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VERMONT

AGENCY OF TRANSPORTATION

RADIO FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY FOR TRANSPORTATION SIGNAGE MANAGEMENT

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The University of Vermont
Department of Electrical and Biomedical Engineering
Department of Computer Science

April 2020

Research Project
Reporting on VTRC 18-1

Final Report 2020-03

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This material is based upon work supported by the Federal Highway Administration under SPR VTRC 18-1. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Federal Highway Administration.

TECHNICAL DOCUMENTATION PAGE

1. Report No.
2020-03

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Radio Frequency Identification (RFID) Technology for
Transportation Signage Management

5. Report Date
May 4, 2020

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
Department of Electrical and Biomedical Engineering
The University of Vermont
33 Colchester Ave.
Burlington, VT 05405

10. Work Unit No.

11. Contract or Grant No.
VTRC 18-1

12. Sponsoring Agency Name and Address
Vermont Agency of Transportation (SPR)
Research Section
219 N Main St
Barre, VT 05641

13. Type of Report and Period Covered
Final Report 2018-2020

14. Sponsoring Agency Code

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.
https://vtrans.vermont.gov/sites/aot/files/documents/Deliverable10_Final%20Report%20-%2004252020.pdf

16. Abstract

Transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives. One important component of transportation asset management is inventory management, which involves asset data collection and data transfer between field and central offices during the planning, design, fabrication, construction, operation, and maintenance stages of transportation projects. According to the FHWA Manual on Uniform Traffic Control Devices (MUTCD), agencies are required to maintain traffic sign retroreflectivity at a certain minimum level.

To ensure that traffic signs comply with MUTCD requirements, an effective management method must be developed. The current method involves locating signs, measuring their retroreflectivity, recording the inspection data into a database and replacing poor quality signs. This method requires all measurement work to be done in the field and each sign must then be updated in the database. The signs along the roadway have no associated ID numbers, which causes issues when trying to match the data recordings. This method is error prone and time consuming.

This research explored the radio frequency identification (RFID) approach for transportation signage management. RFID is a wireless tracking technology that enables a reader to activate, read and/or write data remotely between a transponder and a radio frequency tag attached to, or embedded in, an object. Using RFID tags on the signs and RFID readers to send an encoded electromagnetic signal to interrogate an RFID tag attached to the object, the RFID tag responds by sending back its ID information. RFID software manages the interrogation, performs data processing and can store the data in its memory. This would allow for automation of remote ID interrogation with minimum human intervention and no line-of-sight requirement.

This research developed a mobile traffic signage management system where the RFID tags are attached to traffic signs and an RFID reader mounted on a survey vehicle performs the RFID tag interrogation and programming while moving at driving speed. VTrans specified a system that can achieve remote interrogation at a distance of 60 feet in a vehicle driving 60 mph. The results from field tests indicated that the system created was unable to achieve these results. Using current RFID technology it is not feasible to achieve such specifications. This technology was able to achieve 100% scan rate at a maximum of 35 mph and a distance of 30 feet.

17. Key Words RFID Asset Management Inventory Management Data Collection Data Transfer	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 47	**22. Price**

Radio Frequency Identification (RFID) Technology for Transportation Signage Management

Deliverable 10

FINAL REPORT

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04 /25/2020

1. Introduction

Transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives [1]. One important component of transportation asset management is inventory management, which involves asset data collection and data transfer between field and central offices during the planning, design, fabrication, construction, operation, and maintenance stages of transportation project [2]. Traditionally, inventory management focuses on collecting and maintaining inventory and inspection data for roadway pavement, bridges, rails, etc. In the newly revised FHWA Manual on Uniform Traffic Control Devices (MUTCD) [3], FHWA emphasizes new traffic sign -- including *guardrail terminals* -- retroreflectivity requirements *in order* to improve nighttime traffic safety. According to MUTCD, agencies are required to maintain traffic sign retroreflectivity at a certain minimum level.

To ensure that traffic signs comply with MUTCD requirements, it is important to develop an effective management method. The method consists of the following basic steps: locating signs, measuring sign's retroreflectivity, recording sign's attribute data into a database, and replacing poor quality and damaged signs and/or taking other engineering actions. Even though these steps may seem straightforward, their implementations in practice are very difficult and prohibitively time consuming. As all traffic signs are deployed along the roadway, their retroreflectivity measurements have to be done in the field and the measurement results need to be recorded into the database to match each traffic sign. However, the traffic signs along the roadway have no IDs, therefore, the matching and data recording into the database have to be done manually. Since the number of traffic signs deployed along the roadway is huge, such a manual process is tedious, error prone, and time consuming.

The key to mitigating this problem is to give each traffic sign a unique ID, which allows the traffic sign attribute data to be effectively managed. One simple ID approach is to attach a barcode to each traffic sign. However, barcode scanning has some critical drawbacks. First, it is an optical technique. Thus, the scanning needs a direct line of sight to the barcode. If the barcode is polluted or covered (by vegetation, snow, water, etc.), its readability is deteriorated. Second, a barcode scanner must be closely positioned to the barcode in order to read it, typically within a few feet. It means that the inspection personnel holding a scanner must stay closely in front of each traffic sign. Third, a barcode has no read/write capabilities and does not contain any added information. Fourth, barcode scanning is very laborious, as each barcode must be scanned individually. These shortcomings make it impossible to automate barcode scanning, making it unusable for efficient traffic signage management. Therefore, a different approach is needed.

This proposed research will explore the *radio frequency identification (RFID)* approach for transportation signage management. RFID is a wireless tracking technology that enables a reader to activate, read and/or write data remotely between a transponder and a radio frequency tag attached to, or embedded in, an object. The technology involves three main functional elements: RFID reader, RFID tag and RFID software. An RFID reader operates by sending an encoded electromagnetic signal to interrogate an RFID tag attached to the object it wants to identify. The RFID tag then responds by sending back its ID information, which could be a unique tag serial number and/or other object attribute data stored in its memory. The RFID software manages RFID interrogation, performs data processing, and interacts with other applications. Compared with the barcode technology, the RFID technology is far more robust and supports the automation of remote ID interrogation with minimum human intervention and no line-of-sight requirement.

The aforementioned advantages of the RFID technology make it a key enabler to the development of a mobile system that can manage transportation asset, notably the traffic signage.

In this research, we have developed a mobile traffic signage management system. In this system, RFID tags are attached to traffic signs deployed along the roadway and an RFID reader mounted on a survey vehicle performs RFID tag interrogation and programming while moving at a driving speed. In addition, a handheld reader is used to allow manually interrogate and program RFID tags which add more system flexibility. A backend database is developed to manage the tag attribute data.

Based on the communications with Vermont Transportation Agency (VTrans), VTrans is looking for a system that can achieve remote interrogation at 60 feet distance and vehicle driving speed of 60 mph. Therefore, this project has two R & D aspects: 1) Developing all proposed functions of the mobile traffic signage management system; 2) Exploring viability to achieve VTrans specifications, evaluating realistic specifications that can be achieved with current RFID technologies, and suggesting possible methods to leverage system performance.

This report provides a synthesis of all of the reports that were created during the RFID project. This is not a chronological account, but an organized synopsis of our findings as we summarized briefly in each quarterly report along with a synthesized final summary of the team's latest findings and endeavors.

Project Tasks

The project consists of the following 10 subtasks.

Task 1: Conduct analysis on RFID traffic signage management criteria that will serve as guidelines for the development and configuration of transceiver circuits on an RFID reader and RFID tags.
Task 2: Laboratory study of handheld, stationary, mobile RFID reader circuits.
Task 3: Laboratory study of RFID tags, including active, semi-active and passive tags.
Task 4: Develop RFID scans and data acquisition program and a user-friendly graphical interface (GUI).
Task 5: Develop a traffic signage management database.
Task 6: Develop methods for mounting RFID tags on signs and RFID readers on the vehicle.
Task 7: Integrated RFID system.
Task 8: Perform field tests and debug the RFID system.
Task 9: Evaluate statewide deployment of the RFID technology for traffic signage management and explore other intelligent transportation services.
Task 10: Submit project reports and disseminate research results.

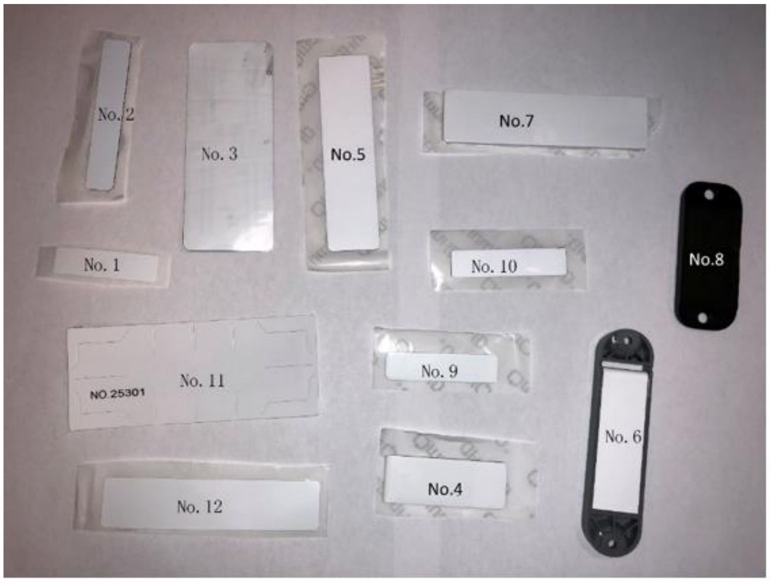
2. RFID Hardware Study

Task 1: Conduct analysis on RFID traffic signage management criteria that will serve as guidelines for the development and configuration of transceiver circuits on an RFID reader and RFID tags.

The focus of the proposed work for the first month was on conducting a comprehensive study of RFID system specifications, selecting and comparing different RFID products (i.e., tags and readers) and their functional parameters, and identifying appropriate ones. To this end, we acquired a number of different RFID tags and performed a series of tests both indoors at UVM laboratory and outdoors on UVM campus. In these tests, RFID tags of different types were evaluated in various configurations (e.g., metal- vs. nonmetal mount, scan distance, stationary vs. moving scan). We report below the test results obtained.

2.1 RFID Tags

Task 3: Laboratory study of RFID tags, including active, semi-active and passive tags.



Tag 13 - XTREME RFID VX-Mid MM

Tag 14 – Omni-ID Exo 750

Fig. 1. RFID tags used in the tests.

Fig. 1 and Table 1 show RFID tags used in the tests which are all passive tags. We inquired with multiple vendors about active RFID tags as well as passive tags. According to the vendors, the lifetime of most active tags is approximately one year, and the price of each tag is typically in the range of \$20 - \$100. These can be critical limiting factors in traffic signage management. Therefore, we have decided to evaluate only passive RFID tags with regard to the functional specifications mentioned above in Section G.a (Kickoff Meeting). (Evaluation of active RFID tags was deferred until other products became available and in the end was suspended.)

Table 1. RFID tags used in the tests.

Number	Name
1	CONFIDEX SILVERLINE MICRO
2	CONFIDEX SILVERLINE SLIM
3	CONFIDEX SILVERLINE CLASSIC
4	Omni-ID Fit 210
5	Omni-ID Flex 600
6	Omni-ID Flex 800
7	Omni-ID Flex 1200
8	Omni-ID Flex 1600
9	Omni-ID IQ 600
10	Omni-ID IQ 400P
11	TAGEOS EOS-500
12	Omni-ID IQ 800
13	XTREME RFID VX-Mid MM
14	Omni-ID Exo 750

The scan distances measured using these RFID tags under various test scenarios are presented below.

We have tried 12 different types of RFID tags, of which 10 are for metal mounting and 2 are for nonmetal mounting. Metal-mount tags were placed on metal substrate and nonmetal-mount tags were placed on nonmetal substrate, and the scan distance was measured for each tag. Table 2 summarizes the results comparing the measured distance with the distance specified in the product datasheet. First of all, nonmetal-mount tags on nonmetal substrate gave a far longer scan distance than metal-mount tags on metal substrate.

Table 2. Scan distances measured and specified.

Tag Name	Measured Distance	Specified Distance (per Datasheet)
Metal-mount	Metal substrate	
CONFIDEX SILVERLINE MICRO	1ft	5ft
CONFIDEX SILVERLINE SLIM	3ft	13ft
CONFIDEX SILVERLINE CLASSIC	7.5ft	20ft
Omni-ID Fit 210	1ft	9.8ft
Omni-ID Flex 600	3ft	19ft
Omni-ID Flex 800	8ft	26ft
Omni-ID Flex 1200	6ft	39ft

Omni-ID Flex 1600	7ft	52ft
Omni-ID IQ 600	1.5ft	19ft
Omni-ID IQ 400P	0.6ft	16ft
Nonmetal-mount	Nonmetal substrate	
TAGEOS EOS-500	31ft	32ft
Omni-ID IQ 800	52ft	32ft

There were significant discrepancies between the distance measured in the test and the distance published in the vendor's datasheets. We suspect the main reason for this discrepancy is with the RFID reader used in the test, shown in Fig. 2. The reader is a non-branded one purchased from Amazon.com. To work around the delay in the project account setup, we ordered this low-cost simple reader from an alternative account.

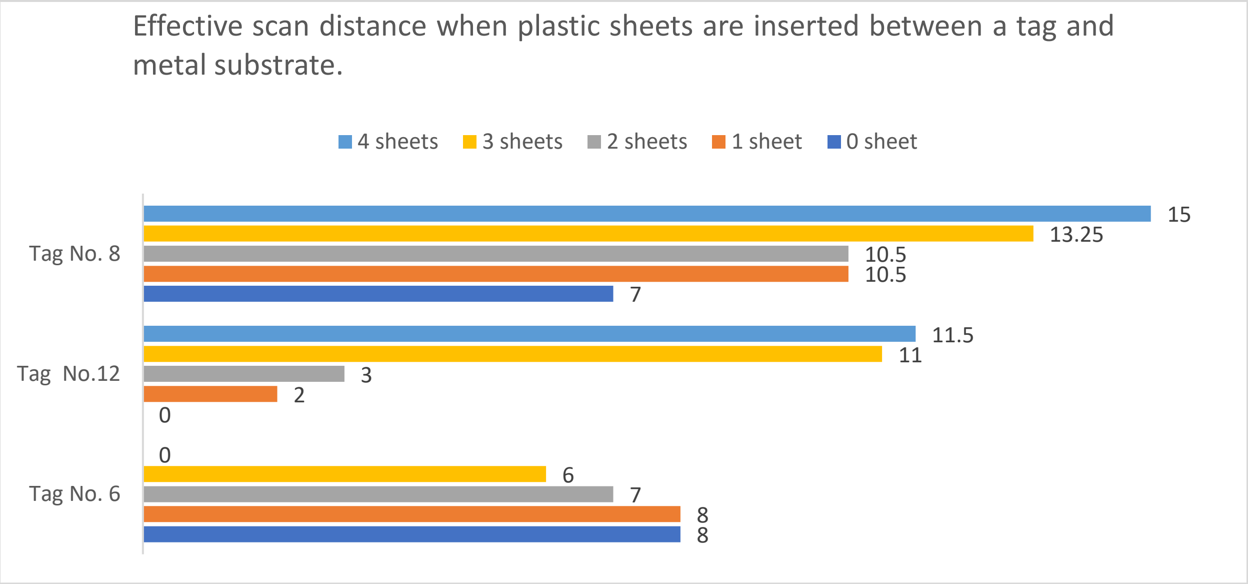


Fig. 2. Spacing test result (see Fig. 1 and Table 1 for the tag information).

Fig.2 shows the test results for metal substrate testing. For tag 8 and tag 12, increasing the spacing resulted in increasing the effective scan distance noticeably. The trend seems to be opposite for the tag 6, however. Our speculation is that tag 6 has a different packaging, in a plastic casing (see Fig. 1), and it may be reducing the effect of the spacing. These findings can be utilized for the design of RFID tag mounting structure.

Proximity Test with Nonmetal Tags Installed Near Metal Substrate

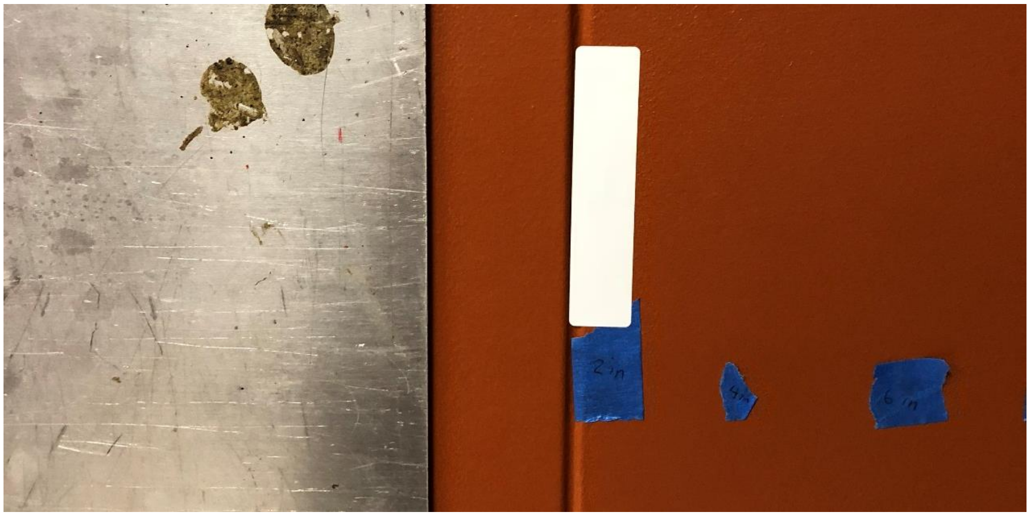


Fig. 3. Nonmetal tags at different distances from metal plate.

To examine the influence of metal substrate on the scan distance of a nonmetal-mount tag, the tags were placed at different distances from a metal plate (see Fig. 3 for the setup). This test assumed a RFID tag new mounting structure where a tag would be mounted next to a traffic sign's metal plate or pole.

Table 3. Scan distance for different spacing between metal plate.

Distance between metal plate and tag	**Measured scan distance**	
	Horizontal orientation	Vertical orientation
< 0.25 inch		2ft
2 inches	21ft	10.5ft
4 inches	20ft	10.5ft
6 inches	35ft	9.5ft
8 inches	22ft	35ft
∞ (no metal plate nearby)	52ft	41

Table 3 shows the result for a tag Omni-ID IQ 800, a nonmetal-mount tag (see Fig. 1 and Table 1). As expected, increase in the distance between metal plate and tag tends to result in increase of the scan distance, but the effect does not seem that significant.

2.2 RFID Readers

Task 2: Laboratory study of handheld, stationary, mobile RFID reader circuits

2.2.1 In-vehicle RFID Reader

Our efforts thus far have included the selection of an RFID reader, antennas, and tags whose specifications fit our stated goals. Each reader itself is essentially a miniature computer in the same vein as a Raspberry Pi that has all the necessary I/O ports required for connecting to antennae and to a paired computer. Many readers, such as our chosen Sargas model, contain on their internal memory pre-installed programs that allow a connected computer to directly access the incoming data through a web interface. Readers include Ethernet ports allowing a direct to computer local area (LAN) connection and threaded cables for connection to the required antennas. RFID tags are transponders to the antenna, and typically contain an integrated antenna and a programable memory chip. The operating frequency of a tag and a reader should be in a same frequency band, which in our case is 902 to 928 MHz (FCC). They receive waves sent by an antenna and bounce them back to the antenna's receiver with a small slice of data, typically a tag ID. This ID can be modified dynamically (i.e., "written") by the reader/antenna combo.

Fig.3 shows the proposed RFID system including the RFID reader, the antenna and the RFID tags. The RFID reader we are using was purchased from ThingMagic® Sargas. It is a high-performance, two antenna port, UHF reader in a low profile enclosure. There are two antenna ports available, to allow two antennas to face toward different directions to extend the coverage.

RFID antenna (top) and reader (bottom)

Omni-ID Flex 1200

Omni-ID Exo 750

Fig. 4. RFID system configuration.

Table 4 shows the specifications of the RFID system. After a series of tests on different RFID tags, we have selected two highest performance tags as the objective tags: Omni-ID Flex 1200 and Omni-ID Exo 750. Omni-ID Exo 750 has a more stable performance with its plastic packaging, whereas Omni-ID Flex 1200 is less expensive.

Table 4. RFID system specifications

Specification	**Values**
Air Interface Protocol	EPC Gen 2V2 ISO 18000-63
Operating Frequency	Global 865-956 MHz
Antenna Gain	7 dBic (865-870 MHz) 7.5 dBic (902-928 MHz)

		6.5 dBic (950-956 MHz)
Transmission Power		0 dBm to +30 dBm (1 W)
Dimensions	Reader	87 x 80 x 23.8 mm (3.4 x 3.1 x 0.94 in)
	Antenna	190 x 190 x 30 mm (7.5 x 7.4 x 1.2 in)
Weight	Reader	0.27 kg (0.60 lbs)
	Antenna	0.80 kg (1.76 lbs)
Operating Temperature		-20 to +60ºC (-4 to +140ºF)
Maximum Read Distance	Omni-ID Flex 1200	76 feet (on-metal) 7 feet (nonmetal)
	Omni-ID Exo 750	55 feet (on-metal) 45 feet (nonmetal)
Price	Omni-ID Flex 1200	$1.75 Per Tag (100 Tags) $0.86 Per Tag (900 Tags) $0.79 Per Tag (4,500 Tags) $0.75 Per Tag (9,000 Tags)
	Omni-ID Exo 750	$4.9 Per Tag (10 Tags) – possibly with a significant discount for bulk order

2.2.2. RFID Reader Test

Reading Range Tests

several experiments we conducted on the RFID system to test its approximate reading range. The experiments took place in a parking area near UVM Harris Millis Residence. Fig.4 shows an in-situ view of the testing site.

Fig.5. The RFID system maximum reading range test.

In the experiment, the antenna was attached on one side of the vehicle in stationary (i.e., not moving). In practical deployment of the system, some mechanical support structure could be utilized to make antenna face toward a sign in an angle. Besides, the RFID tag (Omni-ID Flex 1200) was attached on a metal plate that emulated the traffic sign. The maximum reading range detected was approximately 76 feet in the distance and 15 feet in the width.

Distance test

The signal strength RSSI was measured for different distances. Fig.6 shows the result. Evidently, the signal strength became weaker when reading tags was moved farther away. The weakest signal detectable was -80 RSSI.

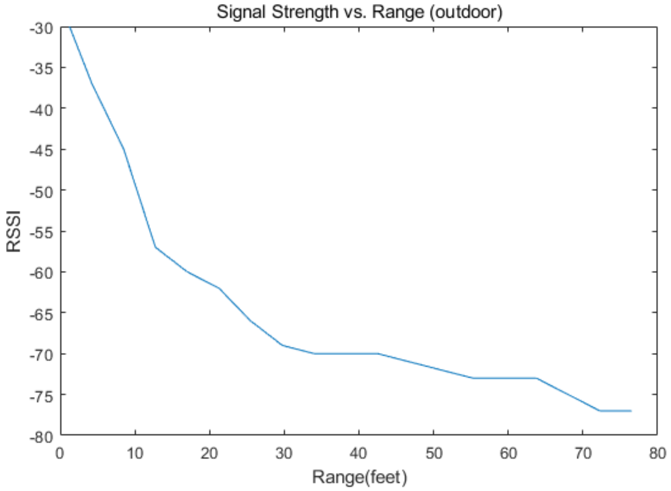


Fig.6. The relationship between RSSI and reading range.

Height test

Fig.7 illustrates the setup of heights in the mounting height test, and Table 5 shows the test results. The height number 3 (i.e., 3ft 10in) is at the same height as the antenna placed on the vehicle. The conclusion is that a tag could be mounted at any height on the pole without affecting the reading performance significantly.

Fig.7 RFID tag mounting height.

Table 5. Signal strength vs. height (measured at 8 feet from the antenna).

Number	Height	RSSI
1	6in	-60
2	2ft 8in	-42
3	3ft 10in	-45
4	5ft 2in	-57
5	6ft 4in	-65

Angle test

Scanning angle also played a role in the signal strength, as shown in Table 6. Using an antenna at a static height from a distance of 15 feet to the tag, we tested various heights on-sign in order to determine the results of various angles.

Table 6 Signal strength vs. angles (measured at 15 feet distance)

Angle (degree)	RSSI
0	-79
30	-60
60	-58
90	-55
120	-50
150	-58
165	-79

Obstruction test

Given that traffic signs and guardrail terminals are placed alongside the road, RFID tags on them may be behind various obstacles, so experiments were done to emulate such conditions. Two cases are shown in Fig. 8 – in one case, the tag was covered by a thick blob of snow (left), and in the other case, the tag was blocked by a thick bush (right). The test results are summarized in Table 7. It is discovered that unless the tags are fully covered by snow or bush, they can be detected well. These scenarios should be rare in the real deployment.

Fig. 8. Different obstacles tests.

Table 7. Received signal strength indication (RSSI) (under different conditions (measured at 8 feet from the antenna). (N/A means “no reading detected”.)

Condition	RSSI	
Normal (no obstruction)	-58	
Tag covered with 1-inch thick snow	-62	
Tag covered with 6-inch thick snow	N/A	

Tag blocked by a wood stick	-58	
The car window rolled up	-58	
Tag inside a thick bush	-78	
Tag behind a thick bush	N/A	

Speed Tests

Some field tests were done on this RFID system when the vehicle was moving. The location of the experiments was the Jeffords Hall parking lot on UVM campus. The test was performed during the school break and a care was taken to ensure that no other people was around. The vehicle drove on different trails with 10 feet, 25 feet, 51 feet, or 67 feet distance from the tag (see Fig. 9). The driving speed was 20 mph. The RFID tag was detected in every trail and its ID number was displayed correctly on the computer connected to the RFID reader.

Fig.9. Field test with different distance.

Tests were performed with the reader mounted in one researcher's car window at a constant height of approximately 50 inches above the ground. The reader was held by one researcher on the window in order to maintain perpendicularity while another researcher drove the car around a loop in the parking lot shown in Fig. 9. In each iteration of the test, it was ensured that the RFID reader was maintained at the approximate planned distance while the vehicle was on cruise control to maintain a constant speed of 20 mph. Tests were successful at all distances tried.

The parking lot in which the test was performed only allowed us to test up to 67 feet distance, at which distance the reader could still perform multiple successful reads on each pass. Further test at a longer distance can be performed in a different test-site.

Traffic signs on either side of the road can be covered with two antennas mounted on a vehicle, facing opposite sides (see Fig. 10). The feasibility of this configuration was validated in a field test.

Fig. 10 Two antennas are operating at the same time.

Reader Antenna Tests

Fig. 11 shows the photo of the two antennas acquired and used in this project. SecureContol was used during the first month (September), and Invengo has been adopted since then. **Table 8** shows their specifications.

Fig. 11. The two antennas acquired: Invengo (left) and SecureControl (right)

Table 8. Specifications of the two antennas.

Parameters	**ThingMagic Sargas**	**SecureControl**
Operating frequency	FCC (902-928 MHz), ETSI (840-868 MHz)	FCC (902-928 MHz)
Gain	12 dBi	8 dBi
Polarization	Right hand circular	Circular
Beamwidth	45˚	N/A
Dimensions	16.97 x 16.97 x 2.36in	16.93 x 3.94 x 10.24in

The S11 parameters of the two antennas were measured using a network analyzer (Keysight N5277A) for in the frequency band spanning from 500 MHz to 1GHz. (S11 is the input return loss of a device under test which indicates the reflection of the antenna and the efficiency of the signal transmission.) The results are shown in Fig. 12. The FCC specified RFID operating frequency band (902-928MHz) is shown between two dashed lines. This plot shows that the Invengo antenna's return loss in the operating frequency band is below -20dB which is less than SecureControl antenna's.

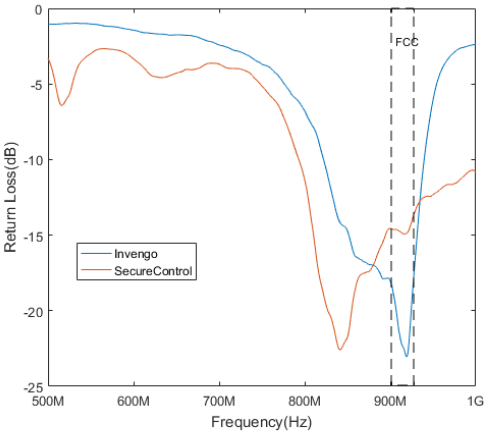


Fig. 12 Measured S11 value of the Invengo antenna and the SecureControl antenna.

The radiation patterns of Invengo antennas is shown in Fig. 13. In the polar plot, the numbers around the circle represent the angular direction, and the concentric rings indicate antenna gain (Unit: dBi). For Invngo antenna, as it is a linear polarization antenna, its radiation mainly exists in a single plane (E-pane), shown in Fig. 13. While for MTI antenna, as it is circular polarization antenna, its radiation field exists in two orthogonal planes, which are azimuth plane (AZ-plane) and elevation plane (EL-plane). The corresponding radiation patterns are plotted in Fig. 14. Note, both antenna gains are around 8.5 dBi. However, MTI antenna allows signal radiation and receiving in two orthogonal planes, which enables scanning RFID tags in arbitrary orientations.

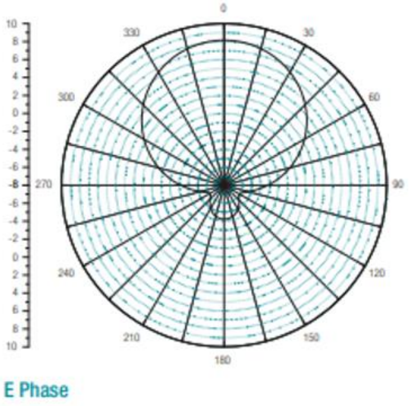


Fig 13. Radiation pattern of Invengo antenna.

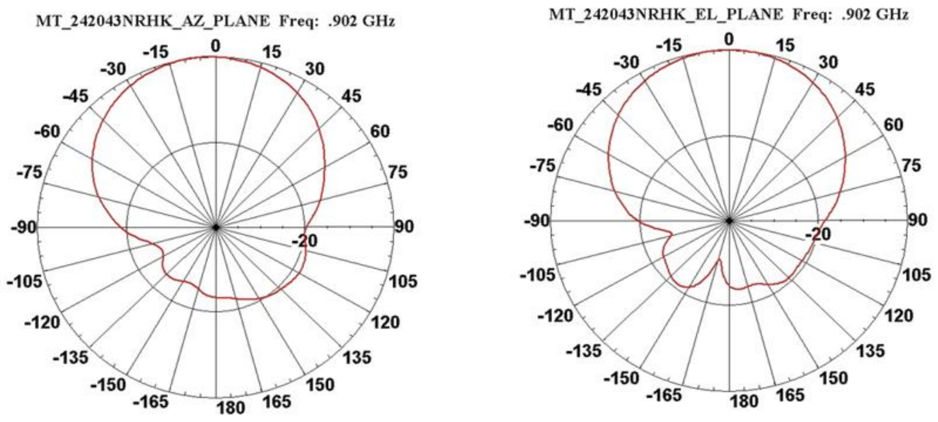
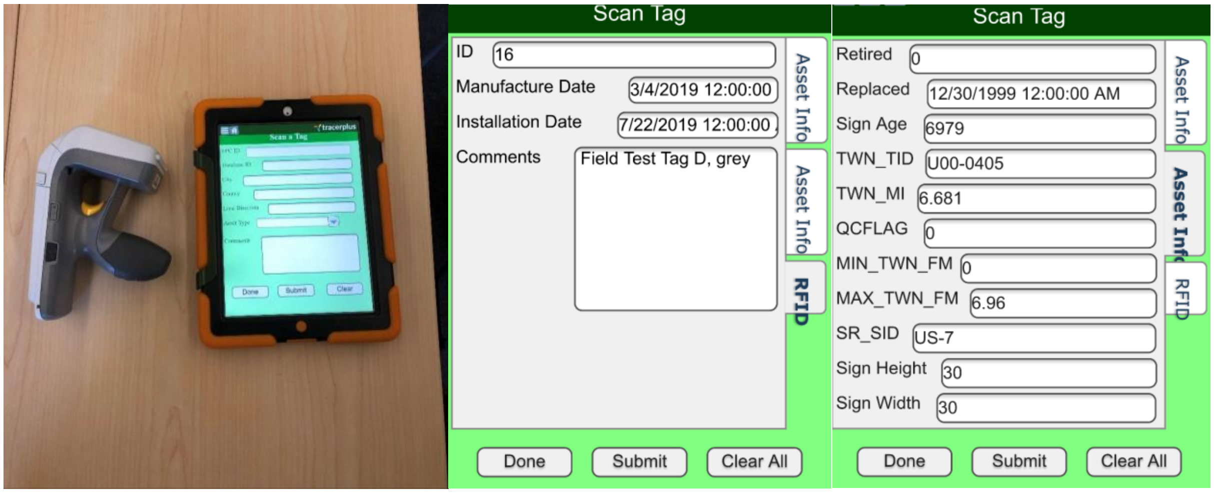


Fig 14. MTI antenna radiation patterns on two orthogonal planes- azimuth plane and elevation plane.

2.2.3 Handheld Reader

The handheld reader is used for individual tag reads to display or modify the relevant tag information (Fig. 15). In our system, the handheld reader has the requirements of using an iOS platform (as opposed to Windows or Android) and being able to connect to a remote database (on Microsoft SQL Server). To meet both requirements, a mobile RFID reader firmware, consisting of TracerPlus and TracerPlus Connect, is adopted in conjunction with Zebra handheld reader. TracerPlus is customized to support filtering, reading, displaying, and saving RFID tag data in the same manner URA does for in-vehicle reader. TracerPlus Connect provides database connection and synchronization of data to and from an SQL Server.



ID	16
Manufacture Date	3/4/2019 12:00:00
Installation Date	7/22/2019 12:00:00
Comments	Field Test Tag D, grey

Retired	0
Replaced	12/30/1999 12:00:00 AM
Sign Age	6979
TWN_TID	U00-0405
TWN_MI	6.681
QCFLAG	0
MIN_TWN_FM	0
MAX_TWN_FM	6.96
SR_SID	US-7
Sign Height	30
Sign Width	30

Fig. 15 Photo of the handheld reader and the interface of the operating software.

In deployment, the handheld reader connects to an iOS device via Bluetooth. When the trigger is pressed, the reader scans the ID of a tag in the close point of view and, given the ID, retrieves the pertinent tag data from the database and displays the information on the screen of the iOS device. The tag data can then be edited and written back to the SQL Server. Any such changes to tag data are reflected both locally on the reader and remotely in the database on the server (details will be discussed in the Software and Database Organization section).

2.3 Passive, Active and Semi-active RFID Tags Performance

Task 3: Laboratory study of RFID tags, including active, semi-active and passive tags

There are a variety of RFID tags available on the market. Therefore, it is possible to test many different tags and compare their performances before settling on a few strong candidates for high speed testing, largely based on the capability of long-distance reading and the required substrate for the tag itself. Some tags are metal-specific (i.e., must be mounted on a metal surface to function properly), some tags are nonmetal-specific (i.e., must not be mounted on a metal surface), and some are metal-agnostic (i.e., may or may not be mounted on a metal surface).

The new RFID reader, Sargas, purchased from ThinkMagic showed a great improvement over the older provisional one (SecureControl) in term of the detection range (see Table 9). Fig. 16 shows the RFID tags used in the test. Fig. 17 shows the setup for the tests, where the reader is fixed in its position while the tags are moved to find the maximum reading distance.

Table 9. Maximum reading distances for the different passive tags.

Tag#	**Orientation**	**Substrate**	**Price**	**Reading Distance (feet)**		
				Sargas	**SecureControl**	**Datasheet**
6	Horizontal	Metal	$29 for 10	21.25	8	26
	Vertical			49		
14	Horizontal	Metal	$49 for 10	55	19	36.1
	Vertical			50		
	Horizontal	Non-metal		48	12	
	Vertical			38		
12	Horizontal	Non-metal	$480 for 1000	33	41	32
	Vertical			55	52	
7	Horizontal	Metal	$0.86per for 900	15	6	39
	Vertical			55		

Fig. 16. RFID tags used in the experiment. (From left to right are tag 6 (Omni-ID Flex 800), tag 14 (Omni-ID Exo 750), tag 12 (Omni-ID IQ 800), and tag 7 (Omni-ID Flex 1200).)

Fig. 17. Experiment configuration.

Distinctions among passive, active, and semi-active RFID tags

- A *passive* tag has no internal power source. It receives energy transmitted by the RFID antenna to have its coiled antenna energized. It then uses the energy received to read the tag data and transmit it with the embedded antenna. Passive tags can have a variety of specifications and casings depending on the intended use. Some tags are highly durable, some are made for extreme temperatures, some are mode for long-distance reads, etc. These tags often cost between $0.25 at the low end and $5 at the very top end.

- An *active* tag is internally powered by a battery and is therefore more limited in lifespan and far more expensive. However, since it powers its own antenna, it provides a much greater reading distance. Active tags can cost from $20 to $100 depending on the use case – some industries require tags that are both long distance and highly durable.

- A *semi-active* tag has a battery in it, however the battery does not power a RFID transmitter. Instead it only powers a small logic circuit board of sensors and memory integrated with the passive RFID tag. Semi-active tags typically store extra amount of data compared with passive tags. As the battery is not used to power the tag transmitter, the signal transmission distance of the semi-active tag is essentially the same as that of the passive tag.

Comparisons of 4 passive RFID tags

There are a large variety of RFID tags. To select appropriate tags for this project, we consider several main factors: substrate, reading distance, casing and price. Note, as most traffic signs are built by metal, the tags need to support metal substrate for operations.

In Table 10, four different tags (Fig. 13) are selected for comparisons. All these tags are operable on metal substrate. The experimental setup shown in Figure 14 was used here as well , where the reader is placed at a fixed location while the tags are moved from the reader to evaluate the maximum reading distance.

Table 10. Maximum reading distances for different passive RFID tags.

Tag#	**Orientation**	**Substrate**	**Price**	**Reading Distance (feet) with different readers**			
				Sargas	**Izar**	**Mengqi Control**	**Datasheet**
Omni-ID Flex 800	Horizontal	Metal	$29 for 10	21.25		8	26
	Vertical			49			
Omni-ID Exo 750	Horizontal	Metal	$49 for 10 units	55	45	19	36.1
	Vertical			50	45		
	Horizontal	Non-metal		48	38	12	
	Vertical			38	36		
Omni-ID IQ 800	Horizontal	Non-metal	$480 for 1000 units	33	45	41	32
	Vertical			55	45	52	
Omni-ID Flex 1200	Horizontal	Metal	Unit price $0.86 for ordering 900 units	15		6	39
	Vertical			55			

3. Software & Database Organization

Task 5: Develop a traffic signage management database

There is a very large repository of industrial-strength RFID programming software, called Mercury API, hosted by Jadak: https://www.jadaktech.com/documentation/rfid/mercuryapi/. Research has been done in consultation with Jadak technical support team to figure out the best strategy to implement the software side of the project. (The implementations of this project include the Sargas RFID reader programming, GUI development, and database access). Due to the sheer size, complexity, and cost of high functioning RFID software programs, the most feasible development strategy is to leverage the existing open-source software to carry out the needs of this project with minimal customizations.

3.1 User Interface

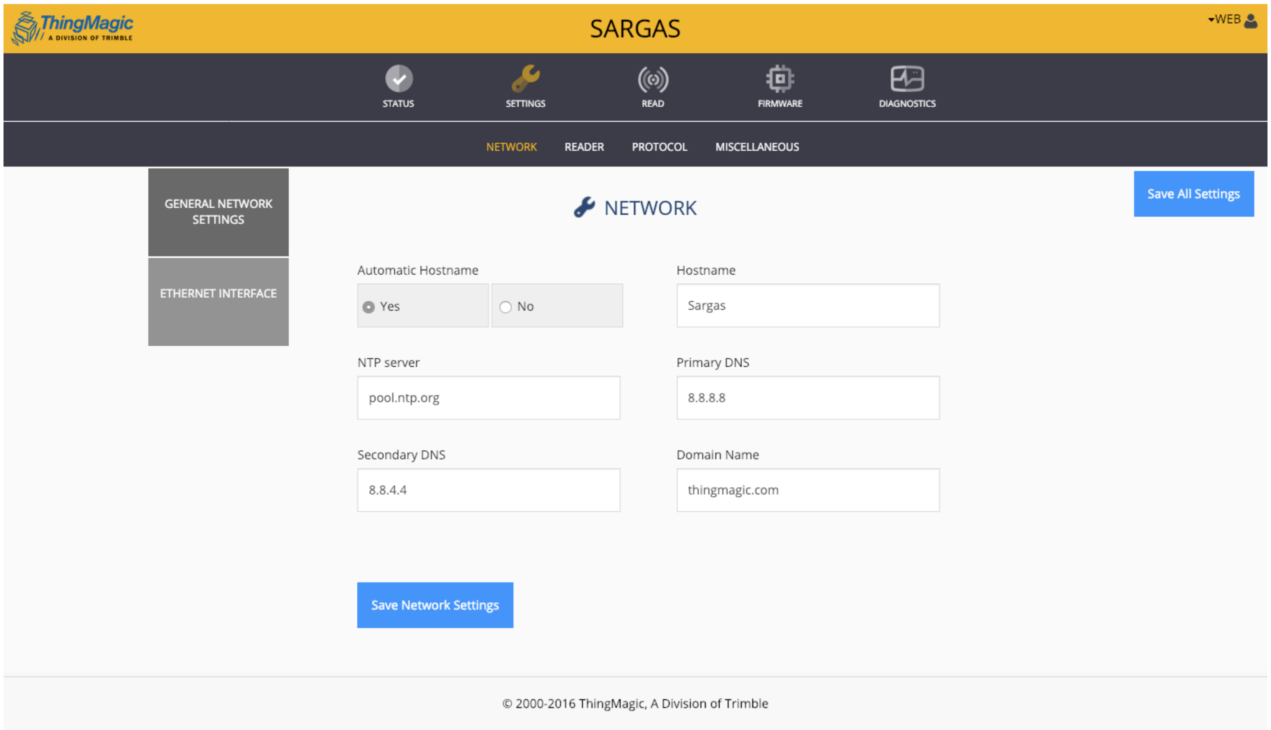
Task 4: Develop RFID scans and data acquisition program and a user-friendly graphical interface (GUI).

After selecting the RFID reader (Sargas), a focused effort has been made to enable the reader actually read tag data and display them on a graphic user interface (GUI). Sargas is a network reader, and we are able to successfully make the network connection work using the codes built in the reader (written in programming language C). Then, we look into building the GUI. Our finding is that there are two functional GUI packages, both built from the Mercury API, that can work with the Sargas RFID reader: (i) Sargas Web User Interface (Web UI) and (ii) Universal Reader Assistant (URA).

The primary software for our data collection and laboratory testing is the Sargas Web UI for connections to the Sargas RFID reader. This software is cross-platform and is currently located on the Sargas reader itself and can be accessed from a laptop/PC from a browser. The Web UI has the capability to collect multiple data points on tags including, but not limited to, tag ID, signal strength (RSSI) and read frequency, which are collected and displayed live as tag data are read by the Sargas reader. There are user-friendly settings for reading tags with up to two antennae simultaneously. The Web UI is largely comprised of HTML, CSS, and Javascript and provides a very user-friendly interface.

Unfortunately, it turns out Web UI is not customizable for the purpose of this project, as they do not release the source codes. Therefore, we investigate the other package, URA, for our own customization. On Mercury API website, the URA source codes are provided which are written in a programming language called C#. URA provides efficient and smooth connection to Sargas reader, and also collects and displays data live. The Mercury API website also has extensive documentation for software customization of URA.

Fig. 18a shows user interface to the Sargas reader via the local network, and Fig. 18b shows a screen snapshot of tag IDs captured and displayed. Both are from the Web UI.



Automatic Hostname: ● Yes ○ No

Hostname: Sargas

NTP server: pool.ntp.org

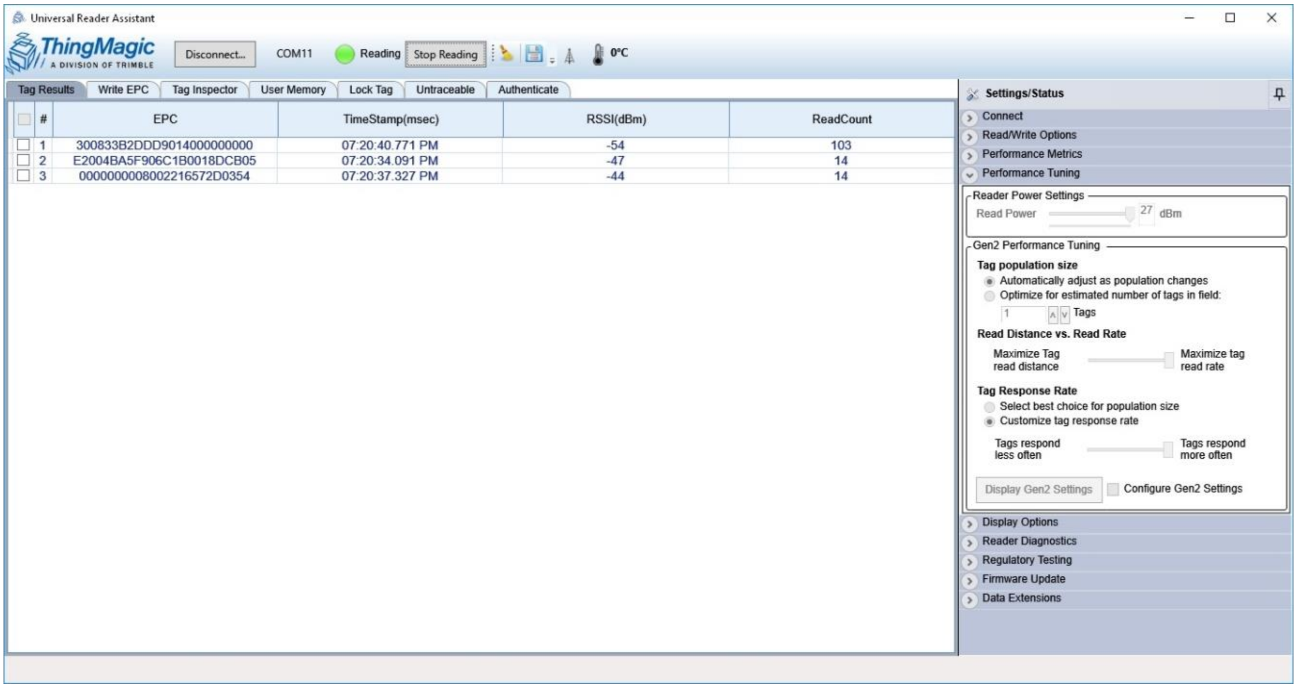
Primary DNS: 8.8.8.8

Secondary DNS: 8.8.4.4

Domain Name: thingmagic.com

© 2000-2016 ThingMagic, A Division of Trimble

Fig. 18a. Connection to the Sargas reader over the network.



☐	#	EPC	TimeStamp(msec)	RSSI(dBm)	ReadCount
☐	1	300833B2DDD9014000000000	07:20:40.771 PM	-54	103
☐	2	E2004BA5F906C1B0018DCB05	07:20:34.091 PM	-47	14
☐	3	000000008002216572D0354	07:20:37.327 PM	-44	14

Reader Power Settings

Read Power: 27 dBm

Gen2 Performance Tuning

Tag population size

● Automatically adjust as population changes
○ Optimize for estimated number of tags in field:
1 Tags

Read Distance vs. Read Rate

Maximize Tag read distance — Maximize tag read rate

Tag Response Rate

○ Select best choice for population size
● Customize tag response rate

Tags respond less often — Tags respond more often

Display Gen2 Settings ☐ Configure Gen2 Settings

Fig. 18b. User interface displaying tag information live as they are read from RFID tags.

3.2 Database Access and Organization

As mentioned earlier, the program provided by JADAK with the Sargas reader does not have a connection to a database. We are using Microsoft SQL Server Express 2017 to test database connectivity.

Fig. 19 shows a preliminary database table schema which has two tables, with the fields based off a New England Transportation Consortium document. More fields and more tables can be added depending on the application needs. The table on the left is a Structure table designed to organize the structures on which RFID Tags will be placed. The table on the right is an RFID table, meant for the RFID tags themselves.

Structure
Description
Code
Manufacture_Date
Date_Entered
Structure_ID **(PK)**
Installation_Date
Condition
Last_Inspection_Date
Lane Direction
Comments

RFID
Tag_ID
RFID_Code
Manufacture_Date
Date_Entered
Structure_ID **(FK)**
Installation_Date

Fig. 19. A toy database table schema. (PK designates a primary key, and FK designates a foreign key.)

In order to streamline the data collection process at high speeds, only the Tag ID field (EPC) is transmitted and stored in the database during scanning tours.

4. System Mounting Structure

<u>Task 6:</u> Develop methods for mounting RFID tags on signs and RFID readers on the vehicle

This section summarizes mechanical structure for mounting RFID reader antennas on a test vehicle, Fig. 20, specifically a 2015 Honda CRV. This custom vehicle mount utilizes a standard Thule Square Bar 108 roof rack, Fig. 21. The remainder of the mount is fabricated using 1.5” fiberglass box tubing, fiberglass plates and square tubing connectors. The structure can be used to install multiple antennas, Fig.22.

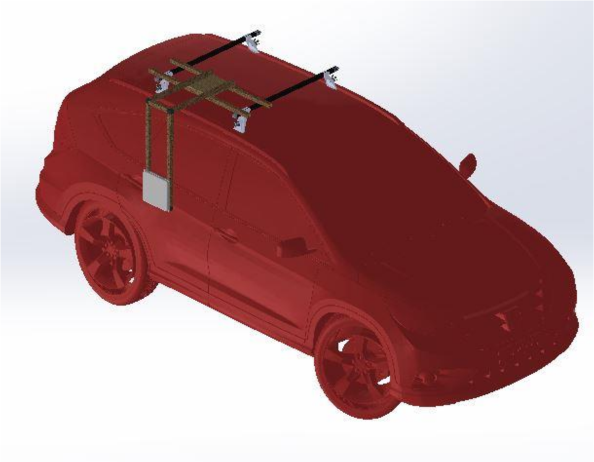


Fig. 20: RFID antenna and custom mount attached to the roof rack of the Honda CRV

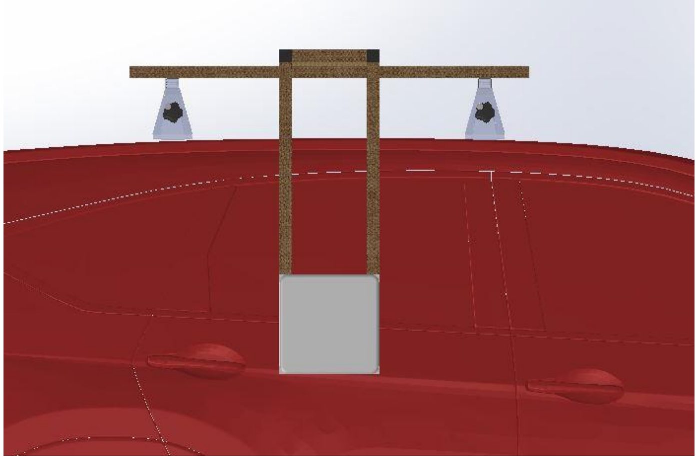


Fig.21: Side view of the RFID antenna and custom mount attached to the roof rack of the Honda CRV

Fig. 22: RFID antenna custom mount

RFID Tag mounting

Between the two types of tags chosen (i.e., Omni-ID Exo 750 and Omni-ID Flex 1200), Exo 750 tags come encased in plastic packaging that is believed to be sturdy enough. Flex 1200 tags may be fragile and, thus, mounting them inside a small case can enhance the protection (see Fig. 23).

Fig.23. Tag mounting of Omni-ID Exo 750 (left) and Omni-ID Flex 1200 (right).

Parts list:

- Fiberglass box tubing (www.mcmaster.com/fiberglass-(frp)
    - 1.5” by 1.5” Outer Dimensions. 9 inches long (2)
    - 1.5” by 1.5” Outer Dimensions. 30 inches long (2)
    - 1.5” by 1.5” Outer Dimensions. 36 inches long (2)
    - 1.5” by 1.5” Outer Dimensions. 48 inches long (2)
- Square tubing connector

    - Elbow (2)
    - www.estoconnectors.com/product/pn-521150
- Square tubing connector
    - Corner, 3 section Connector (2)
    - www.estoconnectors.com/product/pn-533150
- Arc-Resistant GPO3 Fiberglass Sheet
    - 12" Wide x 12" Long, 1/2" Thick (2)
    - www.mcmaster.com/8549k48
- Thule Square Bar 108 roof rack
    - www.autoanything.com/roof-racks/thule-base-rack-system
- Hardware for assembly
    - Nuts
    - Bolts
- Adhesive (Gorilla glue)
    - www.amazon.com/dp/B0000223UU/ref=cm_sw_em_r_mt_dp_U_Nc-QCbABCJ6CZ
- RFID Antenna
    - www.atlasrfidstore.com/mti-mt-242043-trh-a-k-rhcp-outdoor-rfid-antenna
- Antenna mounting kit (for angle adjustments)
    - www.atlasrfidstore.com/mti-rfid-antenna-mounting-kit-mt-120018/

5. System Integration

Task 7: Integrated RFID system

RFID database management development through Rest API

This section summarizes the prototype database system created and monitored by the UVM team for testing and deployment. We used Microsoft SQL Server as our DBMS of choice as well as a remote database located on the Azure SQL Server cloud. Both the in-vehicle and handheld RFID readers have the ability to save data locally in its own device and remotely in a remote database server. The project sponsor Vermont Agency of Transportation uses Microsoft SQL Server to manage their large transportation assets and, therefore, we also integrated our reader software with Microsoft SQL Server. Fig. 24 shows the entire system and where the database schema fits into this system. In the current database design, each RFID tag is associated with exactly one traffic asset (i.e., sign, guard rail). Tables 11A & 11B show the database schema with one example record in each table.

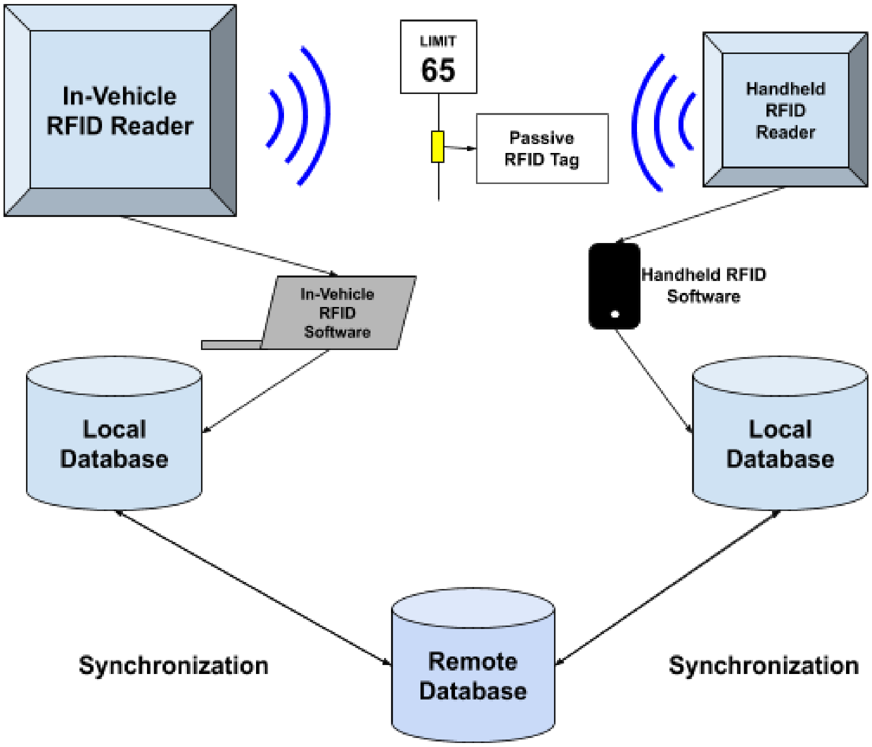


Fig. 24: RFID System

Table 11a: RFID Table

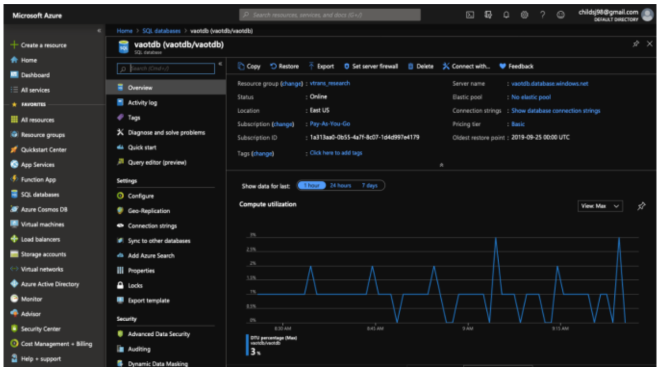
epc	manufacture date	installation date	asset id	comments
56414F5400000000000000000000000001	2019-03-05T00:00:00.0000000	2019-07-04T00:00:00.0000000	3	Field Test Tag 1, white

Table 11b: Asset/Sign Table

Street name	twn_mi	sign_age	sign_width	sign_height
I-89	178.009	null	36	35

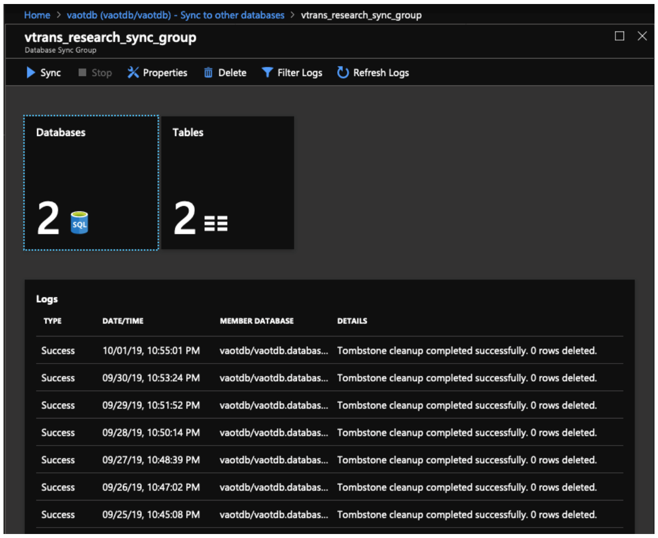
Table11b: A brief version of Asset table in the database schema where many attributes have been omitted for brevity.

Lack of internet connectivity is common in many areas of Vermont. Therefore, connection with remote database is not always possible. To address this issue, tag data are saved locally on the reader and are synchronized with a remote database when Internet connection is reestablished. There are two techniques we have used for synchronization. One is to use SQL Server replication utilities to distribute and copy data from one database to another. Each time a modification is made to one database, the change is logged and then copied to each database in the replication topology. The other is to use Microsoft Data Sync in Azure. Using Azure SQL Sync tools, we create a process that synchronizes a remote database and a local database every 5 minutes. This means that when changes are made to either local or remote database, the two databases will be kept consistent every 5 minutes with an automated Transact-SQL process upon stable connection between them. Fig. 25a shows the Azure SQL Sync dashboard displaying the diagnostics for our remote server instance in real time, thus providing access to our database so we can monitor the synchronization process efficiently. Fig. 25b shows the Azure SQL Sync dashboard displaying the synchronization process for the two tables (RFID and Asset/Sign) between the local database and the remote database; it is specifically displaying individual requests sent back and forth between the local and remote databases.



Resource group (change) : vtrans_research
Status : Online
Location : East US
Subscription (change) : Pay-As-You-Go
Subscription ID : 1a313aa0-0b55-4a7f-8c07-1d4d997e4179
Tags (change) : Click here to add tags
Server name : vaotdb.database.windows.net
Elastic pool : No elastic pool
Connection strings : Show database connection strings
Pricing tier : Basic
Oldest restore point : 2019-09-25 00:00 UTC

(a)



Logs

TYPE	DATE/TIME	MEMBER DATABASE	DETAILS
Success	10/01/19, 10:55:01 PM	vaotdb/vaotdb.databas...	Tombstone cleanup completed successfully. 0 rows deleted.
Success	09/30/19, 10:53:24 PM	vaotdb/vaotdb.databas...	Tombstone cleanup completed successfully. 0 rows deleted.
Success	09/29/19, 10:51:52 PM	vaotdb/vaotdb.databas...	Tombstone cleanup completed successfully. 0 rows deleted.
Success	09/28/19, 10:50:14 PM	vaotdb/vaotdb.databas...	Tombstone cleanup completed successfully. 0 rows deleted.
Success	09/27/19, 10:48:39 PM	vaotdb/vaotdb.databas...	Tombstone cleanup completed successfully. 0 rows deleted.
Success	09/26/19, 10:47:02 PM	vaotdb/vaotdb.databas...	Tombstone cleanup completed successfully. 0 rows deleted.
Success	09/25/19, 10:45:08 PM	vaotdb/vaotdb.databas...	Tombstone cleanup completed successfully. 0 rows deleted.

(b)

Fig. 25 a) The Microsoft Azure SQL Server portal showing the diagnostics for our remote server instance in live time. b) Microsoft Azure SQL Server Sync dashboard showing the synchronization process for the two tables in our database schema RFID Tag and Asset (Sign) tables.

Our own customization of the URA also included a more comprehensive database access and modification scheme of synchronization between a local database and a remote database. A local database is managed by Microsoft SQL Server and is automatically synchronized with a remote SQL database located on a Microsoft Azure cloud server. Using Azure SQL Sync tools, we create a process that synchronizes the two databases every 5 minutes. This means that when changes are made to either the remote database or the local database, they will be kept consistent every 5 minutes with an automated Transact-SQL process upon stable connection between them. This mechanism leaves room for merge conflicts between remote database and local database. Currently, we use a "member-win" rule to resolve such a conflict, where a local database overrides any conflicting changes detected during the sync process.

Integration with ArcGIS REST API

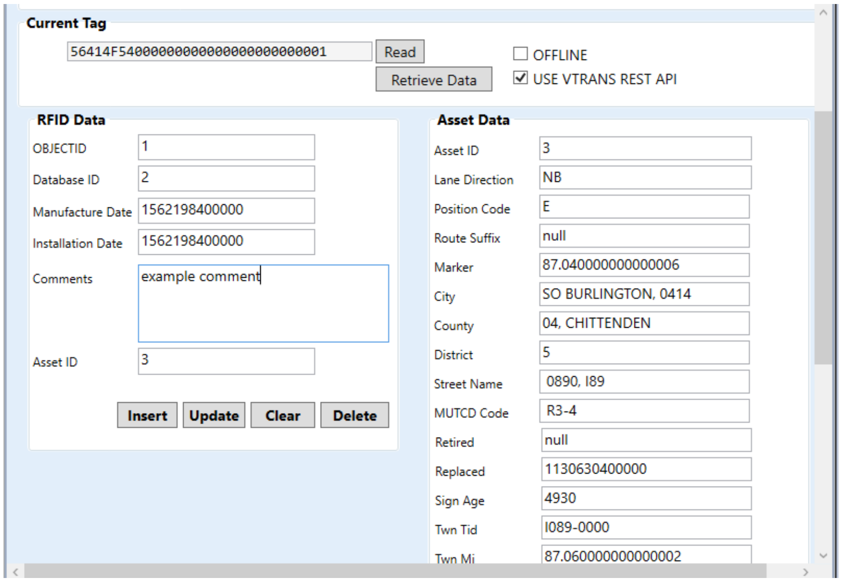
The existing RFID application built using the Mercury API in C#/.NET adopts Microsoft SQL Server for demonstrating database functionality. In order to preserve the potential for portability with SQL Server, we create the option to use either the "native" SQL Server backend, or the VTrans REST API Endpoint. Therefore, our previous work remains intact for potential use cases. Here is the REST API endpoint:

https://maps.vtrans.vermont.gov/arcgis/rest/services/AMP/Asset_Signs_RFID/FeatureServer

VTrans Server

In order to begin interfacing with the VTrans server, we used the documentation provided on the VTrans server (the link to the server end point is shown above). VTrans is currently using the ArcGIS REST API for this purpose. Staff members from the VTrans team assisted us creating an exact copy of our proposed database schema on the VTrans server. The tables are located inside a Feature Service titled "Asset_Signs_RFID". A Feature Service can contain datasets with or without spatial information. Since RFID tags have not been actually deployed to permanent locations, their database does not contain any spatial information in the Feature Service. The database currently contains one table for Signs and one table for RFID tags. The Signs table contains VTrans-provided data while the RFID table contains records associated with a real test set of RFID tags we keep at UVM.

In order to connect the application to the VTrans server, the application's various functionalities need to be connected to the respective REST API calls. In order to retrieve data for a specific RFID tag being read by the RFID reader, a GET request is made using the correct syntax and correct endpoint URL. The EPC of the tag is used as the defining parameter in the GET request. For both the RFID tag table and Signs table, the "query" route is used. There are many parameters available to execute a query using the ArcGIS REST API; among them, the most straightforward ones. In this project are: Where, Object IDs, and Out Fields. Fig. 26 shows the user retrieving data for a specific RFID tag.



Current Tag

56414F540000000000000001

☐ OFFLINE
☑ USE VTRANS REST API

RFID Data

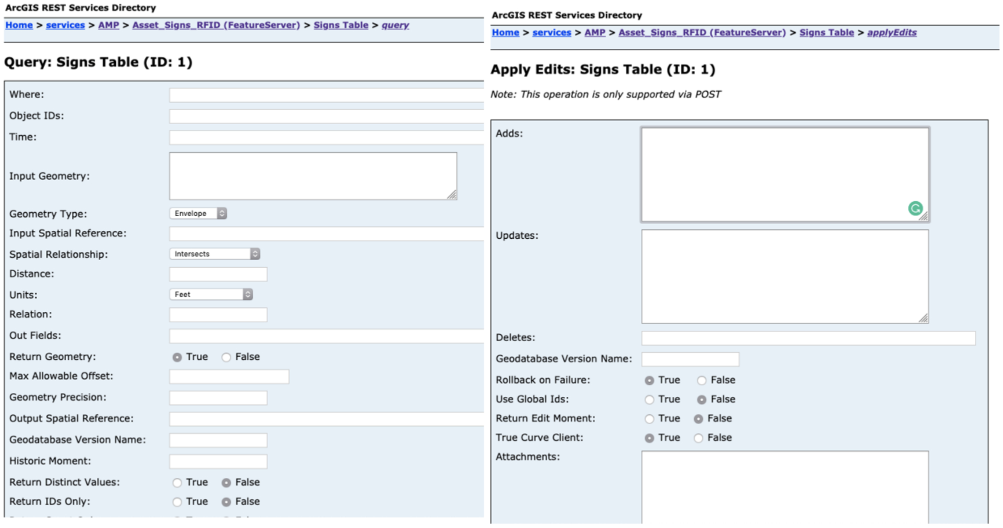
OBJECTID: 1
Database ID: 2
Manufacture Date: 1562198400000
Installation Date: 1562198400000
Comments: example comment
Asset ID: 3

Asset Data

Asset ID: 3
Lane Direction: NB
Position Code: E
Route Suffix: null
Marker: 87.040000000000006
City: SO BURLINGTON, 0414
County: 04, CHITTENDEN
District: 5
Street Name: 0890, I89
MUTCD Code: R3-4
Retired: null
Replaced: 1130630400000
Sign Age: 4930
Twn Tid: I089-0000
Twn Mi: 87.060000000000002

Fig. 26: Retrieving Data with from VTrans Server via REST API Call

In its current state, when a user scans a tag and clicks the “Retrieve Data” button while in VTrans REST API Mode, the application generates a proper GET Request using JSON as the format type. The rest API endpoint contains HTML Forms which represent request format. They are shown in Fig. 26 for reference. For clarification, Fig. 27 shows an HTML Form representation of the requests the UVM Application is autogenerating upon user input. Keep in mind, some of the fields shown are not required and are irrelevant for this project. There are HTML Form representations for all possible requests which come in handy for testing functionality and syntax.



ArcGIS REST Services Directory

Home > services > AMP > Asset_Signs_RFID (FeatureServer) > Signs Table > *query*

Query: Signs Table (ID: 1)

Where:
Object IDs:
Time:
Input Geometry:
Geometry Type: Envelope
Input Spatial Reference:
Spatial Relationship: Intersects
Distance:
Units: Feet
Relation:
Out Fields:
Return Geometry: ● True ○ False
Max Allowable Offset:
Geometry Precision:
Output Spatial Reference:
Geodatabase Version Name:
Historic Moment:
Return Distinct Values: ○ True ● False
Return IDs Only: ○ True ● False

ArcGIS REST Services Directory

Home > services > AMP > Asset_Signs_RFID (FeatureServer) > Signs Table > *applyEdits*

Apply Edits: Signs Table (ID: 1)

Note: This operation is only supported via POST

Adds:
Updates:
Deletes:
Geodatabase Version Name:
Rollback on Failure: ● True ○ False
Use Global Ids: ○ True ● False
Return Edit Moment: ○ True ● False
True Curve Client: ● True ○ False
Attachments:

Fig. 27: HTML Form Representation of Query HTTP Request on VTrans Server

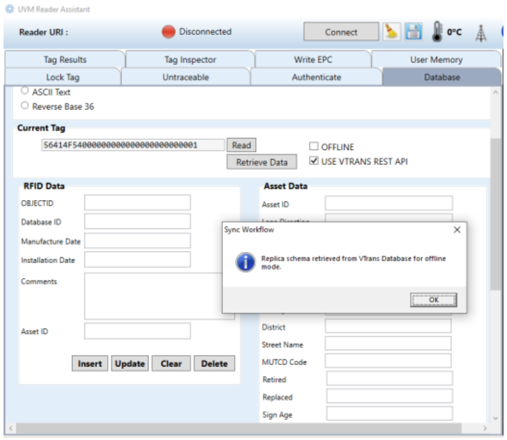
In order to manipulate the data on the server, the “applyEdits” route is utilized using a POST request. Applying edits is packaged in the form of ‘adds’, ‘updates’, and ‘delete’. Each of these functionalities require specific format and syntax in the form of a JSON object that specifies the object needing to be edited and the edits needing to be made. For multiple edits, these JSON objects can consist of multiple arrays, therefore it is important to provide the proper syntax as these objects can become quite complex. For clarity, Figure 23 shows the applyEdits route in an HTML Form so that the parameters can be easily visualized. If users want to insert, update, or delete either a sign or tag in the database, they can click on the respective buttons in the GUI.

Synchronization prototype

In order to synchronize a client with the VTrans Server, the ArcGIS REST API Sync protocol is used. The Sync protocol is well documented in the ArcGIS REST API documentation. There are three stages to this sync protocol which have been implemented within the UVM RFID Application in its current state. These three stages are i) create replica, ii) synchronize replica and iii) unregister replica. Each of these stages has its own unique route in the VTrans server.

Creating a replica involves submitting a POST request specifying which dataset is to be replicated on the client. For our purposes, we request the replicas in JSON format. Upon submitting the POST request, a full replica of the database and its records can be downloaded via a GET request from the URL provided in the create replica response. For best performance, the application should be configured to create a replica of the database on the server periodically while it has internet connection. In its current state, the UVM application polls for Internet connection and downloads a JSON replica to store in local storage.

When the client goes offline, all requests and manipulation of data must go through the replica stored locally in the form of a JSON object. When the client regains Internet connection, it sends a POST request to the synchronize replica route, which combines the edits made from the client with the edits made on the server while the client was offline. The server then updates the replica with all edits and the client can redownload for the same process. At the end of a cycle, the replica can be unregistered with the unregister replica route. Replicas can also be named and continuously used due to its continuously updating Replica ServerGen (server generation) which gets updated after each synchronization process. Fig. 28 shows an example of the UVM application creating a replica upon Internet connection.



UVM Reader Assistant

Reader URI : ● Disconnected

Current Tag: 56414F54000000000000000000000001

☐ OFFLINE

☑ USE VTRANS REST API

Sync Workflow

Replica schema retrieved from VTrans Database for offline mode.

Fig.28: Creating a replica upon Internet Connection

6. Integrated System Field Test

Task 8: Perform field tests and debug the RFID system.

Field Test Results

To evaluate the system performance, the field tests were conducted on different roads. In the following, these road test results are reported.

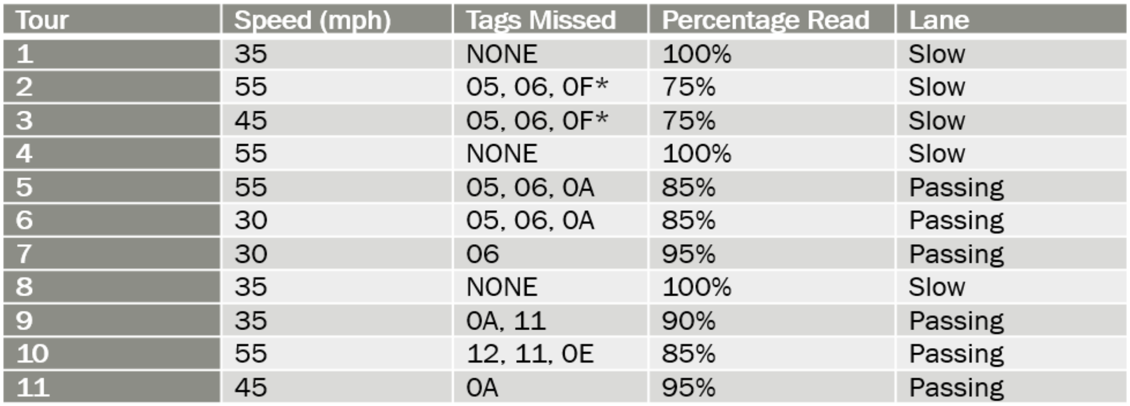
VT State Route 63 Road Test

The test was performed on Vermont State Route 63 (Fig. 29) on July 19, 2019, where an in-vehicle reader continuously read from tags attached to signs and guard rails nearby while the vehicle was running. A total of 20 RFID tags were deployed on traffic signs and guard rails (Fig. 29). Specifically, 5 tags were mounted on the metal pole of a traffic sign at different heights 45, 48, 52, 58 and 61 inches, and 2 tags were mounted on each guard rail, one at each end. Additionally, the test crew stepped out of the vehicle and walked to signs to read tags using a handheld reader. The in-vehicle reader was powered from a 9V DC outlet built inside the vehicle and was connected to two antennas mounted on a physical structure at approximately 52 inches above ground. The vehicle was driven in two lanes (slow lane and passing lane) such that the distance from the antennas to the traffic signs was at least 4ft in the slow lane and 16ft in the passing lane.

Fig. 29. VT State Route 63 field test

In another test, the RFID tags were mounted on the signs across the road. The distance from these tags to the in-vehicle RFID reader antenna was over 34 ft. All the test results are summarized in table 12.

Table 12 Field test results



Tour	Speed (mph)	Tags Missed	Percentage Read	Lane
1	35	NONE	100%	Slow
2	55	05, 06, 0F*	75%	Slow
3	45	05, 06, 0F*	75%	Slow
4	55	NONE	100%	Slow
5	55	05, 06, 0A	85%	Passing
6	30	05, 06, 0A	85%	Passing
7	30	06	95%	Passing
8	35	NONE	100%	Slow
9	35	0A, 11	90%	Passing
10	55	12, 11, 0E	85%	Passing
11	45	0A	95%	Passing

Catamount Drive Tests

This road test was performed at Catamount Dr. on UVM campus. 12 RFID passive tags were deployed (Fig. 30). We placed tags in various locations on both signs and guard rails. The parameters were fine-tuned to achieve 100% reading rate for all tags deployments. The equipment used are list in Table 13.

Table 13. new part list

Device	Part number
RFID reader	Thingmagic IZAR
Linear antenna	MTI MT-263003
Circular antenna	MTI MT-242043
RFID tags	Omni-ID Flex 1200
	Omni Exo 750

Fig. 30: Map of Catamount Drive

Using the mechanical structure shown in Fig. 31, three antennas were attached on the side of our test vehicle. Among these three antennas, two antennas are the side are circular polarization antennas and the antenna in the middle is a linear polarization antenna. The antenna mounting structure is attached to the roof rack of the vehicle. Two circular polarization antennas were mounted at the height of 52 inches above the road surface and angled at 45 degrees in opposite directions, and a linear polarization antenna was placed between two polarization antennas and its mounting height is 60 inches.

Fig. 31: Antenna placement

Tags deployment

We placed tags on different road signs and guardrails on the Catamount Drive test site (see Fig. 32). Each tag was encoded with a special hexadecimal code so that we could use tag filtration during our road tests. An example code is 56414F540000000000000000000000, which is contains the prefix VAOT in hexadecimal followed by an incremented value. Table 14 shows the placement of individual RFID tags that were used. (For brevity, we have shortened the ID's in Table 14 to display only the last two hexadecimal digits in each EPC.) The distance of each tag is the approximate range from the vehicle to the sign the tag is mounted on. To achieve optimum reading performance, we made multiple test runs while adjusting the tag mounting positions.

Table 14. RFID tag deployment details

EPC ID (hex)	Tag Type	Height (in.)	Distance (feet)
01	Omni-ID Flex 1200	48	14
04	Omni-ID Flex 1200	68	14
05	Omni Exo 750	55	14
06	Omni Exo 750	49	16
07	Omni Exo 750	53	16
09	Omni Exo 750	50	24
0B	Omni Exo 750	58	34
0C	Omni Exo 750	35	4
0F	Omni Exo 750	36	4
10	Omni Exo 750	52	34
12	Omni Exo 750	52	24
13	Omni Exo 750	54	24

Fig. 32: Passive tags placement

11 tests were performed at different vehicle driving speeds. In addition, the number of antennas connected. The results are shown in **Table 15.** Each test, we performed 3-4 "tours". The percentage read is the percentage of tags read out of the total number of tags averaged amount all tours. Note that, not all 12 tags are placed in every tour, tags that never missed are skipped in the last few tests.

Table 15 Tour results from reading tags from within a vehicle on one side of the road.

Trail	Speed (mph)	Tags Missed *	Percentage Read	Antennas configuration
1	15	0B	91.67%	2 circular polarization
2	25	0B	91.67%	2 circular polarization
4	35	04,0B, (10,12)	77.78%	2 circular polarization
5	20	0C	91.67%	1 linear polarization
6	25	0C, (0F)	86.11%	1 linear polarization
7	35	0C,0F, (0B)	77.78%	1 linear polarization
8	20	None	100%	2 Cir. Pol. and 1 lin. Pol.
9	25	None	100%	2 Cir. Pol. and 1 lin. Pol.
10*	35	0B	86.11%	2 Cir. Pol. and 1 lin. Pol.
11*	35	None	100%	2 Cir. Pol. and 1 lin. Pol.

**For Test 10 and Test 11, the tags mounting positions were adjusted*

In the test, to optimize reading performance, we changed the reader's response time length. In the reader scan test, when there is a single antenna, the reader operates in the continuous reading mode. However, when there are multiple antennas, the reader must switch the reading operation among different antennas, where each antenna is assigned a limited time duration to complete the read and then switch to the next antenna. The system's default "switching time" is 1000ms, which means each antenna is allocated 1000 ms /scan reading time before another antenna is switched in. In this test, there are 3 antennas connected. To leverage antenna response speed, we change the switching time to the shortest possible value of 1ms. Therefore, when multiple antennas are used, they alternate readings in equal increments of 1ms.

As shown in Table 15, by changing the number of antennas, an improvement could be observed in the percentage of tags were read. The tags placement shown in table 14 was used, and the average distance of placement was 30 ft. Tags 0B and 10 were placed at the furthest range (30ft) in the test, and they can be detected only by the linear polarization antenna. Tags 0C and 0F were mounted on the guardrail could be detected mostly by the circular polarization antennas. Using a combination of the circular and linear polarization antennas, all tags could be detected most of the time. It is also important to notice that tags 13, 12, and 09 were placed on the same pole, each tag represents an individual traffic sign respectively. And this multiple-tag group was successfully read 100% of the time with an average RSSI of -66.

7. Conclusions

This report summarizes the RFID-based traffic sign inventory management system developed with the goal of integrating in-vehicle RFID readers and handheld RFID readers through an asset database to achieve high performance and efficiency in tag reading and memory usage and non-stop consistency in data management. It is designed using commercial/off-the-shelf technologies in hardware and software, thereby ensuring ease of maintenance by the users. Stepping up from other works in the literature that showed the promise and viability of RFID technology in transportation asset management, our system provides integrated, comprehensive, and efficient solutions to practical problems arising with a large-scale deployment in various environmental and operational conditions.

Our system can be applied not only to traffic signs but also to many other transportation assets management, including, for example, construction site equipment, materials, and personnel management. Further, its impact in the future can go beyond inventory management once scaled up and being integrated into the Internet of Things (IoT) environment. For instance, in-vehicle RFID reading can enable smart driverless car technology where detecting signless tags for autonomous vehicle navigation.

Note, for vehicle-based RFID scanning, the VTrans expectations are to achieve 60 feet distance and 50 mph speed of data collection. However, this study reveals that based on current available RFID technology, it is not feasible to achieve such specifications. Using passive RFID tags, we are only able to achieve 100% scan rate at maximum 35 mph speed and 30 feet distance. If the scan is conducted at a higher driving speed and a farther distance, the RFID tag read rate will decrease. To achieve faster speed and farther distance scan without degrading read rate, the possible solutions are to increase RFID reader transmission power and antenna gain which will be investigated in future research.

Appendix: **Deliverable 9: RFID Technologies for Statewide Traffic Signage Management**

Introduction

This report shows detailed documentation for the proposed integrated radio-frequency identification (RFID) system. RFID reader and central computer hardware are integrated together with proper interface connections and signaling. The proposed system consists of RFID-based traffic sign detection units on the frontend and a database in the backend. The traffic sign detection and data processing are accomplished by the in-vehicle reader and an optional handheld reader concurrently while independently accessing their own local databases and synchronizing with a common remote database in the cloud.

In the current solution, the software comprises an in-vehicle RFID reader software (called the “UVM Reader Assistant”, modified from Jadak’s Universal Reader Assistant) and an optional handheld RFID reader/writer software. The in-vehicle reader can read RFID tags mounted on the poles of traffic signs at various heights and angles. Two types of readers, in-vehicle RFID reader and hand-held reader, are connected through separate software programs that (i) display relevant tag and asset data on the screen and (ii) connect them to a remote shared database, which is synchronized with local copies of the database on the readers whenever wireless communication connectivity is established. The developed system can serve different scenarios of RFID tag-based signage management efficiently and is resilient to intermittent and unexpected interruptions to database connectivity that is common in rural area as well as in urban environments.

Software

In-Vehicle Reader & Software Setup

Software will be provided via direct file transfer. This documentation is made with the IZAR RFID reader as its reader of choice, but there are other readers than can be configured with this software, some of which can be found at https://www.jadaktech.com/.

To make the required physical connections to the reader:

1. Attach RF cable to the “1” port of the reader, and to the antenna as shown in Figure 2.
2. Attach the LAN cable to the reader LAN/POE connector and to the network or directly to the PC. Note that a cross-over cable is not needed.

Figure 1: Antenna Port

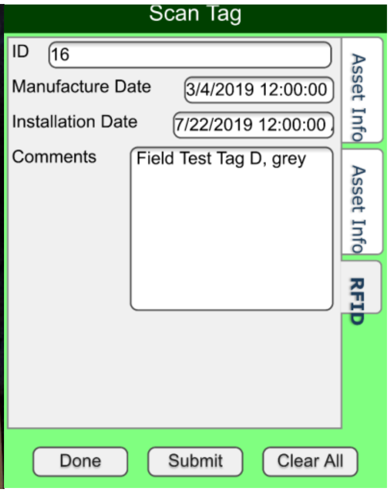
Figure 2: Power & LAN

Figure 3: LED

3. Connect the 24V DC power adapter to the IZAR Reader DC9-30V connector. Install the correct prong assembly for your AC service onto the adapter and plug it into an AC outlet. WARNING -Powering the reader with a USB cable is not supported. When the multicolor LED to the right of the USB HOST connector turns green (Figure 3), the reader has obtained a network address from the network's DHCP server or negotiated one with your PC. This can take several minutes.
4. Open application files provided by UVM team for Universal (UVM) Reader Assistant. The Izar reader is a Network reader, be sure to use to wizard to connect to the Network reader.
5. Upon connection, head to the tag results Tab and use the "Read" button to start the reading process. Tags picked up by the reader should populate the Tag Results Grid.
6. For additional setup, refer to the Universal Reader Assistant User Guide provided by the company Jadak on their website provided above.

Handheld Reader & Software Setup

For this project we used the Zebra RFD8500 RFID reader. In order to connect to connect to iPad or another other mobile device we used a software called TracerPlus. The documentation for the TracerPlus software can be found at these two links below. Manual connection to device is made simple via a Bluetooth connection, make sure your device has Bluetooth connectivity and make sure it is turned on beforehand.
TracerPlus Desktop: Desktop application to create mobile RFID software applications
https://www.tracerplus.com/sites/default/files/TracerPlusDesktop_UserGuide.pdf
TracerPlus Connect: Made to create, manage, and synchronize mobile RFID operations.
https://www.tracerplus.com/sites/default/files/TPConnect_UserGuide.pdfWe have created a sample TracerPlus application on the VTrans iPad. Here are some screenshots for workflow:



Scan Tag

ID: 16
Manufacture Date: 3/4/2019 12:00:00
Installation Date: 7/22/2019 12:00:00
Comments: Field Test Tag D, grey

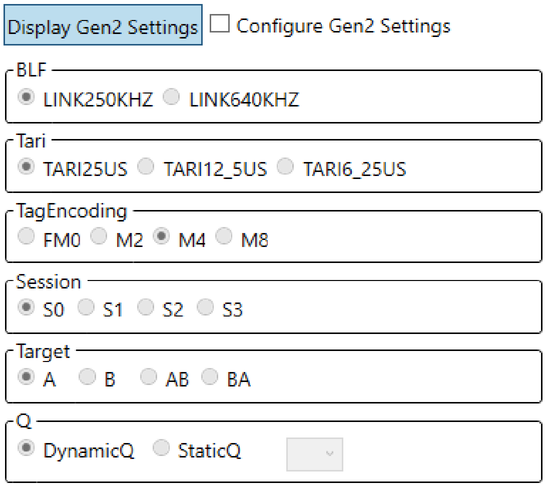
Scan Tag

Retired: 0
Replaced: 12/30/1999 12:00:00 AM
Sign Age: 6979
TWN_TID: U00-0405
TWN_MI: 6.681
QCFLAG: 0
MIN_TWN_FM: 0
MAX_TWN_FM: 6.96
SR_SID: US-7
Sign Height: 30
Sign Width: 30

Performance Tuning (Gen2 Protocol)

The Gen2 protocol is standard for RFID tag systems. For use case, the UVM Reader assistant has been programmed with default settings to fit the use case of the Vermont Department of

Transport. Therefore, the below technical detail is simply for reference if the parameters of the software need to be adjusted for unique circumstances. Below is an image of the In-Vehicle Reader software Gen2 settings adjustments, found in the Settings panel.



Display Gen2 Settings ☐ Configure Gen2 Settings

BLF
● LINK250KHZ ○ LINK640KHZ

Tari
● TARI25US ○ TARI12_5US ○ TARI6_25US

TagEncoding
○ FM0 ○ M2 ● M4 ○ M8

Session
● S0 ○ S1 ○ S2 ○ S3

Target
● A ○ B ○ AB ○ BA

Q
● DynamicQ ○ StaticQ

Gen2 Settings UVM Reader Assistant

BLF: Backscatter Link Frequency, used specifically for tag-to-reader communications (not reader-to-tag). This is known as the raw signaling rate and there are two options for the Izar Reader.
250KHZ - default
640KHZ.

Tari: Controls Tari (and link rate) value used for reader-to-tag communications, affects "link rate". Options are shown as Tari – Link Rate. Only has major effects if tags are being written to. Decreasing Tari(increasing link) better for large write operations to tags. Increasing Tari reduces interference with other RFID readers. Does not have an effect on simple read operations.
6.25usec – 40kbps
12.5usec – 80kbps
25usec – 160kbps (default)

Tag Encoding (aka Miller options): Used in conjunction with **BLF** to control tag-to-reader communication. This controls how many times a signal is repeated. Therefore, M2 means each signal is repeated twice. This maximizes the chances of reading a very weak signal.
Session: Controls session that tag read operations are conducted in. Along with **Target** and **Q**, this control how soon, and how often, a tag responds to a reader.
S0 – Prepare to respond again as soon as RF power drops.
Recommended Tag Population: up to 100 tags
S1 – Prepare to respond again between 0.5 and 5 seconds after first response.
Recommended Tag Population: up to 400 tags
S2 – Do not respond again for at least 2 seconds.
Recommended Tag Population: more than 400 tags

S3 – Do not respond again for at least 2 seconds. *****
Recommended Tag Population: more than 400 tags

*S2 and S3 are identical

Target: Used to force tags to respond more often than they would otherwise, tags are flagged A and B according to read protocol, which is automatically set by the Reader.
A : "A" means that the reader always looks for tags in the "A" state.
A → B : (named in URA as AB, pronounced A then B) "AB" tells the reader to read all tags in the "A" state, then read all the tags in the "B" state. Tags read in "B" state immediately return to "A" state after read.

Q: Controls whether the reader uses a dynamic, reader controlled, "Q" algorithm or uses a static, user defined value. It is defined as the *number of response opportunities (aka "slots") the reader will give to a population of tags.* The number of "slots" is 2^Q. At most 2^15 = 32,768 slots
DynamicQ
StaticQ (int between 0 – 15)
Note: If "Q" is too large, processing could take too long due to slots being "unfilled". If "Q" is too small one or more tags will be more likely to respond in the same slot, resulting in missed tags. Ideal number of slots is determined to be **1.5 times the number of tags in the field.**

Recommendations & Deployment Estimations

Summary: This document gives estimates on the resources required to implement a full-fledged RFID system for more than 1,000 signs. The estimate varies depending on the availability and quality of the existing sign asset data in the VTrans database.
Successful RFID deployment would involve the following steps.

1) Purchase items listed in Table 1.

Assign tags to signs based on their IDs (assuming tags are pre-encoded in the desired EPC ID format at the time of acquisition).

2) Organize database tables for sign data and tag data.
3) Deploy tags on signs following guidelines. (We will provide separate guidelines for hardware/software setup.)
4) Test the deployment.

Note:

- In step 3, the physical orientation and position of RFID reader's antennas and RFID tags should be adjusted according to the guidelines to improve tags successful reading rate.

Table 1. Items to be purchased for RFID tag deployment.

Item	**Cost**
RFID tags (Omni ID Exo 750)*	$2.36 per tag (for purchasing 5000 tags)
RFID reader/antennas	$2,000-3,000
Mechanical structure	$500

Table 2. Estimate of deployment cost under different scenarios

Scenario	Existing Data	Steps to Deploy Traffic Signs with RFID Tags	Cost Estimate $^{(1)}$
1. A brand new road: New traffic signs and RFID tags will be deployed	No *physical signs* on site or no sign data in the database.	1) Build the inventory database with data about signs and tags stored in the Signs table and the Tags table, respectively. (Leave the sign location field in the Signs table empty.) Store the sign data records grouped by the sign type. 2) Write an EPC ID to each RFID tag. 3) Attach RFID tags on the assigned sign poles before site deployment. Link each tag data record in the Tags table to the assigned sign data record in the Signs table. 4) Deployment traffic signs along the road. eploy signs with the attached tags in the field. 5) Drive in the field and scan the RFID tags with an in-vehicle RFID reader. The location data (i.e., GPS coordinates) will be automatically captured and written to database according to the respective tag ID.	1) The inventory database will be created for the new traffic signs and the new road based on VTrans GIS structure and requirements. Time cost: TBD. Should be less than a few hours. 2) Writing an EPC ID to each tag can be done by the RFID manufacturer during the fabrication. The coding scheme is provided by the user, i.e. VTrans. based on traffic sign types and numbers. Pre-programming by RFID vendor can alleviate VTrans effort and time. For some traffic signs/tags that require special handling, users can use handheld RFID reader to generate EPIC codes and program the tags. Tags for different types of signs will be grouped and saved. For instance, "Stop" sign tags are saved together in one group, " X mph" speed limit sign tags are saved together in another group. Time cost: If the coding is done by RFID tag manufacturers, it does not cost VTrans time and effort. The manual programming is only needed occasionally for special requirements. It is estimated that the manual programming method should not take more than 1 minute for a tag. For a traffic sign, the tag from the corresponding type group is selected for installation. For instance, for a "Stop" sign, an RFID

			tag from the "Stop" group is selected for mounting. 3) For the database, assuming traffic signs are new signs ordered from the same vendor, thus the same types of signs should have the same basic attributes, such as manufacturer name, date of manufacturing, except EPC ID. The database can be populated easily with these same attributes while with different EPC IDs. The deployment location attributes are left blank and will be filled up upon deployment. Time cost: As the basic information for all new signs are identical. Populating the database can be done automatically through database programming. Nearly zero-time cost. 4) Carry the traffic signs (mounted with RFID tags) to the site and have the traffic signs deployed along the road. Time cost: Deployment time should be the same as it takes for deploying regular traffic signs. This step should not be considered as an additional overhead as traffic signs deployment should be done anyway for a new road regardless whether RFID tags are used or not. 5) In-vehicle RFID reader and antennas are mounted on the survey truck. The survey truck will carry in-vehicle RFID reader, antennas, and GPS to perform scans. When the RFID tag on traffic sign is activated, the tag's EPC ID is read by the RFID reader which automatically searches for the

			corresponding traffic sign/RFID record in the database. In the meantime, the GPS is triggered to record the coordinates which are saved in the database as traffic sign's location attribute. Time cost: This is determined by the performance of RID reader performance. Through experiments, it is verified to achieve 100% RFID tag interrogating rate, the truck driving speed should not be higher than 30 mph.
2 Existing roads have traffic signs deployed on site however there exists no traffic sign information or record.	Build a database to inventory the existing physical signs.	1) Investigate the area and record the signs amount and types. 2) Build the inventory database with data about signs. (Leave the sign location field and linked sign ID field empty.) 3) Write an EPC ID to each RFID tag. (Done by the RFID tag manufacturer.) 4) Work in the field to attach the tags on the sign pole according to the sign type. 5) Drive in the field and scan the RFID tags with an in-vehicle RFID reader. The location data (i.e., GPS coordinates) will be automatically captured and written to database according to the respective tag ID. 6) Add additional information for traffic signs in the database.	1) To inspect the road and check the traffic signs' basic information, i.e. types, numbers, etc. Time cost: Depending on the road length and the number of traffic signs. This inspection could take several days. 2) The inventory database will be created for these existing traffic signs. The database structure should be designed based on VTrans GIS structure and requirements. All attributes are left blank as RFID tags have not been mounted on traffic signs yet. Time cost: TBD. Should be less than a few hours. 3) Writing an EPC ID to each tag can be done by the RFID manufacturer during the fabrication. The coding scheme is provided by the user, i.e. VTrans. based on traffic sign types and numbers. Pre-programming by RFID vendor can alleviate VTrans effort and time. For some traffic signs/tags that require special handling, users can use handheld RFID reader to generate EPIC codes and program

			the tags. This manual programming method should not take more than 1 minute for a tag. Tags for different types of signs will be grouped and saved together. For instance, "Stop" sign tags are saved together in one group, " X mph" speed limit sign tags are saved together in another group. Time cost: If the coding is done by RFID tag manufacturers, it does not cost VTrans time and effort. The manual programming is only needed occasionally for special requirements. It is estimated that the manual programming method should not take more than 1 minute for a tag. 4) On site (road), the RFID tags will be mounted on traffic signs (poles). For mounting, RFID tags will be screwed on traffic sign poles. Time cost: Each mounting takes 1 ~ 2 minutes. 5) In-vehicle RFID reader and antennas are mounted on the survey truck. The survey truck will carry in-vehicle RFID reader, antennas, and GPS to perform scans. When the RFID tag on traffic sign is activated, the tag's EPC ID is read by the RFID reader, which automatically create a new record in the database with EPC ID populated. In the meantime, the GPS is triggered to record the coordinates which are saved in the database as traffic sign's location attribute with the same EPC ID. Time cost: This is determined by the performance of RID reader performance. Through

			experiments, it is verified to achieve 100% RFID tag interrogating rate, the truck driving speed should not be higher than 30 mph. 6) In the database, if additional information of the traffic signs is available, the corresponding attributes in the database can be populated. Time cost: TBD
3 Existing roads have traffic signs deployed. There is a database recording traffic sign information however the information is incomplete.	Inventory the existing physical signs according to the existing record.	1) Investigate the area and record the signs amount and types. Add a temporary ID (using a mark pen) to label each sign (by its sign ID in the record or database). 2) Write an EPC ID to each RFID tag. (Done by the RFID tag manufacturer.) 3) Link a tag ID with each sign. Label the physical tags with their linked sign ID. 4) Work in the field to attach tags on the signs pole. The label on the sign should be matched with the label on the tag. 5) Drive in the field and scan the RFID tags with an in-vehicle RFID reader. The location data (i.e., GPS coordinates) will be automatically captured and written to database according to the respective tag ID. 6) Add additional information for traffic signs in the database.	1) Doing site inspection and adding temporary IDs on traffic signs. This will allow linking the signs with their record items in the database. Time cost: Depending on the road length and the number of traffic signs. This inspection could take several days. 2) Writing an EPC ID to each tag can be done by the RFID manufacturer during the fabrication. The coding scheme is provided by the user, i.e. VTrans. based on traffic sign types and numbers. Pre-programming by RFID vendor can alleviate VTrans effort and time. For some traffic signs/tags that require special handling, users can use handheld RFID reader to generate EPIC codes and program the tags. Time cost: If the coding is done by RFID tag manufacturers, it does not cost VTrans time and effort. The manual programming is only needed occasionally for special requirements. It is estimated that the manual programming method

			should not take more than 1 minute for a tag. 3) On the surface of RFID tag, adding the same temporary ID as the one on traffic signs 4) Mount the RFID tags on traffic signs (poles). Match IDs on RFID tag and traffic sign. Time cost: Each mounting takes 1 ~ 2 minutes. 5) In-vehicle RFID reader and antennas are mounted on the survey truck. The survey truck will carry in-vehicle RFID reader, antennas, and GPS to perform scans. When the RFID tag on traffic sign is activated, the tag's EPC ID is read by the RFID reader, which automatically point to the record in the database with the same EPC ID. In the meantime, the GPS is triggered to record the coordinates which are saved in the database as traffic sign's location attribute with the same EPC ID. Time cost: This is determined by the performance of RID reader performance. Through experiments, it is verified to achieve 100% RFID tag interrogating rate, the truck driving speed should not be higher than 30 mph. 6) In the database, if additional information of the traffic signs is available, the corresponding attributes in the database can be populated. Time cost: TBD

Note:
(1) The Time Cost Estimate in Table 2 does not consider the travel time among traffic signs.

(2) The data entry cost for new site is minimum. For new site, assume all traffic signs are obtained from the same vendor, the basic information of all traffic signs should be identical, therefore the date entry can be programmed for automation. The manual data entry will be mainly involved for establishing new record or attribute for old traffic signs that are not in inventory.

(3) For vehicle-based RFID scanning, the VTrans expectations are to achieve 60 feet distance and 50 mph speed of data collection. However, this study reveals that based on current available RFID technology, it is not feasible to achieve such specifications. Using passive RFID tags, we are only able to achieve 100% scan rate at maximum 35 mph speed and 30 feet distance. If the scan is conducted at a higher driving speed and a farther distance, the RFID tag read rate will decrease. To achieve faster speed and farther distance scan without degrading read rate, the possible solutions are to increase RFID reader transmission power and antenna gain which will be investigated in future research.