. With a passive system, the tag is stimulated and powered by the magnetic field emanating from the reader; these systems are usually short range (0–1 meter) and have an indefinite life. With the active system, the transponder is stimulated by the reader but powered by an internal battery. Active systems maintain a longer read range (up to about 30 meters), but have batteries maintaining anywhere from a three to ten-year life span. RFID systems can also be classified as read-only and read-write systems. With the read-only system, information content cannot be altered, storage capability is limited (1 to 16 bytes), and there is a rapid data transfer rate (CII 2001). The read-write system can not only be read but it also has the capabilities to be written to. The memory capacity of the tags varies from 64 bytes to 32 kilobytes (Jaselskis and El-Misalami 2003). Since 1979, RFID technology has been used in many different applications which include but are not limited to: personnel identification, material identification, tolls and fees, equipment maintenance, law enforcement, asset location and tracking, and animal tracking (Jaselskis et al. 1995, Akinci 2007). Various industries, such as construction and maintenance, are looking toward better ways to manage their inventory in a more efficient manner and expedite progress of deliverables. Three guiding business benefits that are
driving companies and industries to invest in RFID systems are: efficiency, security, and marketing.

1.2 Highway asset management

The Virginia Department of Transportation (VDOT) has adopted an innovative highway asset management program to maintain quality transportation infrastructure and has contracted with a private concern for the management of certain assets located within the right of way (CHAMPS 2007). In order to monitor progress and efficiency of the maintenance contracts, Virginia Tech assesses the condition of the assets within selected segments of interstate highways included in a section contracted for maintenance. All of the data collected by the inspection crews is analyzed and prepared by Virginia Tech in a partnership with VDOT, called the Center for Highway Asset Management Programs (CHAMPS). Since the partnership was established, Virginia Tech has continually researched and implemented new methods and technologies to enhance the process and results of the partnership.

While the data collected through the inspections performed is useful to VDOT and field inspectors, the problem is that the data is not stored on-site where it is most useful; RFID technology could be the solution to storing data on-site where VDOT and field inspectors could read previously stored data and write to the tag to update data (Fedrowitz 2007).

1.3 Previous research

A previous study (de la Garza 2008) explored the market analysis of RFID technology to find a system that is greatly applicable to highway asset management. The study included long-range and short-range systems, with the long-range tags being read from much farther distances than the short-range tags, but the short-range tags holding more information than the long-range tags. The long-range and short-range products from two companies with the highest total ranking for the key factors were chosen, namely, AAID and Dynasys. This pilot study found that the long-range system can consistently read up to 115 feet from a tag mounted to a mile marker sign under static conditions (vehicle not moving). In addition, the maximum dynamic read range of the long-range system traveling at 10 mph was also 115 feet. The short-range system can read an RFID tag mounted one centimeter away from metal at a distance of two inches. At a highway speed of sixty to sixty-five mph, the long-range system was not very consistent and was capable of reading a tag at a maximum distance of only twenty five feet. The short-range system had a storage capacity of 2000 bits enough to hold asset information collected for up to forty asset items in a 1/10 of mile segment. For both the short-range and long-range systems, the time required to read from an RFID tag was less than two seconds, which is very efficient. Future research suggested by this pilot study included developing toolkits to meet specific applications and to test the systems on operational conditions. One such toolkit required to wirelessly reference the inspection data using the unique ID number of a tag read by the long-range system. Another potential application identified for the short-range system was a toolkit to help visualize the location of hard-to-find assets.

1.4 Scope

This paper reports on the development and testing of two toolkits for both the short-range and long-range RFID systems separately, which aim at making this technology usable in the highway asset management field.

2 METHODOLOGY

Field testing required for both toolkits was performed on the Virginia Tech Transportation Institute’s Smart Road in Blacksburg, Virginia, which simulates a realistic two lane interstate and shoulder setting where the short-range and long-range RFID tags are mounted to metal mile markers.

2.1 Short-Range RFID system

This research investigated several aspects of short range RFID tags; most specifically:

1. The development of an interface that gives users better directional understanding to locate selected hard-to-find assets in a highway segment.
2. The assessment of external security protection methods for RFID tags.
3. The assessment of methods for attaching a short range RFID tag to the back of a metal mile marker.
4. The assessment of the effect of natural weather conditions and ‘in-between’ material on RFID tag performance.

2.1.1 Objective 1 methodology

A new programming component is explored to locate difficult-to-find asset items in the field. The program was tested using two field teams. Team one was instructed to locate a list of assets in one highway segment 1/10th of mile long and record the location and condition using the program. Team one’s data was transferred to the reader and written onto a single RFID tag that represents the highway seg-
ment. Team two was now instructed to find all the assets that Team one had inspected without prior knowledge of their location by using the reader to read the asset information off of the RFID tag. Teams switched roles and the experiment was conducted again.

2.1.2 Objective 2 methodology
A small handful of tags were placed on the mile markers of the Smart Road where they were “theoretically” vulnerable to tampering. Several experiments were conducted on eighteen different external security products from NovaVision, a manufacturer for security hologram stickers, tapes and seals.

2.1.3 Objective 3 methodology
Wood, heavy duty felt pads, and plexiglass were placed between several tags used in Objective 2 (2.1.2) and the mile marker using epoxy, two sided tape, and super glue as the adhesive; a plexiglass encasement for the tags was also used. Tags were revisited two months after installation and the condition of the tags and encasements were assessed based on movement and visual appearance.

2.1.4 Objective 4 methodology
The short-range RFID tag performance was tested after three and a half months of exposure to natural weather conditions in the field. The several tags placed on the mile markers with no physical protection were evaluated on the physical appearance and their ability to be read by the reader.

2.2 Long-Range RFID system
This research developed a wireless broadband-based toolkit for the long-range RFID system that provides the necessary hardware and software to potential users. The specific objectives for this research are:

1. Establish a wireless interface between the long-range RFID system and CHAMPS databases.
2. Perform a market analysis to purchase an optimal wireless internet card to be evaluated in field conditions as a part of the RFID-Data interface.
3. Evaluate performance of long-range RFID toolkit in predicted implementation scenarios.
4. Explore possible use of long-range RFID system in conjunction with short-range RFID system.
5. Perform a total cost analysis of the entire long-range RFID toolkit created for various contract types and sizes.

2.2.1 Objective 1 methodology
The most logical and optimal interface was to create an RFID tag retrieval program that connects the long-range RFID system, using a wireless internet connection, to inspection data files that are posted on a web server. The function of the retrieval program is to display the condition of the assets corresponding to multiple tag ID numbers and to provide links to online supplemental materials that benefit the knowledge of the user.

2.2.2 Objective 2 methodology
An internet connection needs to be available anywhere a RFID tag is located for the retrieval program to work. The wireless broadband internet cards from the major retailers were looked at with a number of factors such as the provider’s service available, type of PC connection, and data transfer rate. The models received total scores based on values that were assigned to each factor with the more important factors’ scores receiving a multiplier; the model with the highest score was purchased and evaluated with the retrieval program.

2.2.3 Objective 3 methodology
The first phase of testing included replicating the static and dynamic tests reported in (Fedrowitz 2007). Static testing involved the reader’s ability to pick up a single tag on a mile marker at the following distances: 5, 10, 25, 50, 100 feet, as well as the maximum distance. Dynamic testing involved reading a single tag on a mile marker while traveling at speeds of 10, 20, 30, and 60 miles-per-hour (mph), and recording the distance away from the mile marker the tag is picked up. The second phase of testing involved all facets of the retrieval program including the ability to read multiple tags and display the corresponding data with links to supplemental materials while traveling at the variable speeds used with the first phase of testing. One trial was performed for each speed in the first and second phase of dynamic testing. The tag durability as well as the effort required by the user to handle the retrieval program and the hardware included in the toolkit were also tested in a typical dynamic scenario for highway asset management.

2.2.4 Objective 4 methodology
The short-range RFID system allows the user to store and locate asset quantities into quadrants of a highway segment model. The long-range RFID toolkit was looked at for possible coupling with the functionality of the short-range RFID system.

2.2.5 Objective 5 methodology
The cost analysis encompassed expenses for the required number of tags as well as the system hardware and software to be implemented on 14 of VDOT’s regional highway asset management con-
tracts. The number of tags required was based upon the number of mainline (both directions of travel, i.e., northbound and southbound) and ramp segments that can be inspected under contractual mile marker ranges, and included a factor for extra tags or replacing tags. The total cost analysis does not include labor expenses for in the initial application of the tags to the mile markers.

3 RESULTS

3.1 Short-Range RFID toolkit

3.1.1 Objective 1 results
The location program developed uses extensible markup language (XML) and Microsoft Access to visually provide the user with general asset location within a tenth of a mile highway segment. The program features a GRID system that is displayed on the reader and the tablet PC screen and divides the segment into two sets of four equal quadrants (one set per road direction) and the user can input location data for different assets. The user writes the data onto the RFID tag at the beginning of the segment and can later read the asset location information from the tag to assist in re-locating the hard-to-find assets. The program and the data file that logs the location information is placed on the tablet PC and linked when opened. The user can choose where the assets are located by entering their location on the grid (Figure 1); “Fail Codes” refers to a list of criterion for why the asset fails, according to VDOT’s contract. All the information entered into the segment data entry form is written to the site asset table, which is written into XML format in order to be transferred to the RFID reader correctly (Figure 2). The information on the reader is read-only; changes to assets can only be made on the tablet PC and transferred again to the RFID reader.

![Figure 1. The location program on the Tablet PC.](image)

The reader was found to be technically sound but cumbersome to use with the tablet PC connected; the reader successfully wrote and read information to the RFID tag. The location program took some time getting used to but became easier after repeated use.

3.1.2 Objective 2 results
The results of the external security and protection products were collected in a weighted table with a scale of 1-10 to determine which product is best suited. Based on product observations related to weather, product size, and cost it was concluded that the following hologram stickers (listed with their title given by NovaVision) are the better choice for external security of short-range RFID tags:

1. M-Valid -0.55” dia (HMV07-01)
2. Sunset 0.55” dia (HSU03-01)
3. Sweep 0.55” dia (HRS02-21)
4. Original Authentic Pattern 0.55” dia (XOA20-01)

In the weather experiment, these hologram stickers were not affected and withstood rain, sleet, freezing rain, snow, and direct sunlight.

3.1.3 Objective 3 results
Based on movement and appearance, the two-sided tape was the best choice for attaching the tag and ‘in-between’ material to the metal mile marker sign. The tape showed a little side-to-side deflection, but not enough for any major concern. In greater than a four month time period, the tape was not negatively affected by weather. Based on movement and appearance, the best ‘in-between’ material was plexiglass. Both the plexiglass and two-sided tape are clear which draws little attention. The plexiglass is thick enough to not allow the metal to interfere with the radio waves reading the tag, and also adheres well with the two-sided tape. Lastly, the encasements are beneficial for protecting the tag from foreign elements, but not practical. It would be too expensive to construct an encasement for each tag. In addition,
the encasement would draw negative security attention to the tag.

3.1.4 Objective 4 results
Overall the tags seemed to be durable enough to sustain the changing weather conditions. There were two tags that were not able to read or write data information, and a third tag with the same attachment properties that was able to be read after being detached from the mile marker. Based on these similarities, it can be concluded that metal mile marker sign was disturbing communication with the reader and the ‘in-between’ material needs to cover a larger surface area than the surface area of the tag.

3.2 Long-Range RFID system

3.2.1 Objective 1 results
The retrieval program is customized to control the tag reading function of the reader. The retrieval program references a data file that contains the highway asset data, corresponding RFID tag ID numbers, and the links to supplemental materials. Once the tags have been placed in the field, the corresponding segment data that each tag represents is stored in the data file which is then posted online to a web server. A table in the data file holds segment ID numbers which are assigned to the tag ID numbers, and the retrieval program displays the asset condition data for that segment when its tag ID number is read from the field. Another table holds the description and link for the supplemental materials being provided for each segment online, and the description shows up in the retrieval program to act as a link for the website of the document. Once the data file has been updated and posted to the online web server, the user can run the program out in the field as they are searching for long-range RFID tags corresponding to the data in the data file. Figure 3 shows what the retrieval program displays for the user when it is launched. The "AutPoll Start" button activates the reader to search for tags which appear in the top table of Figure 3 along with the time stamp of when the reader last read the tag. The user can select any tag ID number from the table and the segment data represented by the tag is displayed along with the link(s) for supplemental materials (I-895 Manual in Figure 3) assigned to the segment.

3.2.2 Objective 2 results
Three major providers and their wireless card models were researched: AT&T, Verizon, and Sprint. The factors considered in the service provider and model comparison were: broadband service coverage, PC connection type, information transfer rate, contract and service price, antenna type, and positive attributes such as an LED status indicator and available memory storage. Each model was ranked among the others for each factor being evaluated, along with certain factors being weighted higher than others through multipliers of 0.5 - 3. Verizon’s USB760 Modem was the selected model because it is a USB type wireless card under the best broadband coverage and one of the cheapest models evaluated with expandable memory.

3.2.3 Objective 3 results
Statically, it was concluded that the reader could pick up the long-range RFID tag on the back of the mile marker at all distances except for 100 feet and was not consistent at 50 feet, with a maximum of 71 feet. Dynamically, the distance the tag was read from the mile marker was 50 feet at 10 mph, 25 feet at 20 and 30 mph. The distance decreased to anywhere from 15 feet in front of the mile marker to 15 feet passed the mile marker while traveling at 60 mph. These results are much less than those reported in (Fedrowitz 2007), and suggest an unknown variable that may lie within part of the long-range RFID toolkit; such variables may be the power to the reader, signal interference levels, or possible system damage.

The second phase tested the retrieval program dynamically with 19 RFID tags on consecutive mile markers. Each tag represented a segment of data and a supplemental document in a data file posted online. All of the tags were picked up by the retrieval program at speeds of 10, 20, and 30 mph, while three of the tags were not picked up non-consecutively at 60 mph. The dynamic reading distances for all four speeds remained fairly consistent.
with results from the first phase of testing. Once read, the tag ID number stayed visible so the user could recall the asset condition data for that segment again; however, the table displaying the tag ID numbers is small and the user has to scroll down in order to see the next tag that gets read. The USB760 Modem wireless card stayed connected to the internet during the entire second phase of testing. One issue that can be problematic are the links to supplemental materials that are password protected because the tablet PC uses an on-screen keyboard that the user has to type with using the tablet PC’s pen; it can be very burdensome time-wise for the user.

Operationally, some of the AAID long-range RFID tags had to be replaced after two years while they are supposed to last for three to five years. This inconsistency can become an issue in planning when to replace the tags out on the highway so that all data can remain accessible. Physically, the tags had no physical damage due to weather extremes. The adhesive used to apply the tags to the mile markers remained strong and in tact for the majority of the tags for over two years of exposure. The different pieces of the toolkit apparatus can be cumbersome for the user when all pieces of hardware involved need to remain connected. Five cables or wires and seven connection points make up the hardware between the antenna, reader, power, and USB port of the tablet PC. The USB760 Modem wireless card and the USB cable create a tight fit and often cause the other to disconnect. If the USB cable is connected to the wrong USB port designated by the retrieval program the tablet PC goes haywire and the program is uncontrollable.

3.2.4 Objective 4 results
Both the long-range and short-range RFID tags are far too unique to combine their primary functions. Instead the long-range retrieval program was combined with the short-range location program as both systems can function through the same tablet PC. The location data is stored in a Microsoft Access data table that the retrieval program can use as well. If the retrieval program pulls a long-range RFID tag corresponding to a segment that was also assigned a short-range tag, then the location data on the short-range tag can be placed in the data file for the long-range retrieval program; the location program display will appear in the retrieval program display.

3.2.5 Objective 5 results
The projected expenses for implementing the long-range RFID toolkit in each of the 14 different VDOT contracts range from about $9,500 for a contract with about 20 miles of interstate to about $146,500 for a contract with about 355 miles of interstate. The average cost per tag was $36, excluding the one-time mounting labor costs.

4 CONCLUSIONS

4.1 Short-Range RFID toolkit
This research accomplished its objectives and will add value and improvement to the current highway asset management program for CHAMPS, and short-range RFID technology will assist inspection crews in locating hard-to-find assets in the field. Customized holograms stickers will provide authentication for each tag as well as security and protection for the information on the tags. The optimal material needed for tag attachment and the tag durability have been reported. In the future, RFID technology is predicted to sustain our world, increase the standard of living, raise the efficiency of our economy, and enhance quality of our lives (Garfinkel 2006).

4.2 Long-Range RFID toolkit
The results give way to certain attributes the long-range RFID toolkit possesses as positive and negative towards assisting VDOT’s highway asset management programs. The long-range retrieval program properly reads tags and displays the correct data when wirelessly connected. The USB760 Modem wireless card by Verizon worked as well as advertised and lived up to the top scoring it received in the wireless card evaluation table. Noticeable differences with the static and dynamic results of the long-range RFID system achieved in (Fedrowitz 2007) take away from the integrity of the toolkit. Further testing of individual pieces of the toolkit, such as tag and reader orientation effectiveness, would benefit the toolkit by eliminating unknown variables and establishing better consistency. A utility box of some sort for stabilizing the equipment and a strong attachment mechanism for the reader would benefit the clumsiness of the toolkit immensely. The inability for some of the tags to maintain their life span according to specification is another cause for concern and adds to the inefficiency of the toolkit. However, the long-range tags have proven to be physically strong in extreme weather conditions. The long-range and short-range RFID systems found a commonality with the location program. Inputting the location data into the retrieval program data file also requires the user to search for the common segment numbers that the corresponding long-range and short-range tags share, which may not always be present. The long-range RFID
toolkit seems very expensive from an overall perspective. It may be necessary to implement the toolkit into a pilot interstate project before a wholesale effort is made to go state-wide.

5 FURTHER RESEARCH

5.1 Short-Range RFID system

There are two potential applications for future research based on the findings of this research; a wireless network and higher security. A wireless network would enable crews to transfer the data information to a central database while in the field. If crews need to compare the data on the short-range RFID tag to the data in the database, the crews can download the data using the wireless network. An internal security method will guarantee VDOT protection for all data on the short-range RFID tags in the field. The reader used for this research does have the capability to provide internal password protection. However, the tags did not have the capability therefore secure tags need to be purchased and tested to ensure adequate protection.

5.2 Long-Range RFID system

It is recommended to focus on improving the highway asset management practices of VDOT by increasing the knowledge of the long-range RFID toolkit presented and looking into other state of the art technologies that mobilize data. In terms of the long-range RFID toolkit, improvement areas exist in the inconsistencies found between similar experiments that should have resulted in more congruent data. The elimination of unknown variables should be targeted with the possible creation of a manual to troubleshoot common pitfalls for new users of the long-range RFID toolkit. The mobilization of data comes in many forms of technology, and the use of GPS should be further researched. GPS coordinates could substitute for the long-range RFID tag ID numbers so that the retrieval program would be using a GPS system instead of a reader to pull the desired data. Using a different technology this way could cut back on hardware and other related costs while still improving highway asset management efficiency.

6 REFERENCES


