Creating a Smart Connected Corridor to Support Research into Connected and Automated Vehicles

June 2022 | Final Report

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16. Abstract
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Abstract

As connected and automated vehicle (CAV) technologies rapidly advance from concept to in-vehicle testing, real-world testbeds equipped with the appropriate technologies to support testing of these vehicles is a requirement. Testing must occur on multiple fronts, including communications and safety, to fully explore and vet the non-traditional methods these vehicles will use for communication, as well as to understand the potential benefits of these approaches. While the testbed must be equipped with traditional Intelligent Transportation System monitoring equipment and the new infrastructure elements to support CAV applications, it should also be designed as a flexible and extensible environment to support future needs. Within such a testbed, research questions concerning system design and safety application development issues can be addressed. This research project was intended to define the needs and requirements for a CAV testbed plan. The project was successful in defining needs and requirements, establishing a plan that was approved by all operating agencies, and securing initial funding. Ultimately, the testbed was not constructed due primarily to challenges of COVID-19, including supply chain procurements and cost increases.

Acknowledgements

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Table of Contents

List of Figures

Introduction

In November 2016, the United States Department of Transportation (USDOT) solicited proposals for a pilot program of designated automated vehicle proving grounds via a Federal Register Notice. The solicitation included broad criteria for selections to include a demonstration of capable safety planning, willingness, and ability to share and disseminate information, and an ability to show that all applicable laws, regulations, and policies are always adhered to. The solicitation also requested information on the types of facilities and research capabilities that are available to applicants to test automated vehicle technologies.

In January 2017, the USDOT announced the following 10 designees from more than 60 entrants:

1. City of Pittsburgh and the Thomas D. Larson Pennsylvania Transportation Institute
2. Texas AV Proving Grounds Partnership
3. U.S. Army Aberdeen Test Center
4. American Center for Mobility (ACM) at Willow Run
5. Contra Costa Transportation Authority (CCTA) & GoMentum Station
6. San Diego Association of Governments
7. Iowa City Area Development Group
8. University of Wisconsin-Madison
9. Central Florida Automated Vehicle Partners
10. North Carolina Turnpike Authority

The intent of designating grounds was to foster innovations that can safely transform personal and commercial mobility, expand capacity, and open new doors to disadvantaged people and communities by fostering a new mobility future. Additionally, the proving grounds were expected to provide critical insights into the numerous questions relating to connected and automated vehicles (CAVs) and big data, as well as building a community of practice around CAV research. However, a major impediment to developing this community of practice was that the designation carried no funding, leaving designees to self-fund any improvements or infrastructure needed to enhance the overall testing capabilities.

Within the Texas AV Proving Grounds Partnership, the Texas A&M University System is one of three premier research entities. The Texas A&M University System contributes to the RELLIS campus, a 2,000-acre reinvestment (see Figure 1) uniting future-focused companies, faculty, and students in a unique, 21st-century community purposely built to foster advanced research, technology development, testing and evaluation, higher education, and hands-on career training. The Texas A&M Transportation Institute is a major stakeholder in the RELLIS campus and has used the facilities for all levels of project, vehicle, and infrastructure testing for decades.

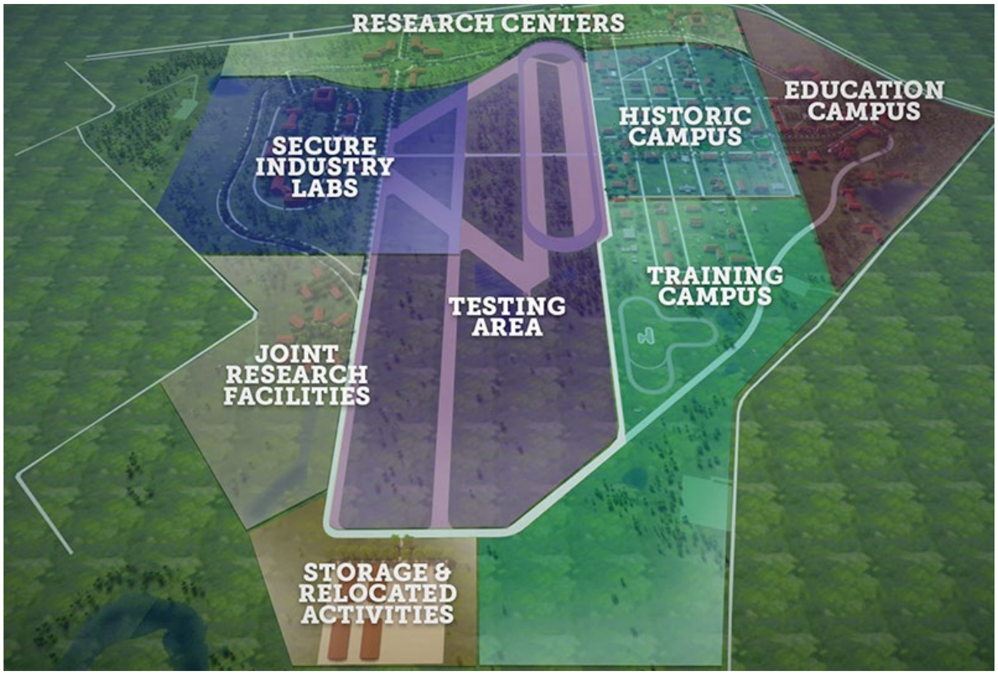

Figure 1. Map. RELLIS Campus at Texas A&M University.

The Texas A&M University and the RELLIS campus are located approximately 8 miles apart and connected by a rural high-speed state roadway designated SH-47 (see Figure 2). It is this facility and the unique intersection it holds between the academic departments of the campus and the research proving grounds that make it ideal to develop as a real-world testing component in the CAV arena.

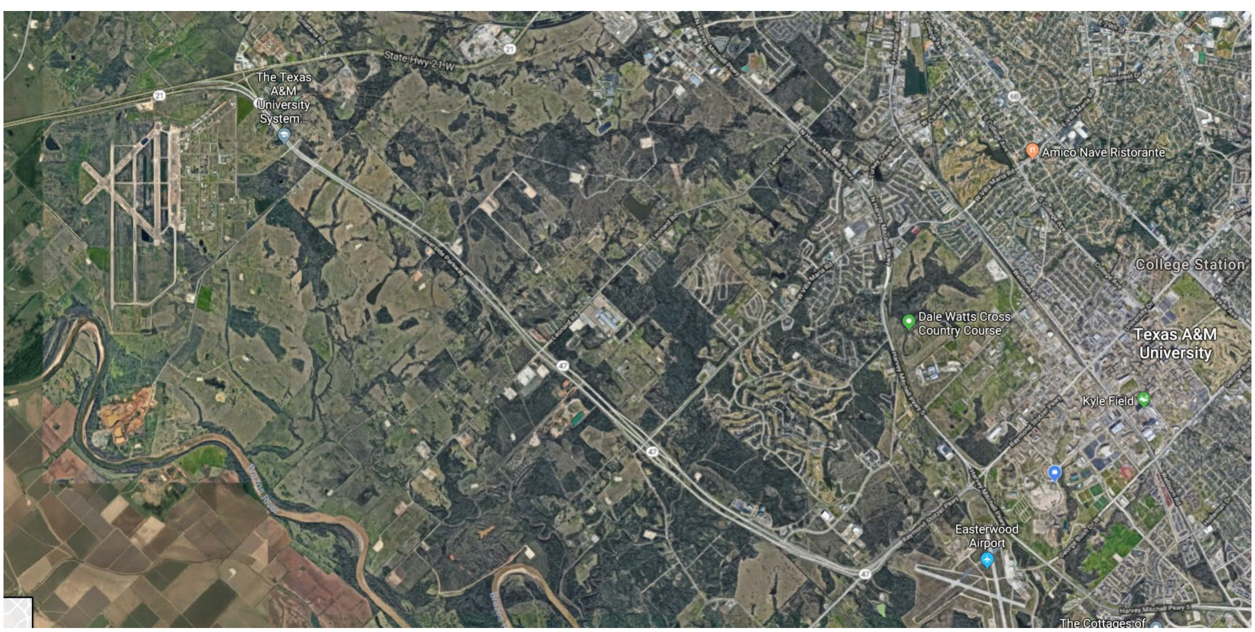

Figure 2. Photo. SH-47 linking RELLIS and the Texas A&M University.

Background

The monitoring of infrastructure generally requires manual investigation to determine status and safety readiness. Creating a smart and connected safety corridor that would contain significant monitoring capability would dramatically increase the data, analytics, and the ability to construct and test CAV safety and mobility applications. The primary question to be addressed in this research was how to develop SH-47 as an extension of the Automated Vehicle Proving Grounds concept to provide real-world testing capabilities for the CAV arena, particularly in the area of safety applications. With a complex mix of ramps, interchanges, at-grade intersections, diverse topography, and cross-sections, SH-47 can make a valuable contribution to the body of knowledge being developed for CAV operations. The questions that were intended to be answered by this research are:

1. What are the needs and requirements for a CAV testbed?
2. What level of CAV infrastructure is necessary for testing, including safety applications?
3. What are the costs of building a complete testing facility?
4. What big-data management techniques and resources must be developed to manage the resulting environment?

Project Methodology

The following tasks were identified to accomplish the goals of the project.

Task 1: Project Management

This task included the necessary activities to monitor and document the progress of the project, including required periodic project updates, teleconferences and other communications with sponsors, and budget tracking. Specific deliverables from this task include required quarterly progress reports, the biannual activity survey, the final report, and any additional requirements for University Transportation Center project tracking.

Task 2: Institutional Liaisons

SH-47 is a public roadway and as such is owned and operated by the Texas Department of Transportation (TxDOT) in the Bryan District. Prior to the development of any plans and/or the procurement and placement of infrastructure, a robust discussion, agreement, and approval process must take place with TxDOT to ensure their support of this project. Specific deliverables were anticipated to be a memorandum of understanding between TxDOT and the Texas A & M Transportation Institute (TTI) detailing the overall plan and the scope and phasing of any infrastructure deployments.

Additionally, SH-47 is bordered on the southern end by Easterwood airport, a regional airport owned and operated by the Texas A&M University. As flight paths from both departing and arriving flights pass over SH-47, liaison activities must also be conducted with the airport to ensure that any devices placed within the roadway do not interfere with airport operations in terms of both their physical characteristics (height, placement, reflectivity) and operating environment (communications band, power outage). Specific deliverables were a submission of locations and equipment specifications to the airport, which in turn were be submitted by the airport to the Federal Aviation Administration (FAA) for clearance in visual and electromagnetic interference.

Task 3: User Group Input

The project team recognized that the diverse environment within the CAV arena means that multiple users are likely to use SH-47, each for applications and needs specific to their research. It was anticipated, however, that some fundamental needs would be widely uniform across all users. What was critical to accomplish via this task was a comprehensive process of engaging fellow researchers and ascertaining their suggestions for building out the SH-47 environment to support CAV testing. The primary information gathering component for this activity was a user group meeting where project staff provided an overview of the project, updated its status, and asked focused questions to solicit optimum feedback from the group on their desired needs and capabilities for deployment.

Task 4: SH-47 Deployment Plan

Building on the outcome of the Task 3 user group meeting, the project team developed an overall deployment plan for SH-47. It was recognized at the outset of this project that sufficient funds were not available for the complete deployment necessary to support every research desire. As such, a deployment plan was constructed that focused on fundamental data gathering capabilities while providing flexible and extensible infrastructure for additional deployment and growth as funding became available. The plan detailed the locations, technologies, and costs necessary to accomplish this critical first step. It was anticipated that the deployment plan would ultimately span several phases over multiple years.

Task 5: Procure and Deploy

Building the facility was the goal of Task 5 efforts. Significant efforts were spent on the financial components of this task. While funds were available from several sources, detailing what sources would be most efficient to pay for what parts of the deployment was a time-consuming undertaking. Additionally, due to COVID-19 delays and supply chain issues, this process had to be repeated several times to both procure materials and personnel available to work on the construction. Ultimately, the team was not able to deploy the plan within the budget and time allocated for the project. The project plan presented in this report can serve as a blueprint for future deployments when sufficient funds become available and supply chain issues are resolved.

Task 6: Safety Application Testing

The true test of the efficacy of the design and deployment process will be an initial demonstration of how the corridor can be utilized to test applications related to CAVs. Architecture Reference for Cooperative and Intelligent Transportation (https://www.arc-it.net/) lists multiple connected vehicle safety applications across both vehicle-to-infrastructure and vehicle-to-vehicle operation modes. Following the start of construction, the project team intended to reconvene the user group and determine which safety applications are best suited for testing in an initial corridor deployment.

Project Results

This section summarizes the activities and results of the tasks performed throughout the duration of the project. Task 1 is not included due to being project management.

Task 2: Institutional Liaisons

Two agencies were identified for liaison activities prior to developing a deployment plan.

Texas Department of Transportation

SH-47 is a public roadway and as such is owned and operated by TxDOT's Bryan District. Prior to the development of any plans and/or the procurement and placement of infrastructure, an approvals process was initiated with TxDOT. The process was initiated by in-person discussions with District personnel and an overview of the project goals and desired activities. Discussion topics included the Department's non-exclusive geographic area license to operate equipment in all channels of the 5.9-GHz band, future construction plans for the SH-47 corridor, and the potential integration of equipment with Lonestar, the Department's Advanced Transportation Management Software solution.

As this corridor would be a research testbed for developing technologies, the individual sites are envisioned to be operated on an as-needed basis corresponding to the research needs. TxDOT and TTI agreed that inclusion of these devices would negatively and erroneously affect the District's device uptime reporting. By means of further explanation, Lonestar reports on the uptime of devices by periodically contacting them electronically and recording a response. If a response is not received, the device is registered as offline, which counts against the mandated District uptime goal of 100%. Operating the corridor with the devices in Lonestar but operating on an as-needed basis would significantly reduce the uptime reporting percentages achievable by the District. Furthermore, as these sites develop, new types of equipment are envisioned to be installed, for which no Lonestar drivers or data interfaces exist. TTI committed to providing direct access to baseline devices such as closed-circuit television (CCTV) as support to District traffic operations needs during significant events, such as home football games for Texas A&M University.

Easterwood Airport

SH-47 is bordered on the southern end by Easterwood Airport, a regional airport owned and operated by the Texas A&M University. As flight paths from both departing and arriving flights pass over SH-47, liaison activities were conducted with the airport to ensure that any devices placed within the roadway would not interfere with airport operations in terms of both their physical characteristics (height, placement, reflectivity) and operating environment (communications band, power outage). This process took place with an initial meeting with the airport manager and subsequent submission of materials to the FAA through the airport staff. All currently identified equipment and locations passed the FAA vetting procedures with no interference forecast by either physical proximity, reflection, or electromagnetic radiation.

Task 3: User Group

The user group meeting included TTI personnel from multiple research divisions, the information technology department, and TTI administration. The listings below detail the findings related to several discussion areas.

Corridor Development

Key concepts identified for the development of the SH-47 corridor included:

- Place or corridor needed for testing
    - Intelligent Transportation System (ITS) technology
    - Communication technology
    - T-intersection/visibility technology
    - Connected infrastructure
    - Infrastructure support for autonomy (e.g., truck platooning)
- Need for high-resolution data collection capability at least at critical points
    - Speeds
    - Counts
    - Travel time
    - Ground truth data needs (by lane, per vehicle record)
- Wrong-way driving and cross-traffic alerts have been discussed in the past as having possible application along the corridor, even though these two are not specifically called out in the Connected Vehicle Reference Implementation Architecture.
- Need for GPS correction capability (local corrections or mapping)
- Transit technology (since this is the primary connection between RELLIS and the main campus)
    - Use of machine vision and alerts for speeds, off-tracking, etc., such as the Roscoe Mobileye Shield+ system on a more widespread basis
- Work zone testing as it relates to the connected vehicle environment
    - Congestion warning
    - End of queue warning
    - Smart sign testing (might need to be non-work-zone as well)
- Game day applications
- Airport information
- Possibility to test weather issues along corridor (e.g., fog)
- Monitoring cell phone usage in vehicles (surrogate: measuring number of occupants)
- Capability to monitor minor roads (need vehicle sensors at one or two critical minor roads)
- Deployment of cameras at critical intersections
    - Use of CCTV for vehicle/lane information

- Wider use of INRIX data for ground truth (e.g., traffic counts and speeds)
- New methods for data management (e.g., infrastructure)
- Ground truth data needs (by lane, per-vehicle)

Data Needs Brainstorming

Key data needs mentioned were as follows:

- Place cameras at critical points as noted herein and cover all directions.
- Volume and speed (per vehicle, by lane) by time interval and by direction
- CRIS (Crash Records Information System) database
- Data included in SAE Standard J2735 (include timestamp) vehicle classification
- Travel time
- Atmospheric weather data
  - Surface condition data
  - Visibility data
- Location information
- Work zone activity
  - Queue length
  - Queueing patterns
  - Map of work zone (e.g., lanes closed)
- CCTV
- Pavement issues
  - Ride quality
  - Pavement marking reflectivity
- Naturalistic driving
  - Connect with roadway elements
  - Connect with weather elements
- Specially equipped vehicles
  - Vehicle(s) equipped with On Board Unit (OBU)
  - Vehicle(s) equipped with eye tracking
- Time base: accurate clock and methods to synchronize all clocks
- Bluetooth equipment
- LIDAR equipment
- Equipment for pedestrian and bicycle monitoring
- Traffic signal information

Deployment Options Brainstorming

User group participants discussed the following concepts to guide the development of a deployment plan.

- Place cabinets near power source.
- Use existing infrastructure to the extent possible (e.g., poles).
- Might consider solar power on case-by-case basis if no grid power
- Ground truth is critical, and location depends on the variable being measured.
- End points are important.
- Mid-point for cross-traffic issues

- Weather considerations
    - Overall weather condition warning
    - Based on excessive speed and weather
    - Geometric features combined with weather
    - Roadway condition warning
    - Visibility warning
- Consider location for drone use.
    - Site to launch
    - Airport approval
    - Extensive list of rules
- CCTV deployment
    - Continuous coverage in space
    - Continuous coverage in time
- Consider testing where needs are met.
    - Horizontal tangent sections
    - Curved sections (e.g., ramps)
- The wide median with heavy vegetation may require monitoring each direction separately.
- High priority: get Per Vehicle Record (PVR) data at high resolution at 3-4 critical locations.
    - Critical mid-point is Leonard Road.
    - Gibson Bend (gravel pit) is important due to truck access.
- Consider input from police, fire, and other emergency services.
    - RELLIS served by Bryan Fire Department
    - Police
- Data privacy may be a concern with all the data monitoring capability that might happen.

Task 4: Deployment Plan

This section details the initial deployment plan developed from the discussions in Task 2 and 3.

The SH-47 corridor was intended to serve as a testbed for CAV transportation technologies and applications in cooperation with TxDOT and TTI. It should be noted that usage of the terms "SH-47 corridor" or "corridor" includes the 8-mile stretch between FM-60 and SH-21, as well as the eastbound approach of SH-21 that fronts the RELLIS campus.

TTI planned to deploy several ITS stations along the corridor at opportune locations to host traffic sensors and to provide resources where researchers and vendors can bring new transportation technologies for experimentation as part of a research effort. Figure 3 provides a visual listing of the planned locations, initial equipment deployment, and the distance between each location.

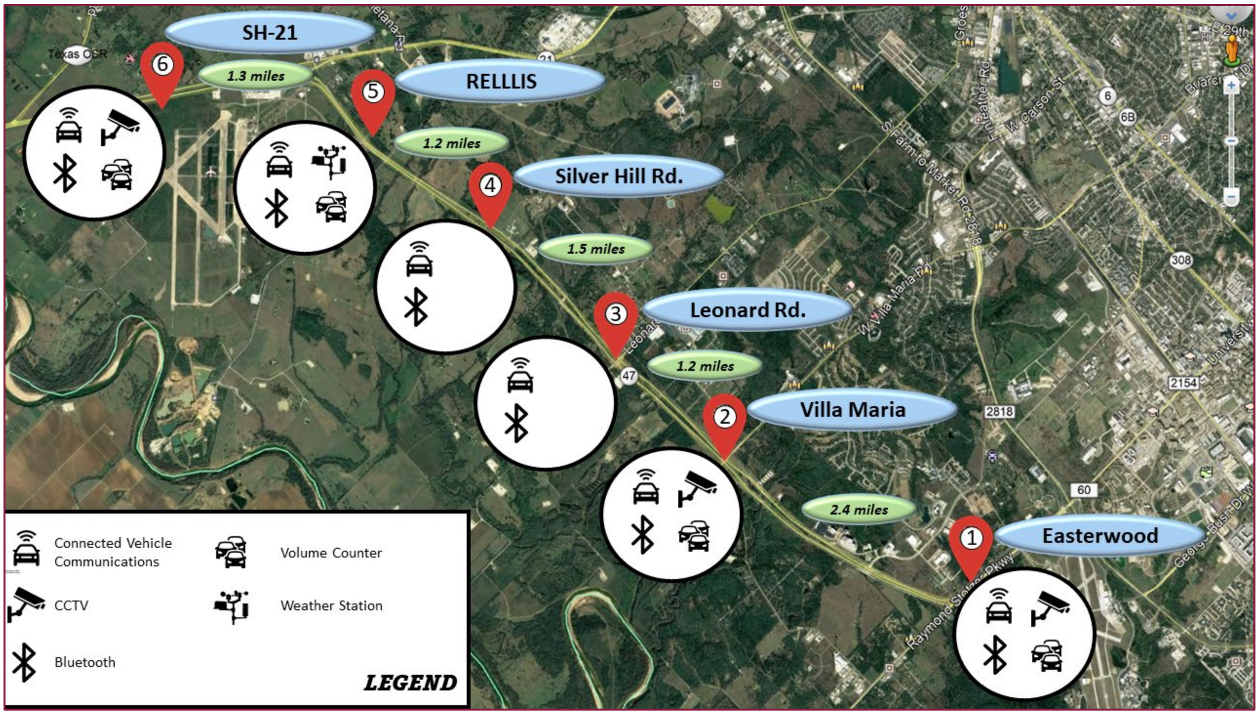

Figure 3. Map. Initial SH-47 deployment overview.

Each site was designed to be able to gather traditional traffic data in the form of traffic speed and volume, as well as provide video at some locations. TTI designed each field site to host the equipment to support functions for current deployment needs and provide extra space for new devices or temporary research equipment.

As part of the deployment plan development, multiple field visits were conducted at each site. At least one site visit at each location included representatives from TTI, TxDOT, and the deployment contractor that would be performing the installation work. Figures 4 through 9 illustrate some of the detailed notes about each location.

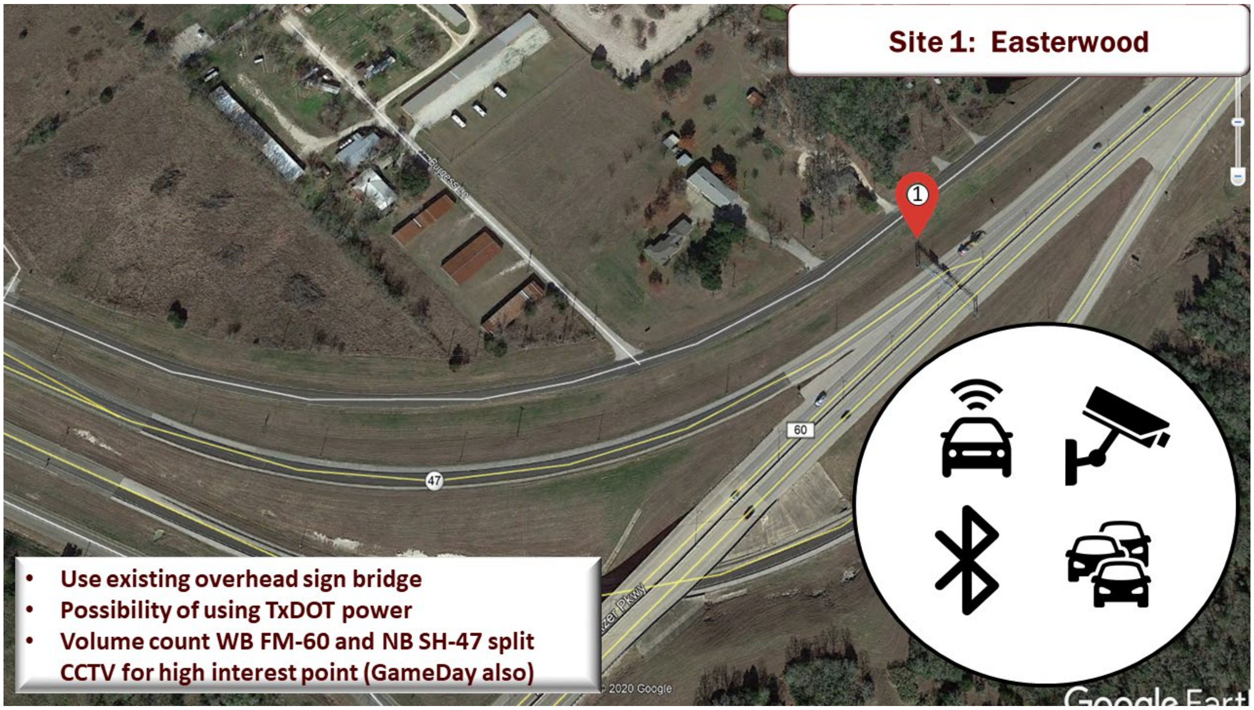

Figure 4. Photo. Easterwood airport location detail.

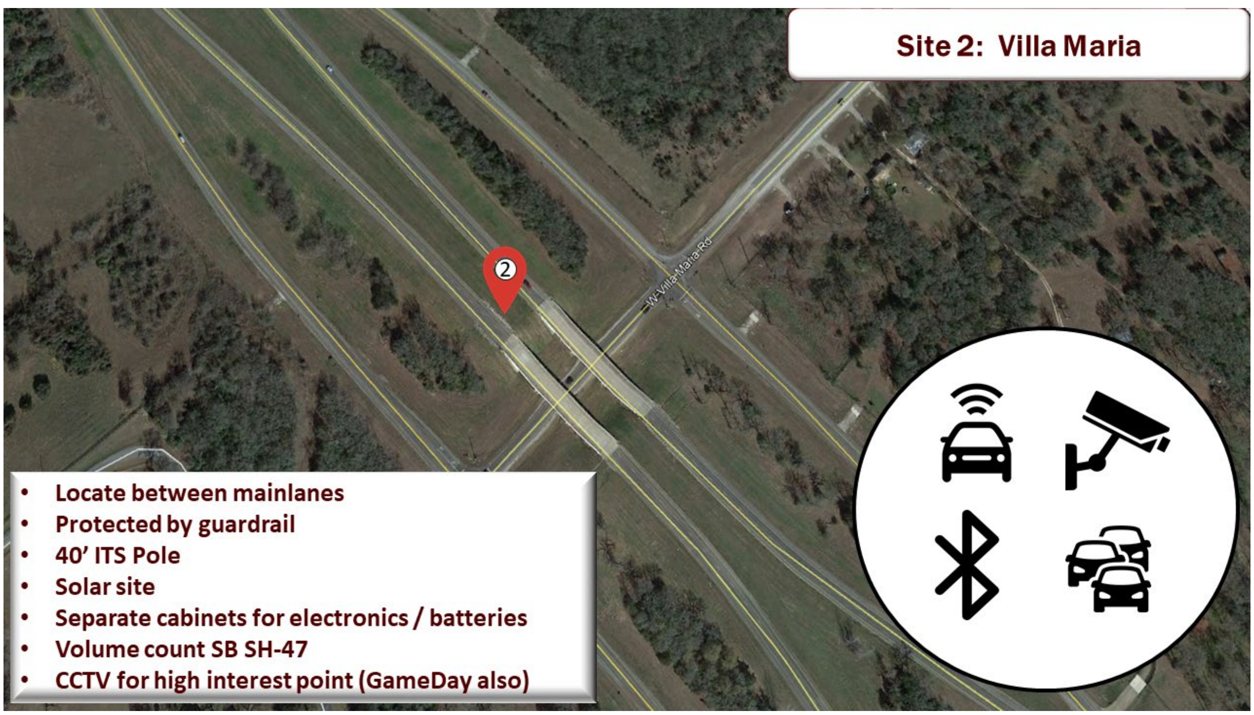

Figure 5. Photo. Villa Maria location detail.

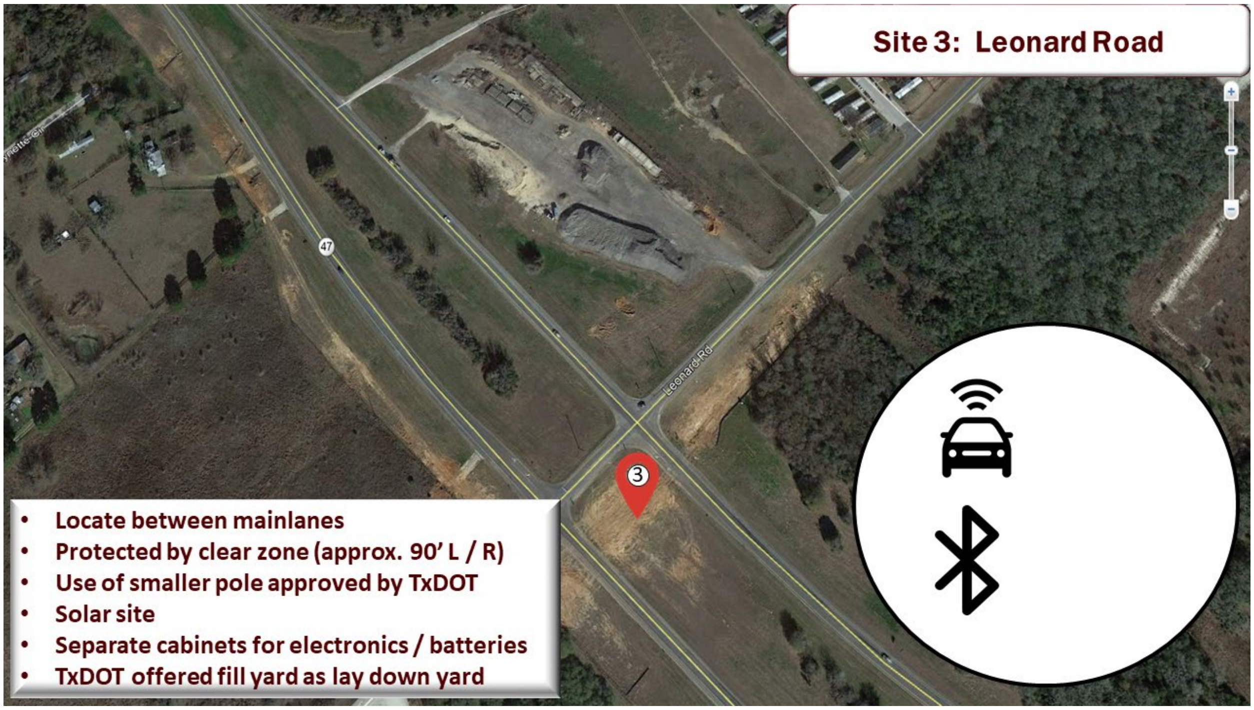

Figure 6. Photo. Leonard Road location detail.

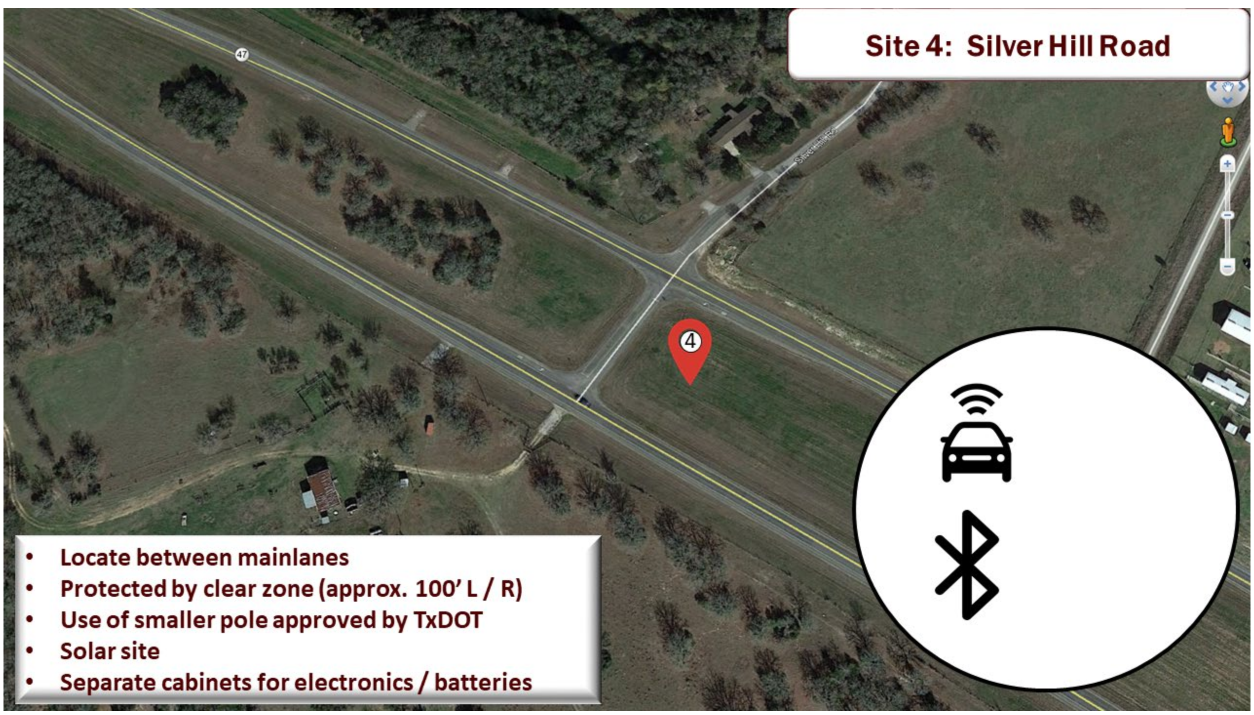

Figure 7. Photo. Silver Hill Road location detail.

Figure 8. Photo. RELLIS Entrance location detail.

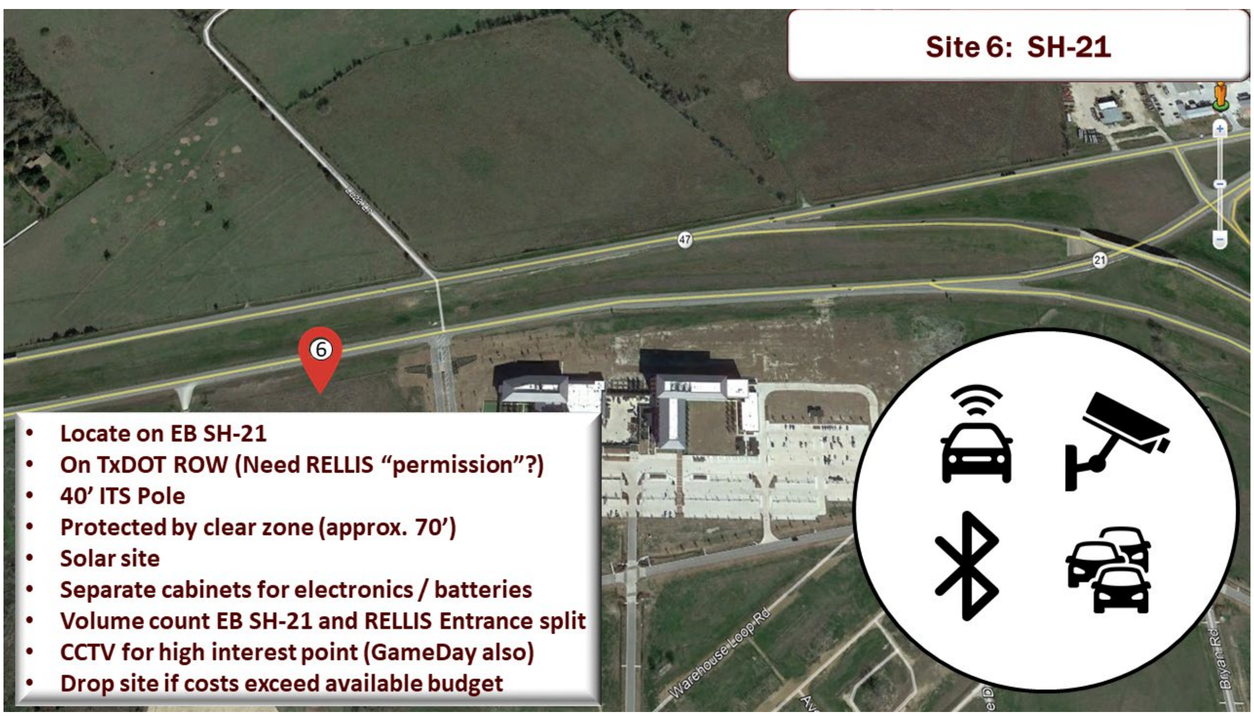

Figure 9. Photo. SH-21 location detail.

The following sections provide information on detailed design questions pertaining to the corridor.

Power Equipment

Permanent vs. Solar Power

The sites were not envisioned to be AC powered. The estimated cost outlay for AC power significantly exceeded the baseline funding available, particularly in locations that are in the median of the SH-47 roadway and would require boring as part of the power drop. Additionally, the process of developing AC power drops at non-standard locations, such as highways, is a time-consuming process. While AC power could arrive in future site updates, all site deployments were designed for solar power due to cost (both initial and ongoing), and the efficiency of establishing sites rapidly.

Solar Power Components

Being solar, the sites must use batteries for energy storage and batteries must be well managed to ensure longevity. An inherent part of managing power is understanding consumption. For instance, one limitation of solar panels is that the energy gathered is reduced in the winter months due to the tilt of the Earth. This reduction is coupled with shorter days, increasing the probability of overcast and dark days. This limitation was considered throughout the design process and helped determine the configuration of the ITS stations' power equipment.

Each site was planned to include a minimum of four 120-watt solar panels that would be held using two mounting fixtures. Each fixture would support two solar modules and be attached to a steel pole supported by a concrete base s strong enough to handle the wind loading on the panels. See Figure 11 and Figure 12 for representative solar panel mounting scenarios for sites along the corridor.

The multiple high-watt solar panels will produce significant current while illuminated. The solar system design was meant to operate efficiently regardless of these currents. By using a 24-volt DC system design for both the generation (panels) and storage (battery) components, the elevated voltage will allow the current in the main feed lines to be half that of a 12-volt system. This allows for smaller, less expensive, energy management equipment. All solar equipment will produce 24 volts, or 12 volts per panel, and panels mounted on a single fixture will be wired in series and wired in parallel to the other pair to meet input needs.

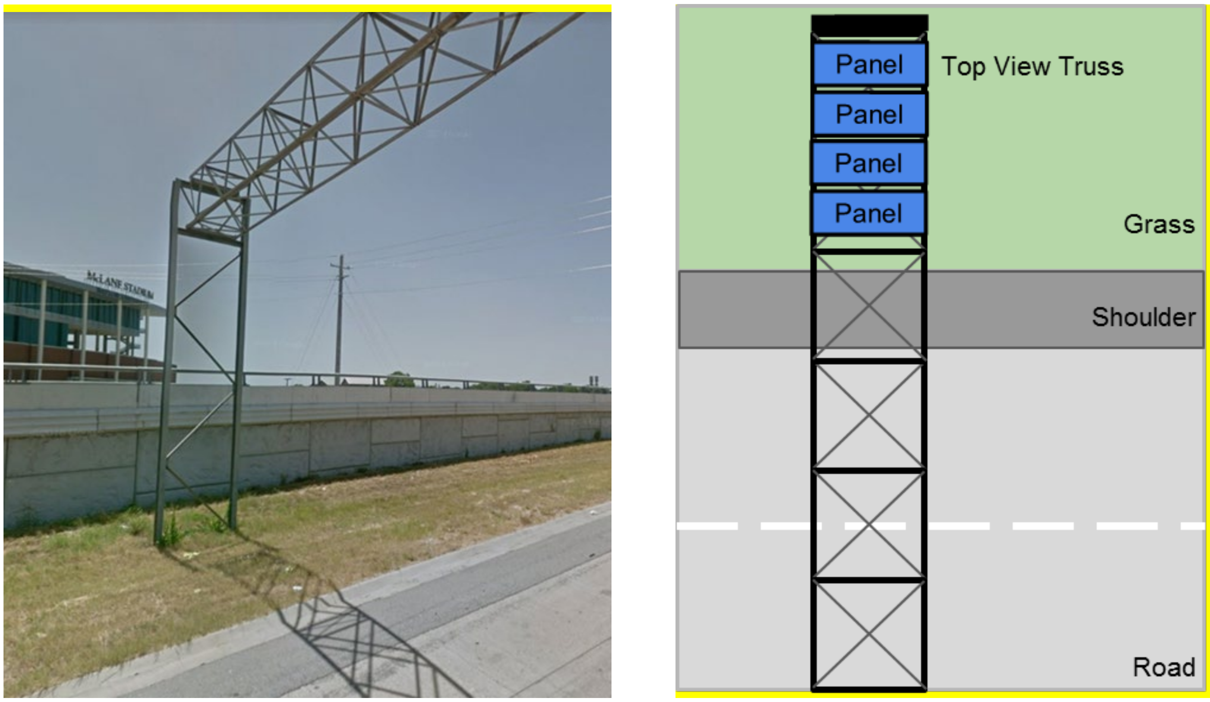

Figure 10. Photo and Diagram. Typical solar panel installation – top of truss.

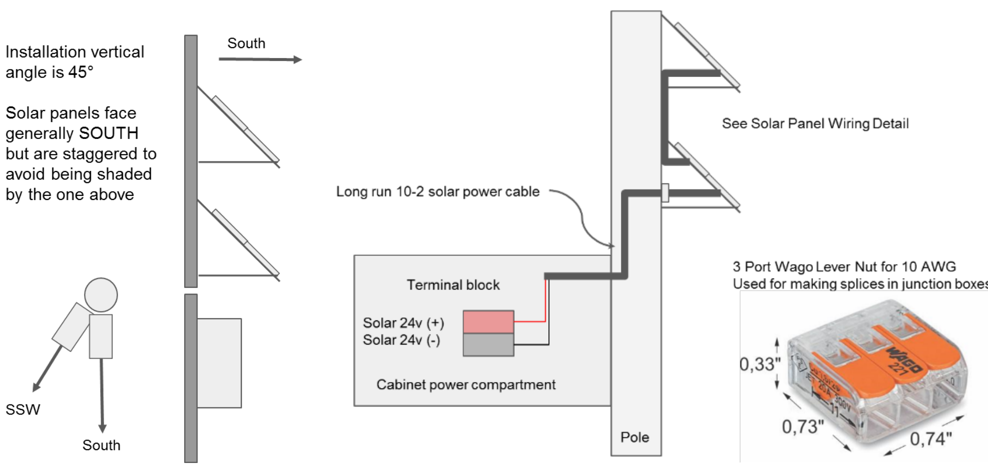

Figure 11. Diagrams. Typical solar panel configuration – pole.

A Morningstar controller, PS-30M, was planned for each site. This device can manage 30 amps of continuous current. This would not only work well with the initial system but allow additional solar panels to be installed if needed with this type of controller. The setup yields approximately 16 amps at 24 volts DC in full summer sun, while yielding 13 amps in the winter. Elaborate Maximum Power Point Tracking solar management will not be used, thus the full rated power from panels will be achievable.

Battery

Given that cabinets were planned to provide extra space for equipment, it is quite possible that several test and measurement devices will be operating simultaneously for the duration of a test cycle. Sufficient battery capacity was planned to provide power during periods of low or no sunlight. Batteries provide energy during periods when the solar panels cannot generate enough energy. More batteries are always better, but they are large, expensive, heavy, and have a lifespan influenced by how they are utilized. The batteries were planned to be no-maintenance sealed batteries for safety and longevity purposes. The site design included eight 12-volt 100 amp hour batteries, installed and configured in 24-volt DC groups. Power draw from the on-site traffic sensors was estimated to be 50 watts or 2 continuous amps at 24 volts DC. This does not include any extra test measurement or computational equipment.

The batteries are heavy (approximately 70 lbs.) but still able to be moved by one person. Larger batteries are discouraged due to weight. They will be sized very similar to an automobile battery at approximately 13 × 6.75 × 9.5 inches. The battery bank can store up to 9.6 kilowatt hours of energy (label capacity). The load will be relatively low, and thus the battery bank does not require high current capacity derating. At the onset, the label capacity will be able to power the site in full operation at the expected load for a continuous period of 8 days. This capacity will decrease as the batteries age. Future operations and maintenance activities will have to include a battery change approximately every 3 years. However, the solar panels should be able to provide energy even on overcasts days, which will help offset the drain on the battery bank during inclement weather.

A low power DC to AC inverter was included to support low power external AC equipment that might be used as part of research at a site. The AC line will not be sufficient to operate higher power AC devices such as motors. The concept was to provide a universal power point for equipment such as notebook PCs, vendor specific equipment that does not directly support DC input, and specialty power supplies. The inverter would be power draw intensive and would likely need to be handled as a special load directly tied to the battery bank with associated battery drainage limits and current management. The planned power equipment for each site includes:

- Four 120-watt (minimum) solar panels
- Eight 100-amp hour batteries
- One 30-amp solar controller with remote management capability
- One solar management adapter (USB to Morningstar MODBUS)
- One remote equipment management solution (four on/off switches for resident load equipment). This board will control relays selected to meet the switched load current.
- Several 24-volt DC circuit breaker protected terminal blocks to be used by extra external equipment to gain access to base power
- Multiple 24-volt DC circuit breaker protected power pick off blocks
- One lower capacity DC to AC inverter for use by low power AC equipment such as a notebook PC

Sensors

Since energy is always at a premium, all sites were planned to have the ability to remotely control resident sensors and systems by turning them fully on and off in concert with the need for their data. The equipment at these sites would not be operated continuously if there was not a defined reason for the data gathering. This was to be accomplished by using a router with discrete port control. A typical unit with port configurations is shown in Figure 13. Several 24-volt DC power terminal blocks will be provided for external equipment to access power. The external block sections are protected with circuit breakers protected for safety. The equipment at each location is identified in Figure 3.

Connected vehicle Roadside Unit (RSU) - 10 watts

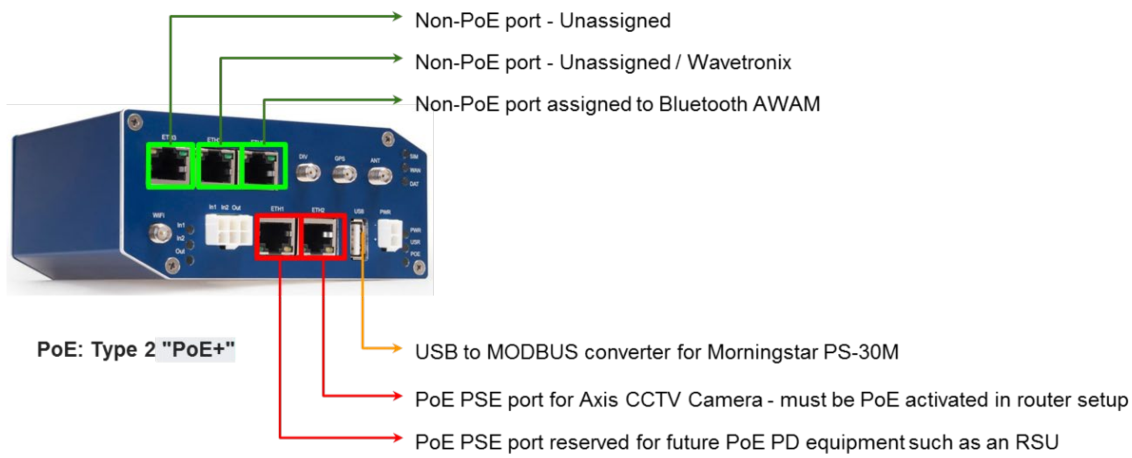

Figure 12. Diagram. Typical router with port assignments.

Cabinet Housing

Any equipment deployed along the roadside must meet all TxDOT specifications for the application. This includes steel poles, concrete bases, mounting hardware, conduit, etc. Equipment cabinets were specified to support current and future equipment including PCs, sensors, and test measurement equipment, as well as digital communications (see Figure 13 through Figure 15).

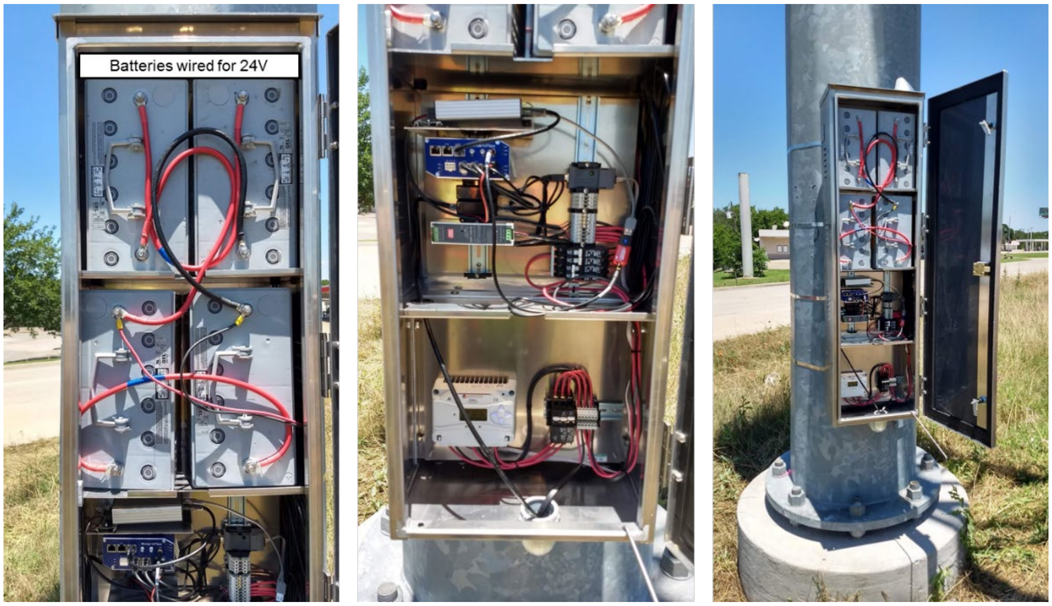

Figure 13. Photos. Typical pole mounted cabinet and battery installations.

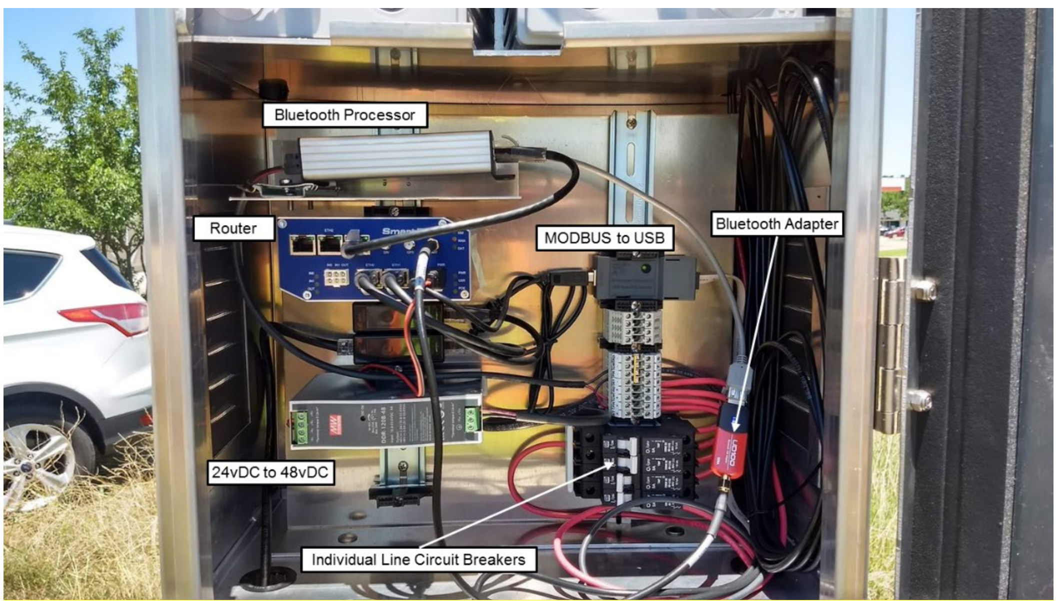

Figure 14. Photo. Typical traffic signal cabinet installation on pedestal base.

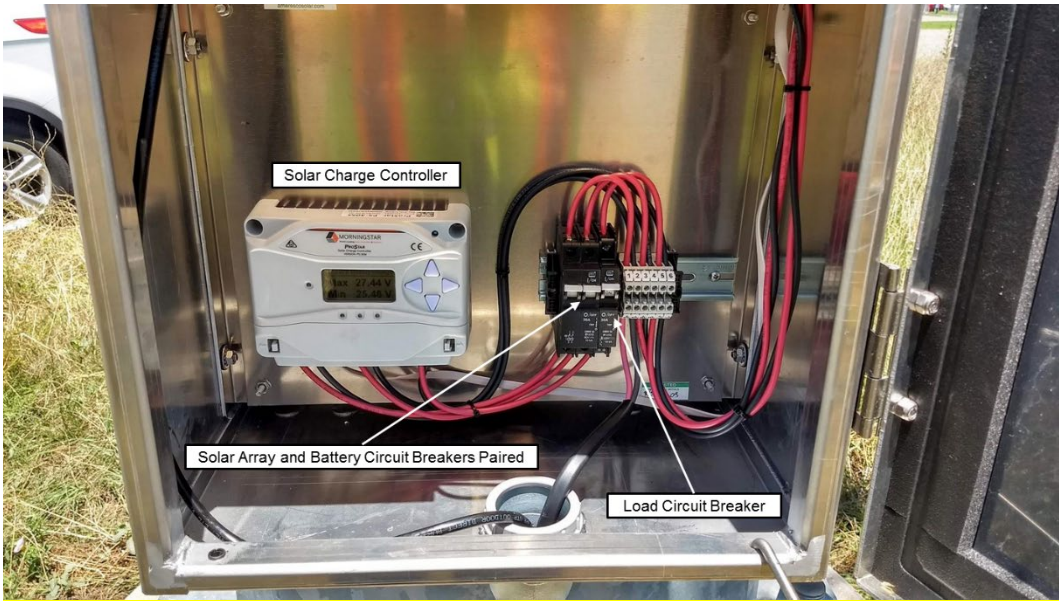

Figure 15. Photo. Solar array equipment in cabinet.

Figure 13 shows a cabinet assembly that has been developed for use in the Waco district. This cabinet, which is highly suited to roadside installations of ITS equipment, has been submitted to TxDOT's Traffic Safety Division for inclusion in the statewide ITS standards.

Figure 14 shows a traffic signal cabinet. For many ITS-equipment-only installations, the size of this cabinet is overkill and overall deployment costs can be reduced by utilizing the new standard shown in Figure 13. However, in some installations for SH-47, particularly those in the interior, a larger cabinet with significant expansion room may be preferred. In these cases, the location of the batteries is variable. They could either be stored at the bottom of the traffic-signal-sized cabinet with sufficient ventilation or mounted to a pole. Another possibility was to have a stand-alone battery cabinet on a base with a conduit connection to the traffic signal cabinet.

In all cases, TTI met with TxDOT Bryan District personnel to conduct a site visit of each location and determine the best cabinet options for safety, expansion, and project cost. Additional site visits were planned post the approval process to ensure construction and deployment matched the detailed planning.

Communication Equipment

All sites were planned to have a continuous internet connection supplied by a cellular router. Much like the power draw described previously, turning off various equipment, such as cameras when not needed, will reduce the overall data usage. Cellular router equipment interfaces are typically Ethernet and RS-232. Further defined functionality includes the following:

- Hardened to operate in an outdoor environment that will be hot and cold
- Efficient design delivering a low power draw

- Power over Ethernet Power Sourcing Equipment (PoE – PSE) capability to support Power over Ethernet Powered Devices (PoE-PD) equipment. Examples of PoE-PD equipment are CCTV and roadside unit (RSU) digital communications.
- Multiple uncommitted Ethernet ports available for external equipment. This can be supplied by an additional hardened unmanaged Ethernet switch. A baseline recommendation is a minimum of four uncommitted Ethernet ports to allow for easy expansion and temporary usage.
- Flexible cellular radio technology allowing the equipment to fully operate with all the common cellular providers.
- Virtual private network capability, as acquiring service with a static Internet Protocol (IP) address is becoming difficult and can add an extra expense.
- Reasonable diagnostic information available in a web interface for remote management and system analysis
- Wi-Fi access point capability that can be activated to extend the broadband network to locations around the cabinet itself for flexibility.
- Surge protection for all Ethernet lines that are external to the cabinet to protect from nearby lightning strikes. The surge suppression equipment must support PoE.
- Multiple antennas inside single dome to keep the external appearance clean, compact, and efficient.
- Antenna needs: Cellular band(s), Bluetooth (2.4 GHz), Wi-Fi (2.4 GHz)

Discussion

During the project activities, the foundational goals of developing the needs and detailed requirements for a CAV testbed corridor were accomplished. Additionally, detailed financial planning, utilizing multiple funding sources with differential rules, was accomplished. Liaison activities were conducted and approvals received from the related operational or impacted agencies for SH-47. Ultimately, delays regarding staff availability from COVID-19 and pricing markups due to supply chain issues made the project infeasible to continue. An additional funding issue was expiration of funds available from different sources and the inability to extend those funds to cover the delays in the procurement chain and installation capability, which arose from the pandemic. Multiple reduced deployment configurations were identified and examined, such as removing SH-21 or Silver Hill Road to reduce costs. This would have been sub-optimal for the baseline desired functionality, and the procurement timeframes from supply chain issues could not be overcome. In conjunction with SAFE-D leadership, a decision was made to stop all work efforts.

Lessons Learned

Several important lessons were learned from this project.

- Generating consensus on foundational capabilities was difficult. While extensive expertise contributed to the overall wish list, reducing the stated needs to an initial plan with future phased developments and enhancements was a time-consuming effort.
- Marrying disparate funding sources in the academic and research environment with different rules and expiration dates made for challenging financial accounting.
- Navigating the complexity of the regulatory approvals process from the infrastructure owner/operator took far longer than anticipated. While the local District approved the plan, central administration components had to review and sign-off, which was a lengthy process. TxDOT standard specifications are not designed for research applications, and getting approvals required significantly more costly infrastructure (poles and cabinets) than originally anticipated.

Ultimately, the challenges presented due to cost increases and time delays proved too difficult to overcome.

Additional Products

The Education and Workforce Development (EWD) and Technology Transfer (T2) products created as part of this project can be downloaded from the project page on the Safe-D website here. The final project dataset is located on the Safe-D Collection of the VTTI Dataverse.

Education and Workforce Development Products

Due to the decision to stop work, no education or workforce development products were completed. The objectives were to use a student to help develop the site equipment solutions, as well as helping with the deployment and testing of the selected safety applications. The construction of the safety applications was also seen as educational development, as these applications are nascent in the real-world beyond automotive OEMs and will provide specific and valuable knowledge for developing future and more complex applications.

Technology Transfer Products

Due to the decision to stop work, not all the desired technology transfer products were developed. However, the detailed planning, coordination, and approvals process with both TxDOT and the FAA (via Easterwood Airport) constituted significant technology transfer. Neither local agency representative is sufficiently experienced developing these types of resources on their own.

Data Products

Due to the decision to stop work, no data products were developed.