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Roadside Truck Placard Readers for Advanced Notice and Response at Safety-Critical Facilities: Phase 2

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Final Report VTRC 23-R18

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Roadside Truck Placard Readers for Advanced Notice and Response at Safety-Critical Facilities: Phase 2

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Abstract:

The transport of hazardous and dangerous materials (HAZMAT) through safety-critical facilities poses significant risk to overall system reliability should those assets be incapacitated by the occurrence of a related incident. This problem is particularly acute for facilities in remote locations such as Virginia's mountain tunnels on Interstate 77 (I-77) due to limitations on alternate routes and the availability and proximity of emergency responders and specialized equipment/supplies. Automated placard reader systems (APRSs) are commercially available camera-based computer vision systems that "read" hazardous material placards on passing trucks from roadside installations. This information, along with other pertinent vehicle identification data may then be forwarded to critical facility operators to inform any preparations or responses that may be required.

The Virginia Tech Transportation Institute conducted an initial phase of work to assess the readiness of APRSs for their reliable and effective roadside deployment and to determine how the data from such a system could be used by facility operators to improve safety and mitigate disruption during an event involving HAZMAT. The findings of the first phase of work indicated that available APRS technology was sufficiently advanced to warrant a second phase of work that included field testing and further refinement of the preliminary deployment plan. In Phase I, an APRS from Intelligent Imaging Systems (IIS) was identified for further evaluation. In this (second) phase of work, a mobile APRS system provided by IIS was evaluated under experimental and naturalistic scenarios at the Virginia Smart Roads and at several locations on Virginia public roads. A photographic survey of public HAZMAT placard usage conducted previously was used to inform this testing. Additional naturalistic data were acquired from a permanent APRS installation in Delaware when difficulties with the mobile APRS were encountered.

The mobile and permanent APRSs were able to classify HAZMAT placard accurately at rates of 96% and 99%, respectively. The mobile and permanent systems were able to read United States Department of Transportation (USDOT) numbers from the sides of tractors correctly at rates of 46% and 67%, respectively, and tractor license plates correctly at rates of 43% and 39%, respectively. Moderate levels of rain and snow, as observed through roadside cameras and reported at nearby weather stations, had minimal impact on reporting accuracy. Performance of the system at night compared favorably with daytime performance. To address potential false negative concerns, a visual survey of 187 commercial vehicles was conducted that revealed that the APRS was 85% successful at locating and identifying the presence of placards on commercial vehicles passing in the near lane. With respect to implementation, the nature of how the subject APRS data is provided to users is not currently conducive to automated integration with existing or future VDOT tunnel or traffic management systems as data must be read from an online interface and no "push" options are currently available. Also, providing advance warning of the approach of HAZMAT to tunnel operators on I-77 is not feasible given constraints related to the geographic siting of potential APRS installations and respective traffic characteristics. However, facility operator access to APRS data after an incident has occurred may provide benefits of improved responder and traveler safety as well as faster clearance times.

FINAL REPORT

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ABSTRACT

The transport of hazardous and dangerous materials (HAZMAT) through safety-critical facilities poses significant risk to overall system reliability should those assets be incapacitated by the occurrence of a related incident. This problem is particularly acute for facilities in remote locations such as Virginia's mountain tunnels on Interstate 77 (I-77) due to limitations on alternate routes and the availability and proximity of emergency responders and specialized equipment/supplies. Automated placard reader systems (APRSs) are commercially available camera-based computer vision systems that "read" hazardous material placards on passing trucks from roadside installations. This information, along with other pertinent vehicle identification data may then be forwarded to critical facility operators to inform any preparations or responses that may be required.

The Virginia Tech Transportation Institute conducted an initial phase of work to assess the readiness of APRSs for their reliable and effective roadside deployment and to determine how the data from such a system could be used by facility operators to improve safety and mitigate disruption during an event involving HAZMAT. The findings of the first phase of work indicated that available APRS technology was sufficiently advanced to warrant a second phase of work that included field testing and further refinement of the preliminary deployment plan. In Phase I, an APRS from Intelligent Imaging Systems (IIS) was identified for further evaluation. In this (second) phase of work, a mobile APRS system provided by IIS was evaluated under experimental and naturalistic scenarios at the Virginia Smart Roads and at several locations on Virginia public roads. A photographic survey of public HAZMAT placard usage conducted previously was used to inform this testing. Additional naturalistic data were acquired from a permanent APRS installation in Delaware when difficulties with the mobile APRS were encountered.

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INTRODUCTION

Automated hazardous material (HAZMAT) placard reader systems (APRSs) are commercially available camera-based computer vision systems that "read" HAZMAT placards on passing commercial vehicles. This information, along with other relevant information such as the US Department of Transportation (USDOT) number and license plate information, may then be accessed by transportation system operators to provide situational awareness before or after an event involving the subject vehicle occurs. An initial phase of work was conducted by the Virginia Tech Transportation Institute (VTTI) in collaboration with the Virginia Department of Transportation (VDOT) with these primary objectives:

- Assess the readiness of automated HAZMAT placard readers for their reliable and effective roadside deployment.
- Develop a conceptual plan for how automated readers would be deployed to most effectively provide advance notifications to facility operators.
- Work with the VDOT Technical Review Panel (TRP) to revise the deployment plan and to enable their decision as to Phase 2 feasibility.

The findings of the first phase of work indicated that available APRS technology is sufficiently advanced to warrant a second phase of work that includes field testing and further refinement of the preliminary deployment plan. A meeting of the project team and TRP members was held in July of 2019 to discuss the results of Phase I work and to inform planning for Phase II activities.

Based on those Phase I discussions, an APRS from Intelligent Imaging Systems (IIS) was identified for further evaluation. This APRS is comprised of multiple cameras and sensors, identifies HAZMAT placard content on passing trucks, and provides real-time notification data streams that can be monitored remotely. The APRS is designed to capture the HAZMAT placard information at different speeds and under various environmental conditions along with other parameters (USDOT number, license plate, etc.). The selected APRS provides accuracy with respect to location and the interpretation of HAZMAT placards (optical and symbol/character recognition technology), USDOT numbers, and vehicle license plates. The selected system was previously installed and tested at several locations across the United States, including weigh and toll stations subject to various traffic levels, vehicle speeds, and weather conditions. Vendor-provided testing results from multiple locations indicated that if properly installed and calibrated, the APRS could successfully identify HAZMAT placard and associated truck identification data with 80% or better reliability.

PURPOSE AND SCOPE

The primary objectives of this research project were to:

1. Assess the real-world performance of an APRS in preparation for a possible future deployment on Interstate 77 (I-77) north of Interstate 81 (I-81) in Virginia.

2. Evaluate how APRSs could be implemented within VDOT operations with respect to geographic placement, physical installation, and virtual integration of the produced data in support of tunnel operations and advanced traffic management systems.

METHODS

Overview of Approach

The major tasks that were conducted to achieve the research objectives are summarized as follows:

- Perform a photographic survey of placarded trucks in operation on public roads to determine how HAZMAT placards are implemented during real-life conditions. The information gleaned during this task was used to inform subsequent testing operations respective to APRS performance.

- Acquire an APRS and develop a mobile sensor package that would be used to assess independent parameters respective to APRS performance. A mobile, trailer-based, APRS was leased, and a separate trailer was equipped with verification sensors and data acquisition equipment.

- Evaluate APRS performance on the Virginia Smart Roads testing facility. This testing was performed under controlled experimental conditions on a closed test track using the mobile APRS. The results of this testing were used to inform the execution of subsequent tasks and to evaluate APRS performance for less common placard types that may not be observed during public testing.

- Evaluate APRS performance on public roads. This was performed at multiple locations in Virginia and Delaware. Limitations experienced with respect to use of the mobile APRS in Virginia led to the utilization of data from a permanent APRS installation in Delaware.

APRS System Description

Two types of APRSs were used for the testing performed in this study. Both systems were manufactured by IIS, the vendor identified during the previous phase of this work. A mobile version of the APRS was acquired by the Virginia Tech Transportation Institute (VTTI) under a multi-month lease agreement. This unit, and key system components, are shown in Figure 1.

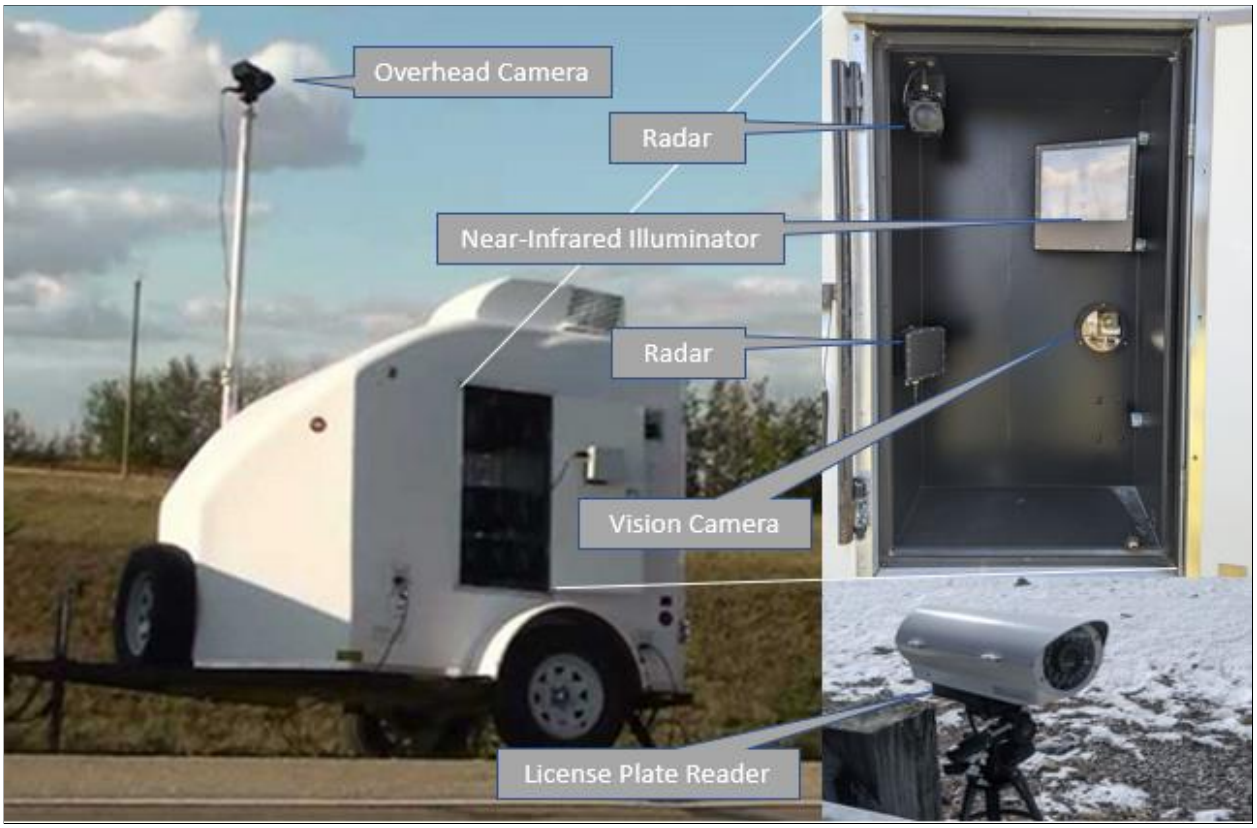

Figure 1. Mobile Automated Placard Reader System (APRS) Trailer with System Component Types and Locations Shown

Access to data from a second, permanent, APRS installation was provided by the vendor when testing with the mobile system proved unreliable during several deployments due to multiple system breakdowns and repairs. This APRS is located on Delaware State Route 1 (DE-1) near the town of Smyrna (Figure 2).

Figure 2. Permanent APRS Installation at the Delaware Site Along DE-1

Both systems operate similarly. Sensors are used to detect approaching vehicles and determine their size to classify their type (e.g., personal, commercial). Only data from commercial vehicles are collected. Once a commercial vehicle is identified, sensors are used to determine the range and rate, and a high-speed camera and machine-vision processes are used to identify and classify placards and other information of interest (e.g., text). Corresponding video stills of the subject vehicle are captured by an overhead camera. Near-infrared illuminators are used to provide improved camera imagery. A license plate reading camera system is used to acquire imagery and interpret text. This information is transferred in near real time to the vendor's backend servers for access by system users through a web browser interface. An example of the data and corresponding user interface is provided in a later section of this report.

The primary differences between these systems other than their mobility relate to power provision, the location of system sensors, and how vehicles are detected and classified. The mobile system is powered by batteries charged before and/or during system operation, all sensors other than the license plate reader (LPR) are located on the trailer (Figure 1), and radar sensors are used on the trailer to detect vehicle presence and provide size classification. The permanent systems typically receive power from an electric utility connection, and aboveground sensors are mounted on one or more poles located at the roadside (Figure 2). Also, in-pavement (e.g., inductive loop) sensors are typically employed for vehicle detection and classification.

HAZMAT Placard Usage Survey

In preparation for subsequent tasks, VTTI research team members performed a photographic survey of vehicles located on public roads, at truck stops, at weigh stations, and elsewhere to collect data regarding the display of HAZMAT placards in actual use. Data noted during this survey included the following:

- HAZMAT placard
  - Location on the side of the truck or trailer (height, longitudinal)
  - Orientation with respect to vertical (rotation)
  - Visual condition (worn, dirty, etc.)
  - Number of placards present
- USDOT number
  - Location on tractor
  - Size
  - Visibility
- License plate
  - Visibility
  - Readability

The primary reason for undertaking this task was to inform how experimenters would present placards to the APRS during testing performed on the Virginia Smart Roads in a subsequent task by more accurately representing the range of conditions likely to be observed during real-life testing. The research team became more familiar with the operation of the APRS and recognized that only those placards visible from the side of the vehicle were relevant and that longitudinal location did not affect APRS operation. Therefore, an informal visual analysis performed on acquired images from approximately 100 placard-equipped trucks focused primarily on placard height, rotation angle, and condition (Figure 3). It should be noted that this survey was conducted during a period of relatively fair weather; the impacts of winter weather and salt application, which may add to the potential for placard obscuration, were not observed.

Figure 3. Sample of Photographs Acquired During the Usage Survey

APRS Acquisition and Sensor Trailer Development

The mobile APRS shown previously in Figure 1 was leased from IIS by VTTI to facilitate its evaluation in this study. This trailer-based unit is fully functional and designed for use by law enforcement officers and others for short periods of time (i.e., 1 to 2 days). A separate DOT-type trailer was configured as a base for sensors used to validate APRS operation and to provide additional information on environmental and traffic conditions that might affect APRS performance (Figure 4). The trailer was equipped as described below:

- Solar photovoltaic panels, batteries, and related power conversion electronics to provide power to onboard sensors, data loggers, and cellular communications equipment.
- A stowable and extendable mast that was used for sensor mounting and elevation.
- A high-mounted camera to collect video of passing traffic and environmental conditions.
- A weather station providing environmental condition data, including temperature, humidity, light level, and wind speed and direction.
- A visibility sensor to determine sight distances.
- A Wavetronix SmartSensor HD® radar to measure traffic speeds, detect individual vehicles, and determine their size and lane position (i.e., inner, outer).
- A data logger for collection of data from all sensors. This data logger also featured a cellular modem to enable remote data sharing.

Figure 4. View of the Sensor Trailer with the Mobile APRS and Generator Shown in the Background

After a study of potential mobile APRS test sites along I-77 was completed, the research team realized that accessing utility grid power for powering the APRS was not feasible given schedule and budget constraints. Connection to the utility grid would also limit the number of potential test locations. Several portable generators of various sizes were tested, but none provided the power capacity and extended run time that was required for the multi-day testing planned. A trailer-mounted generator of sufficient size and fuel capacity to power the APRS continuously was purchased after all options for leasing a suitable trailer were exhausted (Figure 4). The Generac MLG8K generator was chosen because it offered both sufficient power capacity (8.1 kW) to operate the APRS trailer and because it featured a fuel-efficient diesel engine and large fuel tank (56 gal.) that enabled extended run times of up to 80 hours.

APRS Data Acquisition and Reduction Tool Development

APRS Data

As vehicles displaying a placard pass the APRS, the classification event data are packaged and transferred to the vendor's backend server in near real time via a wireless cellular or other data connection. The user interface allows viewing of multiple sequential events (Figure 5), as well as individual events and more detailed information (Figure 6 and Figure 7).

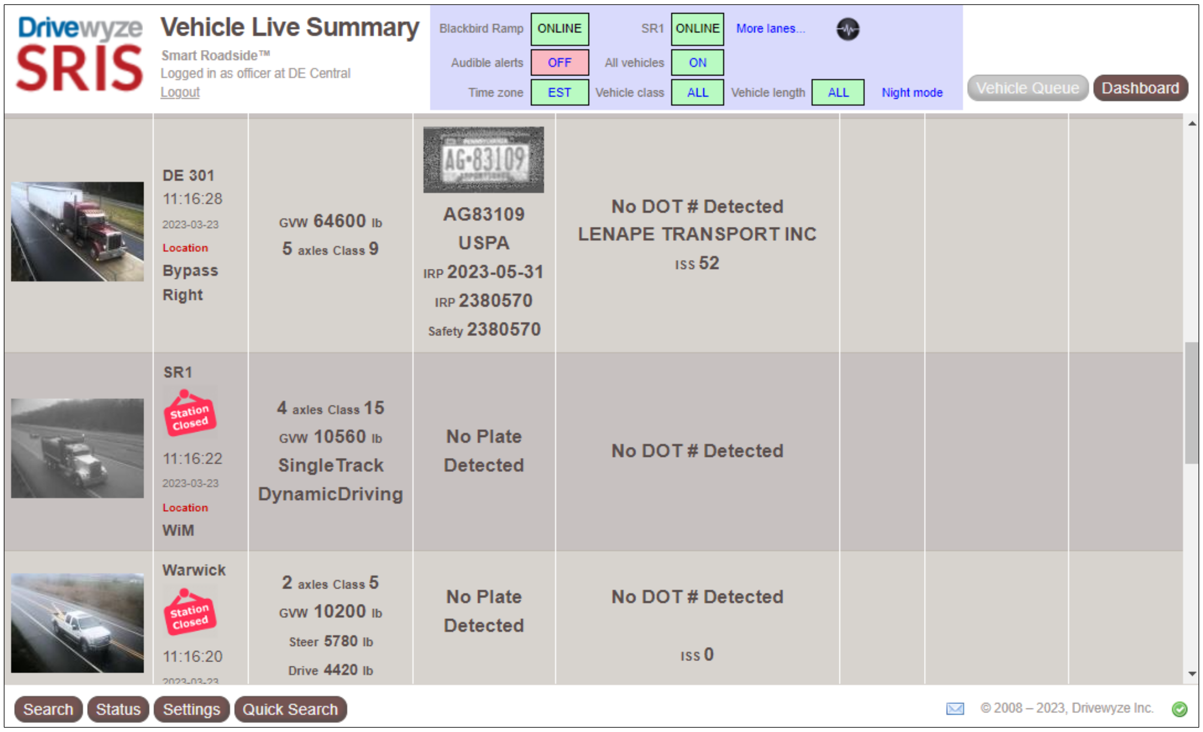

Figure 5. Screen Capture of the APRS Data Server Interface Showing the Vehicle Live Summary View

Individual entry pages display pertinent information for the subject vehicle, with the more common information being placed at the top of the page, such as the images captured by the APRS of the vehicle, the classification of these images, and any applicable alerts (Figure 6). More information is given below, with details on any HAZMAT placards that were on the vehicle placed at the bottom of the page (Figure 7).

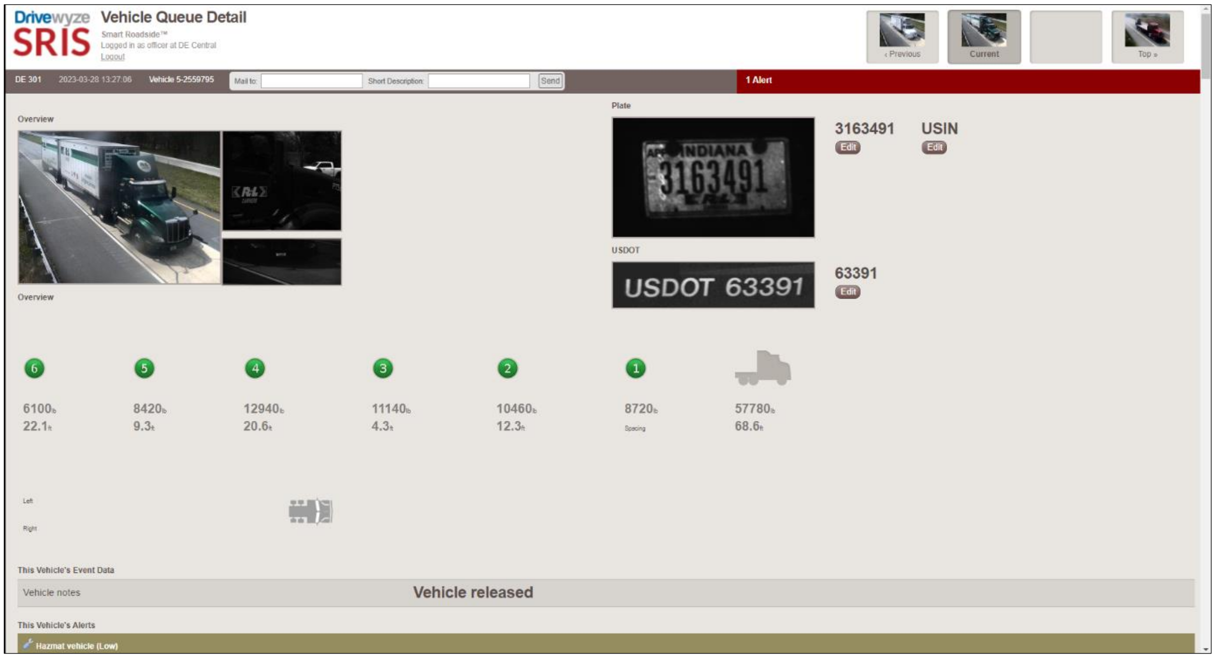

Figure 6. Screen Capture of the APRS Data Server Interface Showing the Vehicle Queue Detail View. The Top of the Page Contains Images of the Event, Text Identified from These Image, and Any Alerts.

Figure 7. Screen Capture of the Vehicle Queue Detail of the Same Vehicle in Figure 6, Viewing the Bottom of the Page, Containing Details of the Attached Placard Including an Image and Identification

Users can perform limited online queries of numeric data (1,000 events or less) based on location, time, and other parameters, but associated graphic information may not be retrieved using this method. Data available via this interface includes the following:

- Date/time
- Recorded vehicle speed
- Vehicle information
  - Length
  - Gross vehicle weight rating (GVWR)
  - Classification
  - Year, make, model, and Vehicle Identification Number
  - Carrier information
  - International Registration Plan information
  - License plate number and state jurisdiction
  - USDOT number
  - HAZMAT placard information, if one or more are present
- Images
  - Overhead view of the vehicle
  - Front of vehicle, for license plate, with additional zoomed-in image of the plate
  - Side of vehicle, for USDOT no., with additional zoomed-in image of the number
  - Photo of placard(s), if one or more are present

The parameters listed above that relate to vehicle characteristics such as GVWR, length, and classification are not typically available from the mobile APRS because of the type of vehicle sensors that are used. Please note that some of the data available via this interface (e.g., Vehicle Identification Number, carrier information, etc.) is pulled from online databases based on available identifying data such as the DOT or license plate designation. These may not be available if the DOT number or license plate is not read by the system.

Data Acquisition Tool

The research team initially planned to access the APRS data to download numeric information and associated graphic files en masse for subsequent reduction and analysis. However, this option was not available as data were only accessible via the user interface shown in Figures 5, 6, and 7, which is a web browser interface designed for short-term use by law enforcement officers and others.

Because human review of many APRS classification events was required to perform the planned evaluation, VTTI developed the HAZMAT Placard Review software tool that "scrapes" numeric and graphical data from the APRS vendor's website for subsequent population of an offline relational database. This tool also provides for data reduction through human review of each classification event (Figure 8). For each vehicle entry, the tool displays:

- Date and time
- An assigned unique vehicle ID

- Identification and classification data (placard, USDOT number, license plate, license plate jurisdiction, etc.)
- Individual images on which classification and identification is based

Data reductionists reviewed classification and graphical data for each event to determine APRS accuracy. Reduced data from this tool was appended to the existing scraped APRS data at VTTI. This dataset was then used for subsequent data analysis.

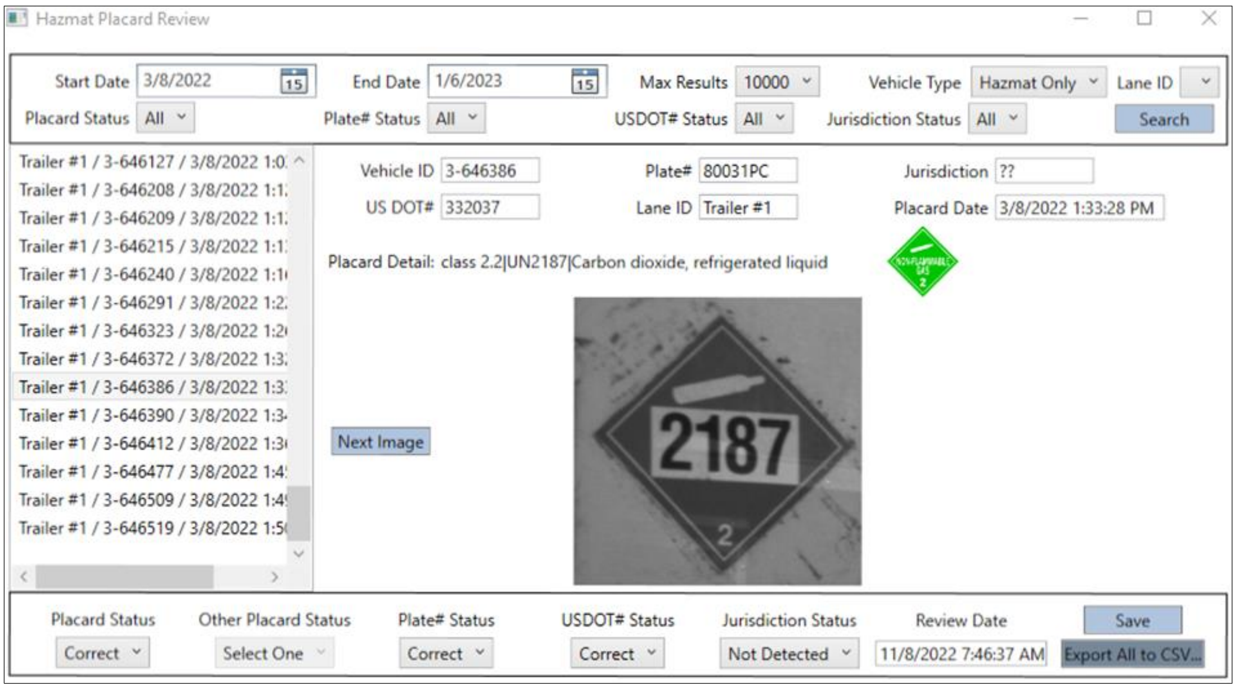

Figure 8. Screen Capture of VTTI's HAZMAT Placard Review Website Data Scraping Software Tool

APRS Evaluation

Two distinct and sequential phases of APRS evaluation were conducted at multiple locations in Virginia and at a site in Delaware. Initial testing was performed on the Virginia Smart Roads under semi-controlled experimental conditions. The primary goals of this work were to assess the performance of the APRS without the confounding influences that real traffic may create, and to test the full range of placard category types, some of which may not be observed under live traffic conditions.

A second phase of testing focused on APRS performance assessment using live traffic on public roads. The primary goals of this work were to evaluate the APRS under the conditions likely to be encountered in a permanent deployment and to take advantage of existing traffic to greatly increase the number of expected placarded truck observations. Test site locations, the type of APRS used, and the number of testing events respective to each site are shown in Table 1. Each testing event required mobilization of the APRS trailer and supporting instrumentation and equipment to the site or use of an existing permanent APRS installation.

Table 1. APRS Testing Locations and Number of Mobilizations

Testing Location	APRS Type	No. of Testing Events
US-460 at various locations near Blacksburg	Mobile (trailer)	2
Transportation Research Plaza at VTTI	Mobile (trailer)	2
I-77 between I-81 and the West Virginia Border	Mobile (trailer)	2
DE-1 near Smyrna, DE	Permanent	N.A.

Experimental Evaluation on the Virginia Smart Roads

The APRS trailer system was tested on the Virginia Smart Roads to evaluate its performance across a wide range of HAZMAT placard types and to minimize any "noise" in the acquired data by controlling test conditions to the extent practicable. The APRS trailer was positioned at a location along the Highway section of the Virgina Smart Roads to emulate its likely implementation on I-77 as far as protection behind a barrier (guardrail) and lateral distance from the APRS cameras and the targeted travel lane; in this case, the near lane (Figure 9). Power was provided by a utility connection already present at the site. A vendor representative provided assistance with the setup and verified that the APRS was operating normally.

Figure 9. View of the APRS Trailer Configuration Used for Virginia Smart Roads Testing

A box trailer and pickup truck tow vehicle were employed as a placard mounting and testing platform after preliminary testing using a Class 8 tractor/trailer combination revealed it to be a suitable surrogate (Figure 10). The use of the pickup truck and trailer combination provided for much quicker and less costly experimentation when compared to the use of a tractor/trailer and commercially licensed driver. Placards were mounted on the trailer in configurations guided by the findings of the HAZMAT placard use field survey.

Figure 10. Placards and Trailer Used for Virginia Smart Roads Evaluation

Testing was conducted under a variety of environmental conditions with vehicle/trailer speeds of 65 mph. Samples of placards in random combinations were mounted on the trailer and the driven by the APRS trailer in the closest lane. The placards were chosen as a representative subset of the range that might be viewed during APRS operation on public roads (Figure 11). Although anecdotal observation of APRS performance was favorable, a portion of the data was lost before it was downloaded from the vendor’s website due to yearly scheduled data management operations.

Figure 11. Placards Used in the Virginia Smart Roads Evaluation

Naturalistic Evaluation on Live Public Roads

Pilot Testing

The APRS trailer was installed at three locations along public roads near VTTI in Blacksburg, Virginia, in preparation for its eventual mobilization to I-77 for testing there. Pilot testing was conducted here using live public traffic to validate the proper operation of the mobile APRS, the sensor trailer, and other ancillary equipment such as generators. Figure 12 shows the locations of these installations and the orientation of the APRS with respect to observed traffic. Locations 1 and 2 lie along US-460 entry and exit ramps, respectively, and Location 3 is adjacent to Transportation Research Plaza, VTTI's entry road.

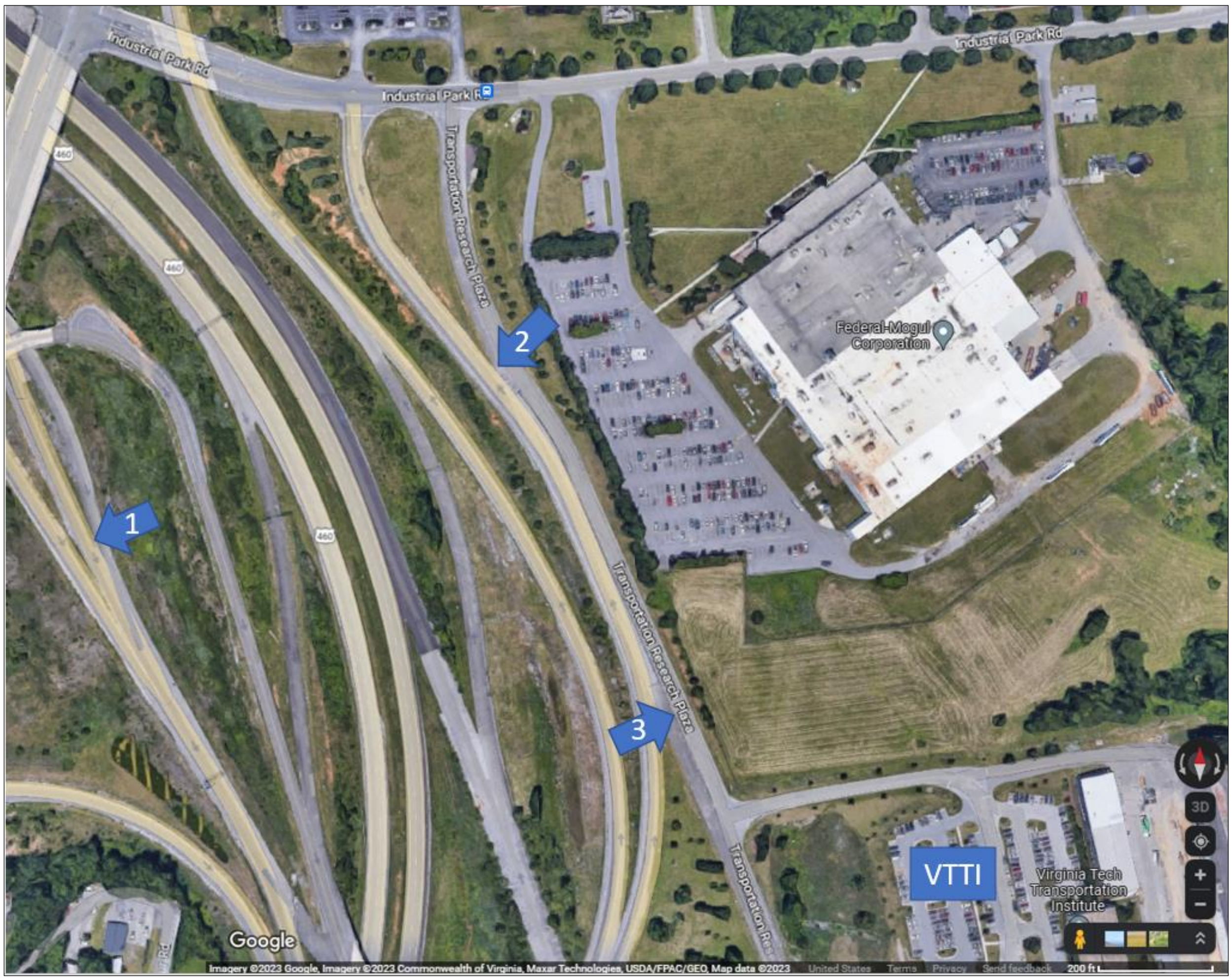

Figure 12. Map of the Intersection of US-460 and Industrial Park Rd. Near Blacksburg Showing the Locations of Pilot APRS Trailer Installations

APRS Evaluation on I-77

The segment of I-77 shown in Figure 13 was targeted for APRS testing and evaluation for future permanent installations due to the presence of the mountain tunnels and the boundaries created by I-81 to the south and the West Virginia border to the north. Interconnecting routes, as well as their relative locations along the length of the corridor, are shown, as are the Big Walker and East River Mountain tunnels and the potential locations of placard and license plate reading equipment for northbound monitoring. While ultimately not utilized, potential locations for automated license plate readers (ALPRs) were designated should tracking of vehicles entering or exiting I-77 between I-81 and the tunnels be required. The APRS is also equipped with an ALPR that allows for temporary linking of placards with license plates. This association then allows placarded vehicles to be tracked using only license plate data within a set interval.

After remote review using Google's mapping and Street View, several site visits to this segment of I-77 segment were conducted to determine potential locations for deployment of the APRS trailer and to inform potential future permanent APRS installations. Criteria for site selection included the following factors:

- Topography – relatively level ground where the APRS and other equipment could be safely installed.
- Physical access – clear of obstructions and accessible by vehicles for placement of mobile equipment.
- Proximity to the targeted traffic lane – lateral distance from the APRS to the closest travel lane of approximately 12–15 ft.
- Personnel and equipment protection – the presence of a barrier such as a jersey wall or guardrail was required.
- Access to utility power – the ability to either connect to existing VDOT infrastructure or the local power utility. The latter would likely require that a temporary power pole and meter be installed.
- Location with respect to ingress and egress routes where placarded vehicles entering or exiting I-77 might confound predictions of these vehicles entering the tunnels.
- Distance from the tunnels – a greater distance is preferred for any scenario involving forewarning of approaching placarded trucks.
- Communication access – connection to an internet service provider via cellular, fiber, cable, or otherwise.

With regard to the criteria concerning the distance from the tunnel(s), the potential for maximizing the effectiveness of advance alerting increases in direct proportion to the distance of the APRS from the subject tunnel. Therefore, the research team initially focused on sites as far from the tunnel as practical. However, given that the southern entrance to Walker Mountain tunnel is approximately 6 minutes from I-81 at typical traffic speeds, and in light of VDOT policies regarding traffic video and/or the use of ALPRs, input from the TRP suggested that APRS use directly adjacent to the tunnel entrances might be the most practical.

On-site inspection by research team members revealed that many potential locations were inaccessible for the trailer to be properly or safely deployed. From the list of candidate sites, two locations were selected for further evaluation. Using a measurement of the road edge to the outer solid line, the distance at one of these sites was considered too far for the trailer to reliably capture passing vehicles, based on the recommended distance for the APRS trailer to record these data. At this same site, the actual slope was considerably greater than anticipated and likely to cause issues with equipment placement.

The most suitable location, and where the APRS and other equipment were eventually deployed during testing, was a relatively flat and secure patch of grass on the northbound side, roughly 600 to 700 feet from the entrance to the Big Walker Tunnel (Figures 14 and 15). This site best fulfilled all locating criteria requirements except for the availability of utility power.

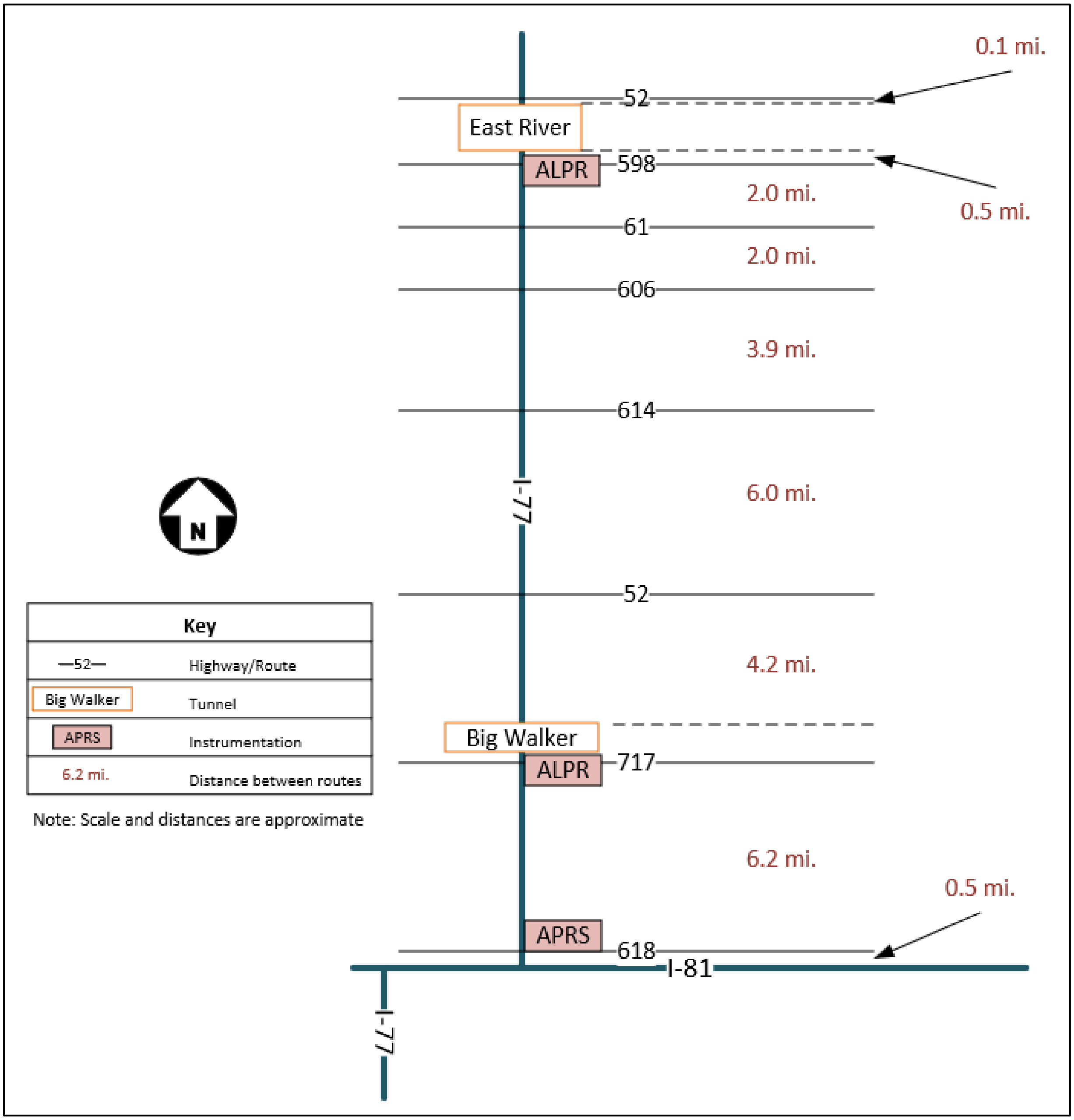

Figure 13. Schematic Representation of the I-77 Corridor and Connecting Routes North of I-81 in Virginia Showing the Potential Data Collection Locations for Placard and License Plate Identification. ALPR = Automated License Plate Reader.

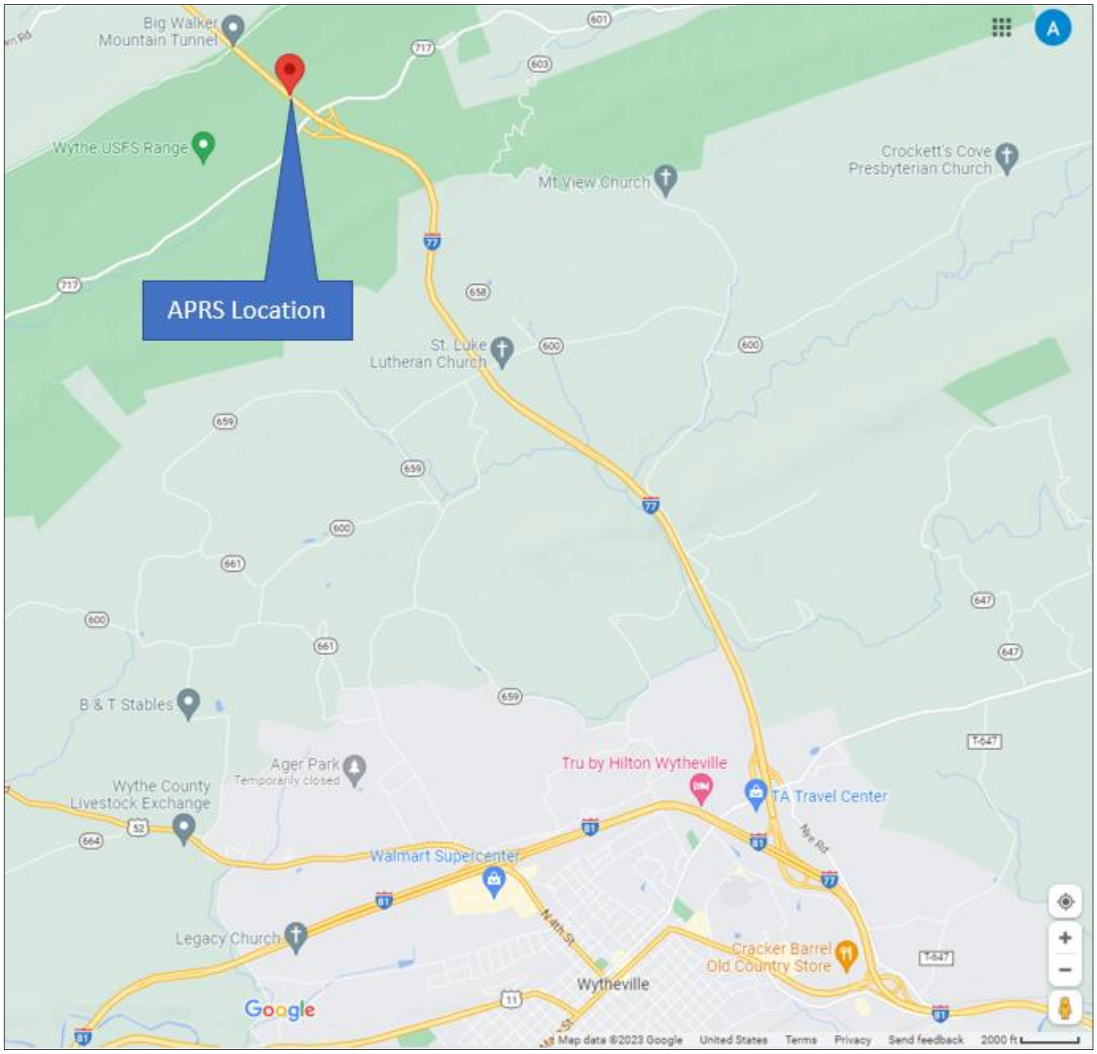

Figure 14. APRS Implementation Site on I-77 Just South of Big Walker Tunnel

Figure 15. View of the South Entrance of Big Walker Tunnel on I-77 Near the APRS Deployment Site

After determining the best area for testing, the APRS trailer was deployed there to collect data (Figure 16). The first deployment to this location spanned from February 28, 2022, to March 8, 2022. The trailer’s sensors and cameras were set up along the side of the road to capture passing commercial vehicles in the outer lane. The APRS vendor was consulted on this deployment. A second, later deployment at this location did not yield any data due to equipment malfunction.

Figure 16. APRS Trailer and Supporting Equipment Installed Adjacent to the Northbound Outer Lane of I-77 Near the Walker Mountain Tunnel

After the deployment and data collection was completed, the data were extracted from the APRS vendor’s website as described previously. Each vehicle the trailer captured was retrieved from this website, including any non-HAZMAT commercial vehicles that passed the sensors. Although the focus is on passing HAZMAT vehicles, some non-HAZMAT data were used in tandem with video footage captured by researchers for a separate analysis focused on understanding the prevalence of false negatives.

Evaluation at the Delaware Site

The original plan for APRS data collection for this project involved only the use of the mobile APRS system in Virginia. Numerous technical problems with this system and its eventual recovery by the vendor for renovation necessitated that the research team devise other methods for APRS data acquisition. After consultation with the vendor, VTTI was provided with access to data from several stationary APRS sites in Delaware. This allowed retrieval of data over a much longer period of time and the ability to target periods of adverse environmental conditions that might adversely affect system operation. Unfortunately, this arrangement, and the project constraints of time and funding did not allow for the use of the sensor trailer and the supporting data that it would provide.

In a survey of the Delaware locations, the APRS located on State Route 1, roughly 1 mile north of the town of Smyrna (Figure 17 and 18), was chosen among these sites because of its location near a reliable weather station at Dover Air Force Base (AFB), approximately 20 miles south of the site. No closer reputable weather stations were found. Data from this site were retrieved from the APRS vendor's website for the time period of January 1 through June 30, 2022. For this site, data were collected, reduced, and analyzed based on weather events from historic data extracted from the nearby weather station site at Dover AFB. The previously mentioned VTTI HAZMAT Placard Review tool was used for APRS data collection at this site.

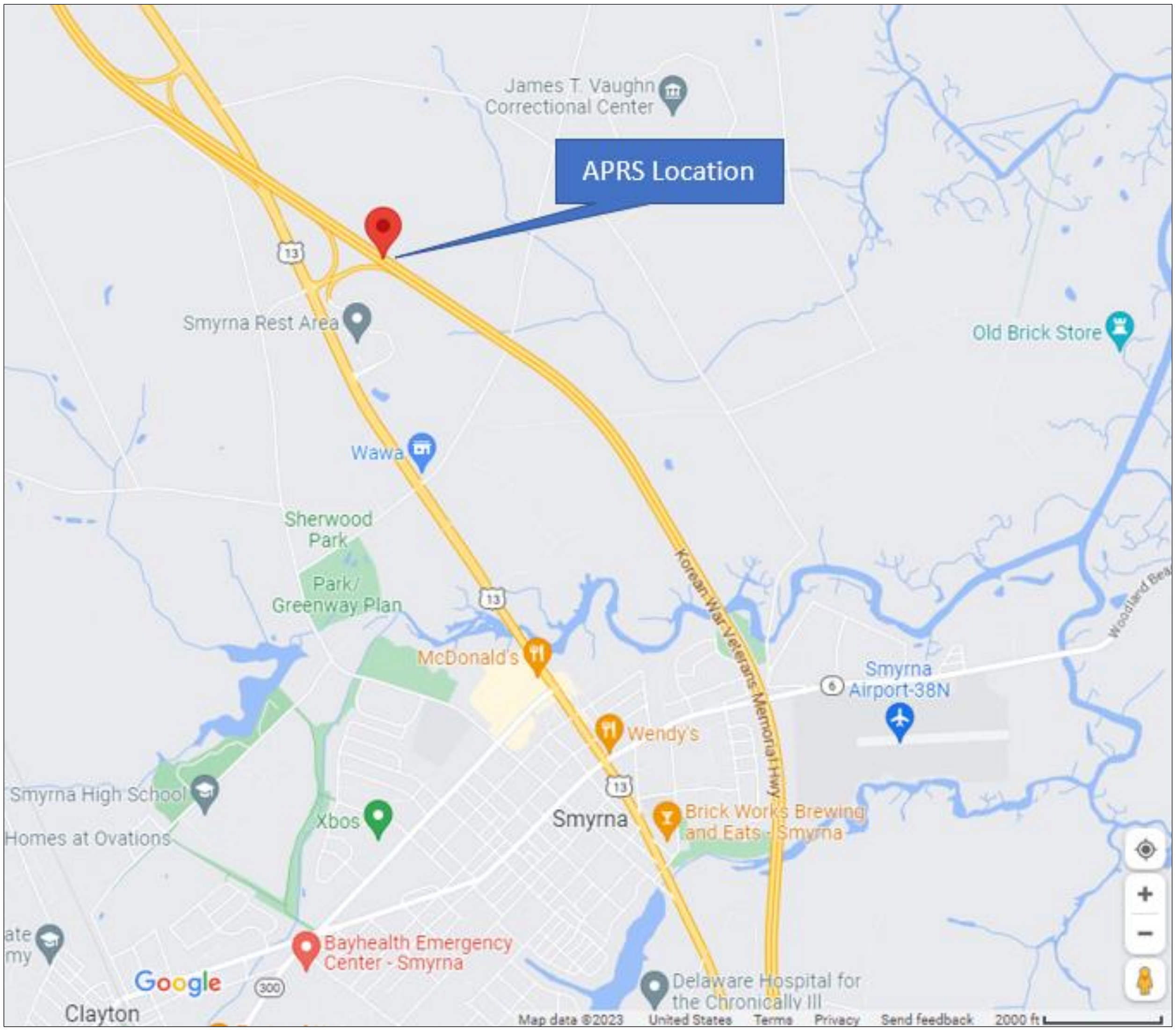

Figure 17. Location of APRS on State Route 1 in Delaware

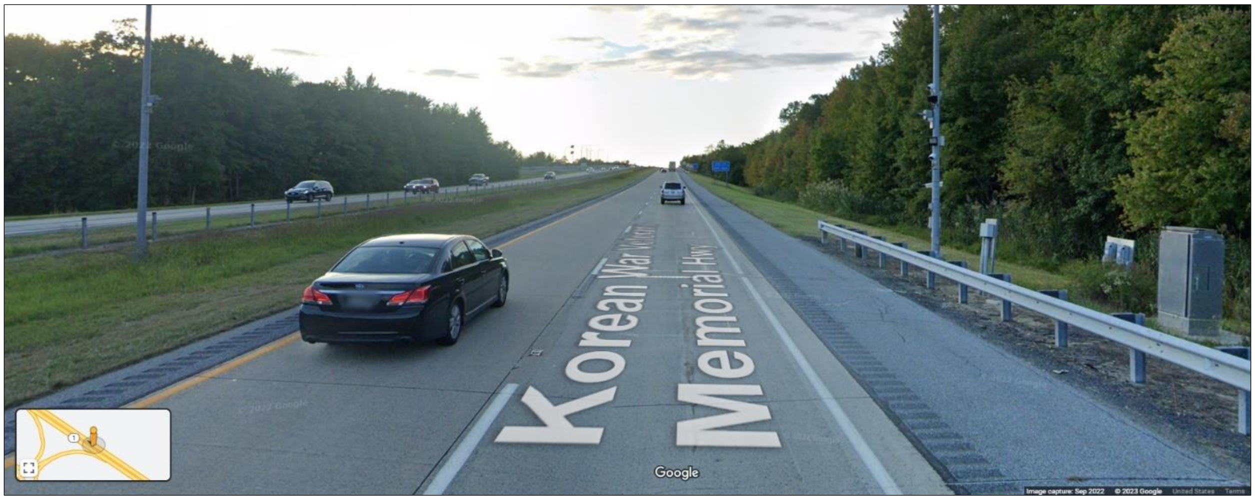

Figure 18. Google Street View Image of APRS on State Route 1 in Delaware

Data Reduction and Analysis

During data reduction, the focus was on HAZMAT placard capture rate and accuracy; other vehicle-related items captured by the APRS included identifiers such as the USDOT number printed on the passenger side of the vehicle, the license plate number, and state jurisdiction. This additional data was considered and analyzed as they have applications to the emergency response of any safety-critical event and communication with fleet owners. Reductionists were tasked with viewing each entry and verifying whether the sensors detected, captured, and correctly identified HAZMAT placards on vehicles passing in the outer lane. Reductionists repeated this process for USDOT numbers, license plates, and state jurisdictions. Additionally, if a vehicle was determined by the APRS to have more than one HAZMAT placard, there was a second placard entry that reductionists could utilize to collect this data as well.

In the reduction process, researchers were tasked with observing the entries retrieved from the APRS vendor's website and determining whether the assigned value or label for each of the vehicle's entries was correct or incorrect. Several options were used to determine the likely reason why an entry may have been incorrect, such as the item not being visible in the captured images or whether the system assigned an incorrect value despite seemingly capturing the image without issue (Table 2). These entry options were created to assist in determining the reason for a data entry type to not be correctly classified and create an understanding of the limitations of the APRS. For the purposes of this analysis, any entry that is not "Correct" will be considered "Incorrect."

Table 2. Entry Options Used in the Placard Reviewer Reduction Tool

Entry	Description
Correct	The image is clearly captured, visible, and the data has been correctly classified.
Mislabeled*	The image is clearly captured and is visible, but is not correctly classified, and therefore not correctly labeled.
Not Detected*	Image shows the item is visible, APRS was expected to detect and classify this, but was not detected by the system.
Not Visible*	Either an image was captured but is unreadable or the item is not visible in the image by the reviewer as well.
Misplaced*	An image appears clearly and was classified correctly but should have been for a different vehicle (either in front or behind subject vehicle).
Unknown*	An image is present but it makes no sense why it is associated with the expected data.
Reinspect	If the reviewer is not certain of the correct selection, another researcher will review this entry later. All "Reinspect" entries will be given a different entry after this review.

**Any entry that wasn't labeled "Correct" is considered "Incorrect" for the purposes of this analysis.*

Selection of Data from the Delaware Site APRS

The data from the Delaware site were first considered based on weather events that occurred at the site by searching historic weather data for these events (The Weather Company, 2022). Reviewers searched for rain events, snow events, and any other event that may cause a loss or reduction in visibility or clarity of the images captured, such as times where fog was present. Days and times were decided ahead of time and were then assigned to reductionists to complete every entry within that timeframe. This was repeated for each weather event considered.

In addition to collecting each data entry, reductionists were tasked with observing the overhead camera image for each entry to determine the weather status during these events, such as rainfall, snowfall, or fog. This was used in the analysis to determine the capture rate during these events versus when weather conditions were calmer and visibility was high. The weather events selected for review are below (Table 3). Reductionists were also tasked with determining when the conditions changed from day to night and vice versa. The historic sunrise and sunset data, retrieved from the same website location as weather data, were used to determine roughly when this would happen for each day of data collected.

Table 3. Weather Events Chosen for Review at the Delaware Site

Events	Date/Time range	Total time (hr.)	Precipitation. (in)	Rate (in/hr.)	Total Entries
Snow 1	1/3/22 12:44 a.m. – 1/3/22 11:15 a.m.	10.5	0.16*	0.015*	24
Snow 2	1/28/22 3:50 p.m. – 1/29/22 12:05 p.m.	9.25	0.11*	0.012*	18
Rain 1	1/1/22 1:00 a.m. – 1/2/22 11:00 p.m.	46	0.47	0.010	48
Rain 2	2/3/22 3:10 p.m. – 2/4/2022 5:40 p.m.	26.5	0.72	0.027	68
Rain 3	4/8/22 10:30 p.m. – 4/9/22 1:30 a.m.	3	0.09	0.030	7
Rain 4	4/18/22 4:00 p.m. – 4/19/22 3:15 a.m.	11.25	1.73	0.154	34

*Precipitation rates and totals are shown in liquid equivalent. Typically, a ratio of 10:1 can be applied to correct for observed snowfall totals and rates (Sosnowski, 2022).

While searching historic weather data, visibility-level data were challenging to source. Sites would either have no data or would have data that did not decrease from the maximum value (e.g., 10 miles), despite reviewing the imagery around these times and observing a noticeable decrease in the visibility of objects in the background that were clearly visible in images previously reviewed at different times at the same site. However, fog tended to occur around the same time as some of the events listed above in Table 3. The task was given to the event reviewer to determine from the overhead camera when the visibility of objects in the background had been obscured from visible fog, considered a fog event, and when visibility returned to the previously observed quality, when the fog event had ended.

Images at the Delaware site were observed by reviewers to determine the type of precipitation and level of fog. A few minor rain events occurred at the trailer site, but the weather-related data analysis was primarily conducted on the Delaware site, as there was a much longer timeframe and an extended and more robust history of weather data at this location.

RESULTS AND DISCUSSION

APRS Placard Classification

In total, 1,533 entries were completed during the data reduction task, 780 entries from the APRS trailer, and 753 from the Delaware site. Of these entries, at the Delaware site, 156 occurred during a rain event, 42 during a snow event, and 39 were considered to have a visibly distinct level of fog in the imagery. The remainder had no considerable weather or visibility issue noted during the reduction process.

In the analysis, the APRS trailer was shown as having a 96.5% success rate at capturing and correctly identifying any passing HAZMAT placard, while the Delaware site had a 99.5% success rate. For the other data entries (USDOT number, license plate number, and state jurisdiction), the capture rates were much lower. For the APRS trailer, the USDOT number, license plate number, and state jurisdiction were 67.2%, 39.1%, and 19%, respectively (Table 4 and Figure 19). The Delaware site rates were 43.3%, 43.2%, and 37.1%, respectively (Table 5 and Figure 20).

Table 4. I-77 Trailer Deployment, Validation by Data Entry Type

Placard			License Plate		
	Count	Percent		Count	Percent
Correct	753	**96.5%**	Correct	305	**39.1%**
Incorrect	27	3.5%	Incorrect	475	60.9%
USDOT No.			Jurisdiction		
	Count	Percent		Count	Percent
Correct	524	**67.2%**	Correct	148	**19.0%**
Incorrect	256	32.8%	Incorrect	632	81.0%

Table 5. Delaware Site, Validation by Data Entry Type

Placard			License Plate		
	Count	Percent		Count	Percent
Correct	749	**99.5%**	Correct	325	**43.2%**
Incorrect	4	0.5%	Incorrect	428	56.8%
USDOT No.			Jurisdiction		
	Count	Percent		Count	Percent
Correct	326	**43.3%**	Correct	279	**37.1%**
Incorrect	427	56.7%	Incorrect	474	62.9%

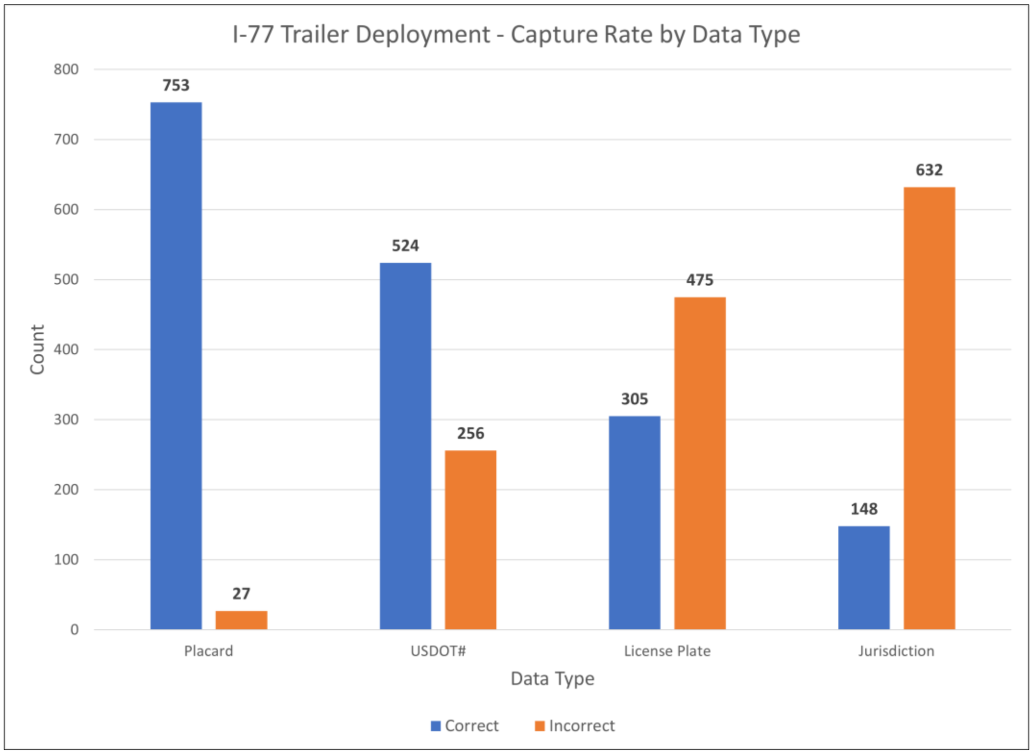

Figure 19. I-77 Trailer Deployment, Validation by Data Entry Type

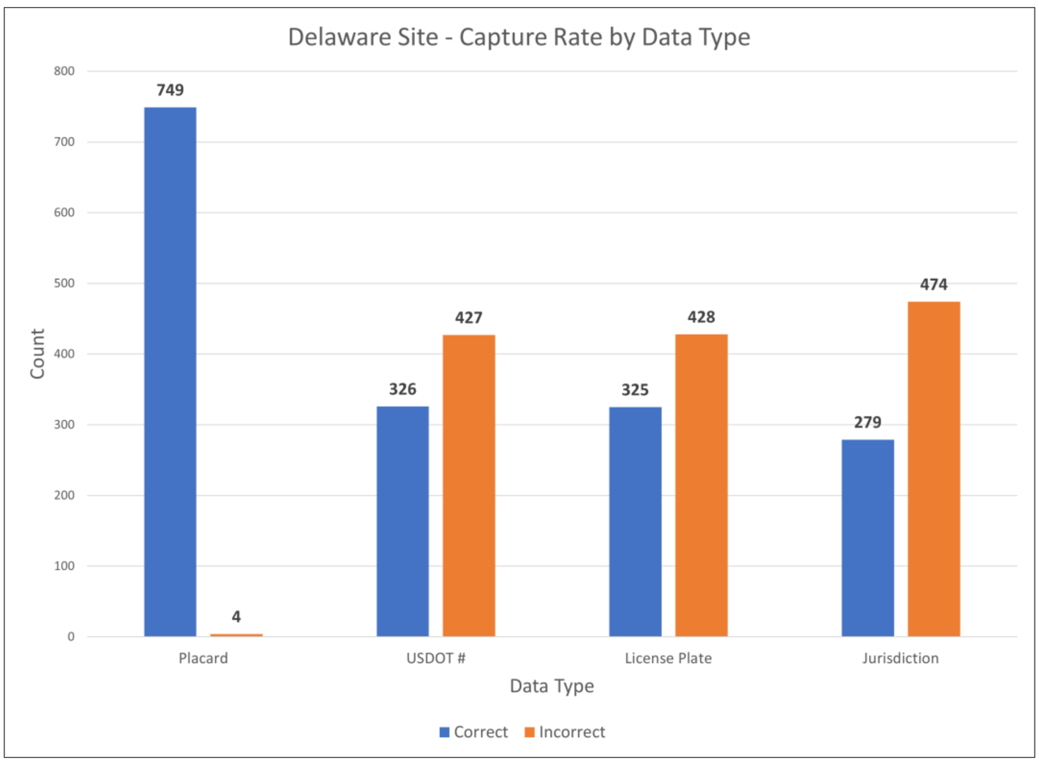

Figure 20. Delaware Site, Validation by Data Entry Type

A detailed breakdown of incorrect entries by type is provided in Tables 6 and 7 per the definitions provided in Table 2.

Table 6. I-77 Trailer Deployment, Validation by Data Entry Type with Expansion of Incorrect Instances

Placard			License Plate		
	Count	Percent		Count	Percent
Correct	**753**	**96.5%**	**Correct**	**305**	**39.1%**
Mislabeled	15	**1.9%**	Mislabeled	177	**22.7%**
Not Detected	0	**0%**	Not Detected	141	**18.1%**
Not Visible	2	**0.3%**	Not Visible	109	**14%**
Misplaced	0	**0%**	Misplaced	24	**3.1%**
Unknown	6	**0.8%**	Unknown	24	**3.1%**
N/A	4	**0.5%**	N/A	0	**0%**
Total Incorrect	**27**	**3.5%**	**Total Incorrect**	**475**	**60.9%**
USDOT No.			Jurisdiction		
	Count	Percent		Count	Percent
Correct	**524**	**67.2%**	Correct	148	**19.0%**
Mislabeled	59	**7.6%**	Mislabeled	198	**25.4%**
Not Detected	180	**23.1%**	Not Detected	260	**33.3%**
Not Visible	14	**1.8%**	Not Visible	134	**17.2%**
Misplaced	1	**0.1%**	Misplaced	14	**1.8%**
Unknown	2	**0.3%**	Unknown	26	**3.3%**
N/A	0	**0%**	N/A	0	**0%**
Total Incorrect	**256**	**32.8%**	**Total Incorrect**	**632**	**81.0%**

Table 7. Delaware Site, Validation by Data Entry Type with Expansion of Incorrect Instances

Placard			License Plate		
	Count	Percent		Count	Percent
Correct	**749**	**99.5%**	**Correct**	**325**	**43.2%**
Mislabeled	1	**0.1%**	Mislabeled	186	**24.7%**
Not Detected	0	**0%**	Not Detected	90	**12%**
Not Visible	0	**0%**	Not Visible	117	**4.6%**
Misplaced	0	**0%**	Misplaced	0	**0%**
Unknown	0	**0%**	Unknown	35	**4.6%**
N/A	3	**0.4%**	N/A	0	**0%**
Total Incorrect	**4**	**0.5%**	**Total Incorrect**	**428**	**56.8%**
USDOT No.			Jurisdiction		
	Count	Percent		Count	Percent
Correct	**326**	**43.3%**	**Correct**	**279**	**37.1%**
Mislabeled	44	**5.8%**	Mislabeled	136	**18.1%**
Not Detected	255	**33.9%**	Not Detected	121	**16.1%**
Not Visible	124	**16.5%**	Not Visible	192	**25.5%**
Misplaced	0	**0%**	Misplaced	1	**0.1%**
Unknown	4	**0.5%**	Unknown	24	**3.2%**
N/A	0	**0%**	N/A	0	**0%**
Total Incorrect	**427**	**56.7%**	**Total Incorrect**	**474**	**62.9%**

The data were then analyzed to observe what differences there might be for entries during the day versus at night. For the APRS trailer, HAZMAT placard data was captured at a rate of 95.8% during daytime, less than during nighttime at a rate of 98.3% (Table 6). At the Delaware site, the daytime capture rate was slightly better at 99.5%, with a 99.4% capture rate at night (Table 8). In addition, the Delaware site was analyzed based on the observed weather events and the rate during each weather event type. The Delaware APRS had a success rate of 98.7% during rain events, 100% during snow events, and 100% during periods of fog, leaving a 99.6% overall success rate for when neither precipitation type or fog was present in the overhead imagery (Table 9 and Figure 21).

Table 8. I-77 Trailer Deployment, Data Entry Validation by Day vs. Night

Totals:		**Day: 545**	**Night: 235**		**Day: 545**	**Night: 235**
	Placard			License Plate		
Correct		522	231	Correct	204	101
Incorrect		23	4	Incorrect	341	134
% Correct		95.8%	98.3%	% Correct	37.4%	43.0%
	USDOT#			Jurisdiction		
Correct		395	129	Correct	105	43
Incorrect		150	106	Incorrect	440	192
% Correct		72.5%	54.9%	% Correct	19.3%	18.3%

Table 9. Delaware Site, HAZMAT Placard Validation by Weather Type and Time of Day

Precipitation Type & Time of Day		**No. Correct**	**No. Incorrect**	**Total**	**% Correct**
Rain	Day	82	1	83	98.8
	Night	72	1	73	98.6
	Total	154	2	156	**98.7**
Snow	Day	16	0	16	100
	Night	26	0	26	100
	Total	42	0	42	**100**
Fog	Day	31	0	31	100
	Night	8	0	8	100
	Total	39	0	39	**100**
No Precipitation/Fog	Day	310	1	311	99.7
	Night	228	1	229	99.6
	Total	538	2	540	**99.6**
Totals	Day	423	2	425	99.5
	Night	326	2	328	99.4
	Total	749	4	753	**99.5**

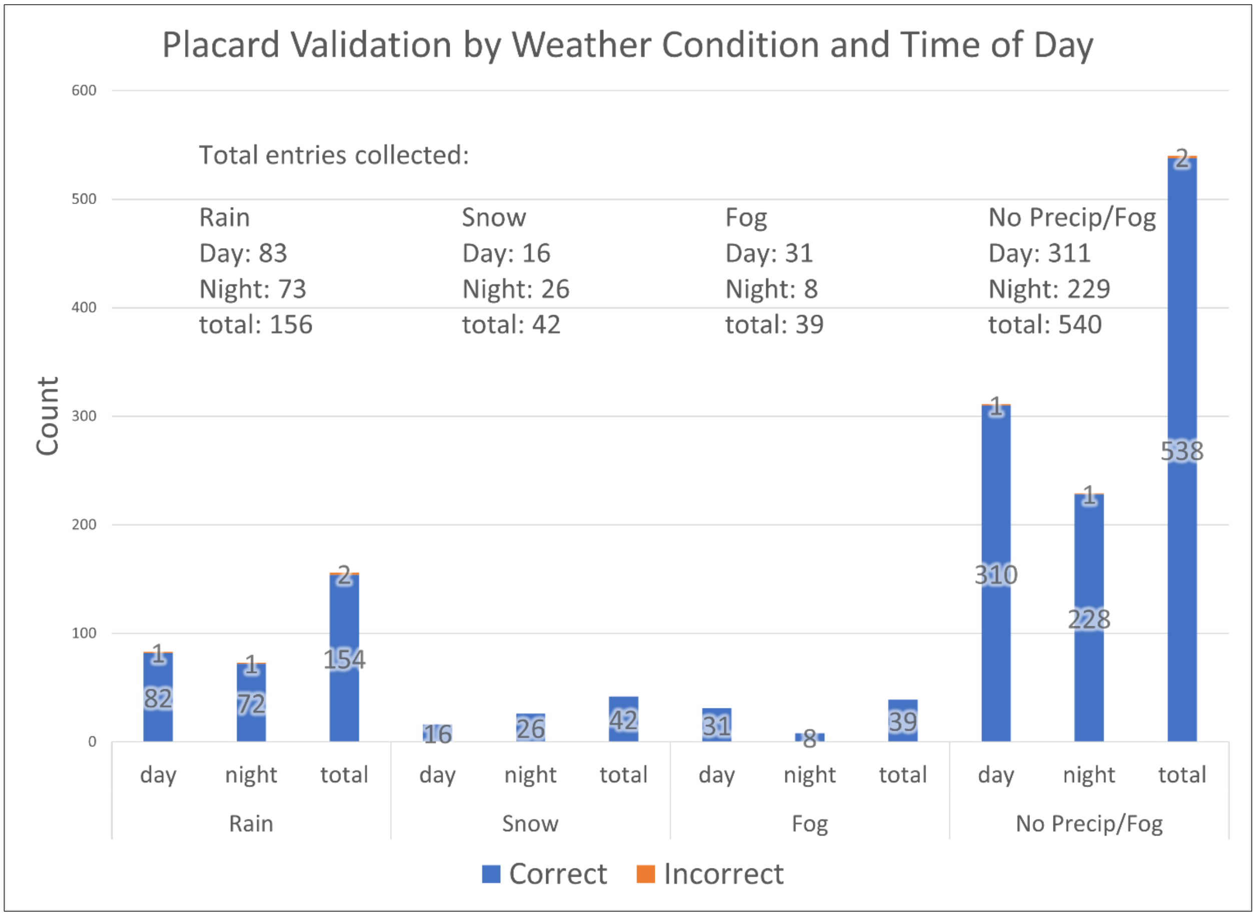

Figure 21. Delaware Site Placard Validation, Viewed by Each Different Weather Type and Time of Day

Key Findings from the Data

Weather conditions and time of day do not appear to have a significant impact on the ability of the camera to correctly identify passing HAZMAT placards. Additionally, while there was a 2.5% difference in daytime versus nighttime data, capture rates do not appear to be significantly affected by the change in lighting that occurs throughout the day. This could be due to several factors, but most likely of these is the APRS's use of near-infrared camera imagery to assist in reducing issues due to glare, obscuration, or any other aspect that may affect visibility.

The APRS appears to have some difficulty in capturing USDOT numbers and the license plates of passing vehicles, regardless of the site analyzed, as the capture rates range from 19% to 67.2%, depending on the entry type and location. While HAZMAT placards have strict regulations on placement and visibility, the relative lack of standardization and increase in variation of license plate and USDOT number placement, position, and contrast may explain this discrepancy. License plates can be placed in many different locations, can be obscured by debris (e.g., snow/brine, mud, etc.) from other vehicles that are disturbing the ground in front of them, or may not appear on the front of a vehicle at all. Unlike HAZMAT placards, USDOT number regulations lack a more standardized font and color. From the data reduction process, it is also likely that regulations do not require these numbers to be printed in high contrast to the color of the vehicle surface where it is placed. In these instances, human reviewers of these images are likely to better determine the information than the camera in cases where the image may be distorted or otherwise difficult to classify.

During the analysis, the data were searched for false positive entries, events in which a HAZMAT placard was seemingly detected on a vehicle where none were visible, to determine a rate of false positives. Of all the events reviewed during the data reduction process, there were 15 vehicles classified by the APRS trailer that were given the “Mislabeled” entry, meaning the reviewer noted the image did not match the generated classification. Six of these images were either blank placard holders or images of objects on the vehicle being mistaken for placards. The remaining nine had placards present but the generated classification did not match the image observed during the data reduction process (e.g., a Flammable placard mistakenly classified as Explosives). For the Delaware site, only one placard was considered mislabeled, which was an entry of a placard not correctly classified. In total, these 16 entries make up roughly 1% of the 1,533 entries reviewed during reduction, leading to a 0.1% false positive rate for the Delaware site, and a 1.9% rate for the mobile APRS.

APRS Placard Detection

Data acquired on the Smart Roads, I-77, and the Delaware site were used to assess whether the APRS was able to classify placards and other vehicle data correctly. However, this assessment is limited only to those placards detected, and subsequently classified, by the APRS. To assess the APRS’s ability to successfully detect placards on a vehicle, a false negative survey was conducted while the APRS trailer was deployed at the I-77 site. Video footage was captured using a camera independent of those on the APRS. This was done to help determine if a prevalence of false negatives exists, and if so, to quantify this value. This footage was captured on the final day of deployment, within the last hour before the system was removed from the location. In total, there is 40 minutes of footage that was analyzed for the afternoon of March 8, 2022. In this analysis, two separate surveys were conducted. One focused only on vehicles with HAZMAT placards, and the other looked at each passing commercial vehicle.

In the HAZMAT-placard-focused survey, the video footage was reviewed for every passing commercial vehicle in the outer lane (Table 10). In the 40 minutes of footage, 13 total commercial vehicles passed by the APRS that the reviewer determined had a placard attached to the trailer. Of those, 11 were captured by the APRS. This would mean a capture rate of 84%. However, in further analysis and research on USDOT guidelines on proper placard placement, it is likely that at least one of these two vehicles not captured were in violation of these guidelines. The first vehicle had only one placard visible by the reviewer, on the front of the trailer, between it and the truck cab, which contradicts the requirement that all HAZMAT carrying vehicles “must be placarded on each side and each end” (Figure 22) (General Placarding Requirements, 2023). The other entry was a propane truck with a placard printed on the curved tank on the rear of this vehicle (Figure 23). Other propane tanks were shown to have passed by the APRS and were captured without issue, so it is unknown why this truck was not captured by the trailer. But if the former truck, likely in violation of USDOT guidelines, was removed from the analysis, the capture rate of passing HAZMAT placard trucks would be 91.7% (11 out of 12 captured).

Table 10. False Negative Survey, Capture Rates Based on Reviewed Footage vs. Vehicles Detected by APRS

Video details:	40 Minutes of footage, from 1:08:53 p.m. to 1:48:53 p.m. on 3/8/2022
Survey of All Passing Vehicles:	Total vehicles reviewed from footage: 237 27 of these vehicles had potential to be captured by the APRS but should not, as the system is designed: 19 tractor trailers travelling in the inner lane, 6 pickup trucks with large trailers, 1 U-Haul moving truck, and 1 motorhome-style recreational vehicle. These entries were removed from the final total. Adjusted total of vehicles: 210 Total vehicles detected by APRS: 174 174 /210 = 83% capture rate for all passing commercial vehicles.
Survey of HAZMAT Placard Vehicles Only:	Total HAZMAT vehicles reviewed from footage: 13 Total HAZMAT vehicles captured by APRS: 11 11/13 = 84% Accuracy Likely one of the vehicles not captured was in violation of USDOT regulations on HAZMAT placard placement. Placard only visible on the front of the trailer. If removed from the final total: 11/12 = 92% capture rate for any passing HAZMAT vehicle.

Figure 22. Potential False Negative, Still Image from Captured Footage Showing the Only Visible Placard on the Vehicle, Meaning Likely Not a False Negative

Figure 23. Example of a False Negative, Still Image from Captured Footage Showing the Placard Clearly Visible, Likely Meaning a True False Negative

For further analysis, the same footage was reviewed an additional time, but considering every commercial vehicle instead of only HAZMAT vehicles (Table 8). This allowed for a higher sample size (174 total captured by APRS vs. 11 HAZMAT-only entries), a clearer determination on capture rate of the APRS, and a better understanding of the prevalence of false negatives.

The reviewer was tasked with identifying each passing commercial vehicle in the outer lane. In addition, the reviewer also identified and noted each commercial truck in the inner lane and any large non-commercial vehicle in the outer lane, such as any passenger trucks with trailers, campers, and box/moving trucks. These other vehicle types could potentially be captured by the APRS if it classified them as commercial vehicles. These entries are not meant to be captured by the APRS, so if the trailer did not capture these vehicle types, or any of the trucks in the inner lane, they were removed from the final capture rate.

In this analysis, 237 total vehicles were reviewed. Of these, 19 were trucks in the left lane, 6 pickup trucks with large trailers, 1 U-Haul truck, and 1 large motorhome-style recreational vehicle. These 27 vehicles were not captured by the APRS, per the system design, and were removed from the final result, leaving 210 total vehicles from the survey. Of these, 174 were captured by the APRS, meaning an 83% accuracy of recording all valid passing commercial vehicles. There is a potential for a small number of other entries to be invalidated. For instance, on two occasions, a VDOT vehicle was driving on the shoulder alongside the commercial vehicle while they both passed the APRS camera, possibly causing a missed entry. Additionally, one truck was changing lanes as it was passing the APRS, possibly causing it to be outside the capture zone. However, removing these entries only slightly increased the accuracy rate to 84%.

Due to the variability of the placement of a mobile APRS like the trailer used in this study, it is possible this is simply a cause of inaccurate placement of the system. Because the stationary site's accuracy rate from the HAZMAT placard data analysis was higher than the trailer (99.5% vs. 96.5%), this same survey could potentially be completed at a stationary site to determine whether the false negative rate is also lower from a more robust system. A stationary APRS is better able to standardize the placement and angle of the instruments used in the classification process, which makes for a system more receptive to improvements in the capture rate by making minor adjustments. Such minor adjustments are more difficult with a mobile APRS. Additionally, the APRS trailer used in this study was at least 10 years old at the time, with no apparent hardware upgrades or improvements since then. With a stationary APRS, it would likely be simpler to replace old components as they wear out or become obsolete.

APRS Implementation Considerations

Proper operation of an APRS requires its placement adjacent to the travel lane to be monitored. Two installations are required for coverage of a two-lane highway. Only the innermost and outermost lanes of a segment of more than two lanes can be monitored by the APRS due to the increased distance between APRS sensors and the vehicles, and obscuration resulting from vehicles traveling in adjacent lanes. Installations on innermost lanes requires adequate space for pole-mounted system components. A different APRS configuration than that currently in use could provide for center lane monitoring if gantry-mounted sensors and ancillary equipment were used to read forward license plates and rear-mounted placards. In this installation scenario, however, reading USDOT numbers would be difficult if not impossible. The approximate cost of a permanent roadside APRS installation capable of monitoring one lane of traffic as of mid-2021was approximately $300,000. Given the recent effects of COVID-19 and inflation, this cost is likely significantly higher now.

CONCLUSIONS

- *While permanent and mobile, trailer-mounted APRS systems perform well at properly reading visible placards (99% and 96% accuracy, respectively), recognition of respective USDOT numbers and license plate numbers is much less reliable. USDOT numbers were read by the permanent and mobile systems at accuracies of 43% and 67%, respectively, and license plates were read at accuracies of 43% and 39%, respectively.*

- *Lower accuracies for USDOT number and license plate reading may decrease the overall effectiveness of the system, especially in automated notification scenarios where such identification data are used for cargo tracking and tunnel entry verification (e.g., camera-based license plate reading).*

- *Although not observed during this investigation, visual obscuration created by heavy precipitation, fog, and smoke is likely to adversely affect system performance as far as locating and reading all APRS data once a certain threshold of visibility obscurity is reached.*

- *Given typical traffic speeds, none of the potential APRS site locations along this segment of I-77 would provide adequate advance warning of the approach of placarded cargo of concern.*

- *The existing APRS user interface is not conducive to providing automated alerts to VDOT tunnel and Traffic Operations Center (TOC) personnel.* The interface presents placard data in a format targeted towards active enforcement operations where relevant numeric and graphical information is pulled by the user from the web-based system. Raw and reduced data stored online is not accessible in a numeric (e.g., tabular) format that can be queried directly or received via a pushed data stream. Current users of this system in New Jersey are not using the APRS data for real-time applications.

RECOMMENDATIONS

1. *Given the current data access and APRS system location limitations described above, use of an APRS to provide advanced warning to tunnel operators regarding the approach of hazardous cargo is not currently practical and should not be pursued by the Virginia Transportation Research Council.*

2. *VDOT should consider implementation of an APRS to provide for increased situational awareness to tunnel operators in scenarios where an incident has already occurred within the tunnel and additional information on the presence of HAZMATs may be useful.* Tunnel operators could manually access APRS data and potentially tunnel traffic entry/exit camera data to determine whether placarded cargo of concern is located within the tunnel during the incident. Tunnel entry/exit camera data are not currently recorded, so a short duration of recording would be required to make this application viable. Alternatively, placement of an APRS at the entrance, and potentially exit of a tunnel, would negate the need for data from traffic cameras.

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, no further action is required.

With regard to Recommendation 2, The Bristol District Traffic Operations Director will conduct a follow-up analysis to assess the potential benefits and costs of deploying one or more APRSs at the I-77 tunnels within 1 year of publication of this study.

Benefits

The benefits of implementing Recommendation 2 include:

- Improved safety – Verification of the presence and type of hazardous cargo within a tunnel during an incident would allow emergency personnel to more safely respond in situations where the visibility of placards may be obscured by smoke, vehicles, and other objects.
- Improved Tunnel Operations – The improved situational awareness afforded by better information regarding the presence and type of HAZMAT involved in an incident may provide decreased clearance times and reduced congestion.

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