Improving highway asset management with RFID technology

J. M. de la Garza, N. J. Yates & C. A. Arrington
Virginia Tech, Blacksburg, VA, USA

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 $1/10^{th}$ 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 segment. 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 contracts. 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.

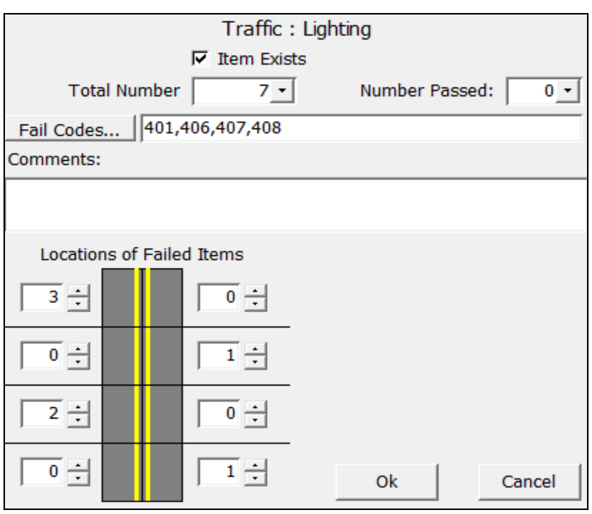

Figure 1. The location program on the Tablet PC.

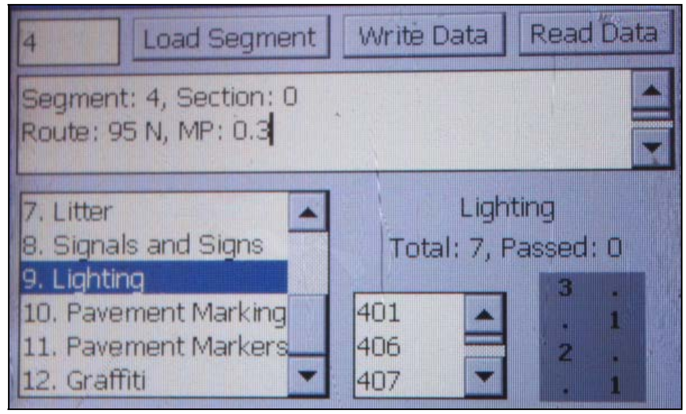

Figure 2. Program screenshot on RFID reader.

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.

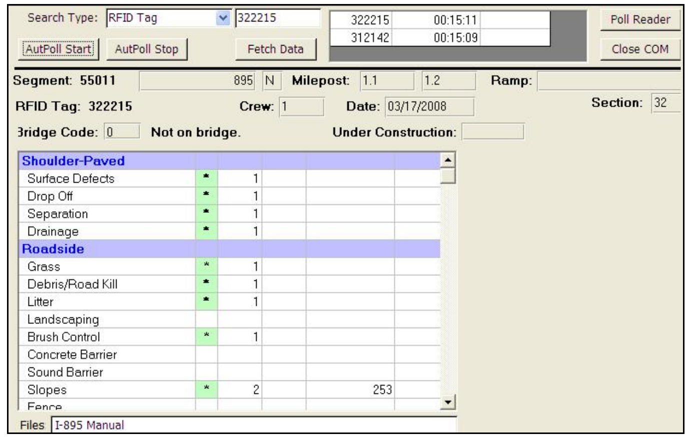

Figure 3. Retrieval program display.

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

Akinci, B. (2007) “Locating transportation infrastructure components and accessing histories for bridge inspection with radio frequency technology.” Research Opportunities in Radio Frequency Identification Transportation Applications, Transportation Research Circular E-C114, Transportation Research Board.

Center for Highway Asset Management Programs (CHAMPS) Website (2007). http://www.champs.eng.vt.edu.

Construction Industry Institute (CII) (2001). “Radio Frequency Identification Tagging: Applications for the Construction Industry.” Radio Frequency Tagging Research Team, 151-2, Austin, Texas.

de la Garza, J.M., and Fedrowitz, W. J., (2008). “Implementation of RFID Technology in the VT-VDOT Highway Maintenance Monitoring Program (HMMP).” Proceedings of the European Group for Intelligent Computing in Engineering Conference, Plymouth, United Kingdom, July 2-4, pp.518-527.

Fedrowitz, W. J. (2007). “Implementation of RFID Technology in VT-VDOT Highway Maintenance Monitoring Program (HMMP).” Master of Science Project and Report. Virginia Polytechnic Institute and State University.

Garfinkel, S., and Rosenberg, B. (2006). “RFID: Applications, Security, and Privacy.” Upper Saddle River, NJ.

Jaselskis, E. J., Anderson, M. R., Jahren, C. T., Rodriguez, Y., and Njos, S. (1995). “Radio-frequency identification applications in construction industry.” J. Constr. Eng. Management,121(2), 189–196.

Jaselskis, E. J., and El-Misalami, T. (2003). “Implementing radio frequency identification in the construction process.” J. Constr. Eng. Manage., 129(6), 680–688.