

SMART Grant Program Final Implementation Report

Smarter Intersections Pilot Project SMARTFY22N1P1G52

Recipient Name: Texas Department of Transportation

Fiscal Year of Award: 2022

Period of Performance: September 15, 2023, to March 15, 2025

Organization Preparing the Implementation Plan: Texas A&M Transportation Institute

Submission Date: June 27, 2025

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Section One: Executive Summary

The Stage 1 *Smarter* Intersections Pilot Project focused on five intersections in College Station, Texas, a midsized community and home to Texas A&M University, the largest university in the state. With the large student population, College Station has a high volume of walkers, bikers, and bus riders. The project was conducted over an 18-month period from September 15, 2023, to March 15, 2025.

The Texas Department of Transportation (TxDOT) was the SMART Grant recipient; and the Texas A&M Transportation Institute (TTI) conducted the project. Other project partners included the City of College Station, Texas A&M University Transportation Services, the Brazos Transit District, and Beep, an automated shuttle operator.

The *Smarter* Intersections Pilot Project deployed and tested smart infrastructure technology in College Station to achieve two main goals: improve intersection safety and mobility for pedestrians, bicyclists, and mobility device users, including people with mobility and visual disabilities; and demonstrate that the technology functions as proposed. Technologies used in the project fell within the categories of connected vehicles, intelligent sensor-based infrastructure, and smart technology traffic signals. The project used cellular vehicle-to-everything (C-V2X) roadside units (RSUs) at five intersections in tandem with onboard units (OBUs) on 49 Texas A&M University buses to alert pedestrians and bicyclists using crosswalks and bike lanes of turning buses through an audible message “Caution bus turning” and an illuminated outline of a bus above the pedestrian sign. The project also developed and tested a smartphone application (app) for use by blind/low-vision (B/LV) individuals to use to navigate the intersections. In addition, the project simulated communicating this information with an automated shuttle and a fire truck.

The performance of the system was monitored over a four-month period from November 2024 through February 2025. The daily log files from the intersections were used along with visual monitoring to examine the accuracy of the system. Overall, the system performed as anticipated, with a 99 percent accuracy rate of detecting the equipped buses and activating the illuminated bus sign and audible alert. The response to the *Smarter* Intersections was positive from the different user groups. Eighty eight percent of the pedestrians, bicyclists, and other individuals interviewed crossing at selected pilot intersections responded that the bus sign and verbal message were helpful for all or helpful for some people crossing the street, making the intersection safer. Texas A&M University bus operators provided positive feedback on both the audio and the visual alerts through an online survey. The B/LV smartphone app worked as anticipated and received positive feedback from the three B/LV individuals and the three typical-vision individuals who tested it. Simulating communication with an automated shuttle and a fire truck was accomplished successfully.

Building on the success of the Stage 1 prototype a potential Stage 2 at-scale deployment in Corpus Christi was developed. The at-scale deployment would focus on equipping 12-15 traffic signals in a major corridor and at other selected intersections in the city and 118 buses. The at-scale project would improve safety at intersections with higher volumes of pedestrians and bicyclists.

Section Two: Introduction and Project Overview

Introduction

This document presents the Final Implementation Report for the Smarter Intersections Pilot Project Stage 1 U.S. Department of Transportation (USDOT) Strengthening Mobility and Revolutionizing Transportation (SMART) Grant. The project uses smart technology traffic signals, connected vehicles, and intelligent sensor-based infrastructure to improve intersection safety and mobility for pedestrians, bicyclist, and other road users. The Texas Department of Transportation (TxDOT) is the SMART Grant Recipient, and the Texas A&M Transportation Institute (TTI) is the state agency conducting the project, including preparing this Final Implementation Report. In addition to this report, a video on the project is available at <https://youtu.be/7yP2fzfx8XY> and the data on the operation of the intersections, the surveys and interviews, and simulating communication with an automated shuttle is available at the ROSA P Repository and the Texas Data Repository - Texas Digital Library. The report is divided into the following sections based on the revised Stage 1 Implementation Plan Guidance provided by the USDOT.

- **Section Two: Introduction and Project Overview**
Following this introduction, a project description is provided, including the issues and challenges the project addresses, the geographic areas for Stage 1 and Stage 2, and the technologies being deployed. The goals and desired outcomes for Stage 2 at-scale deployment are presented. It also describes the Stage 1 prototype scale and the anticipated scale for Stage 2 deployment. The activities undertaken during Stage 1, including key milestones, partners, and outcomes are described. The conference presentations and media coverage on the project are highlighted. The work conducted is also compared to the scope of the original proposal. One change from the initial proposal is the location for the Stage 2 at-scale project. As outlined in the Stage 1 proposal, the Metropolitan Transit Authority of Harris County (Houston METRO) had expressed interest in participating in Stage 2. Due to staffing changes at the executive level, METRO was not able to commit to participating in Stage 2. The Corpus Christi Regional Transit Authority (CCRTA) and the City of Corpus Christi were interest in participating in Stage 2 and TxDOT and TTI worked with CCRTA and city representatives to develop a scope for a Stage 2 at-scale project.
- **Section Three: Stage 1 Prototype Evaluation Findings**
This section discusses the evaluation, methodologies, and findings from the Smarter Intersection Pilot Project based on the evaluation questions, performance measures, and performance targets presented in the Evaluation Plan. The data collection methods are discussed. The evaluation also describes how the prototype addressed the goals in the grant proposal, the original project expectations, and the relevant statutory language.
- **Section Four: Anticipated Costs and Benefits of At-Scale Implementation**
This section discusses the anticipated impacts of at-scale implementation for each of the key goal areas outlined by the USDOT. It includes the costs of the Stage 1 prototype and the estimated Stage 2 at-scale implementation, how the deployment and operational costs of at-scale implementation will be compared with the benefits and savings the project will provide. The baseline data that will be collected for the at-scale implantation are highlighted.
- **Section Five: Challenges and Lessons Learned**
This section describes the challenges and lessons learned from the Smarter Intersections Pilot Project related to legal, policy, and regulatory requirements, procurement and budget, and

partnerships. Other topics covered include technology suitability, data governance, workforce capacity, internal project coordination, community impact, public acceptance, and cybersecurity.

- Section Six: Deployment Readiness

This section discusses the requirements for successful implementation and possible obstacles to scaling the *Smarter* Intersections Pilot Project. The ten topics outlined in the lessons learned section are considered in this assessment. Potential uncertainties and risk mitigations are identified. The ongoing maintenance and operating requirements for continuing the pilot project are discussed, along with the capacity to make possible improvements and prevent technical debt. Finally, the potential impacts on workforce development and the availability of good paying jobs are explored.

- Section Seven: Wrap Up

This section focuses on the *Smarter* Intersections Pilot Project meeting expectations, potential changes for at-scale implementation, and advice for other communities considering similar projects and technologies.

- List of Technical Terms

Table 4 presents the technical terms used in this report.

Project Description

Issues and Challenges

After decades of progress in reducing traffic fatalities, they are back on the rise. As reported by the National Highway Traffic Safety Administration, traffic fatalities increased 10.5 percent between 2020 and 2021, reaching levels not seen since 2005. According to TxDOT, 1 in 6 traffic fatalities involve a pedestrian, and 1 in 50 involve a bicyclist. Nationwide, pedestrians died in 25 percent of fatal crashes involving buses in 2020, and recent stories of bicyclists and pedestrians dying in bus crashes can be found in local Texas news stories in Houston and Austin. While new technologies like autonomous and connected vehicles promise to greatly increase the efficiency of the transportation system, they must also improve safety – especially for pedestrians, bicyclists, and individuals using other mobility devices. This project directly addressed this problem by providing auditory and visual alerts about turning buses that will be moving through the user’s path of travel at signalized intersections.

Several smart intersection technologies have become popular on American roadways, such as transit signal priority and emergency vehicle preemption. While many of these technologies make traffic signals more efficient for a specific mode, they are not fully integrated between multiple road users in any meaningful way. This project addressed this issue through coordinating implementation with public and private entities using open-source technology and communication protocols. At-scale implementation in Stage 2 would further integrate traffic signals, bus operations, and pedestrian and bicycle safety.

Smarter Intersections Stage 1 and Stage 2 At-Scale Geographic Areas, Goals, and Technologies

The Stage 1 *Smarter* Intersections Pilot Project focused on five intersections in College Station, Texas. College Station is a mid-sized community with a population of just over 120,000 in 2021. It is also home to Texas A&M University, the largest university in the state with nearly 75,000 students. With the large student population, College Station has a high volume of walkers, bikers, and bus riders. There are also strong partnerships among the city, university, TxDOT, and local agencies.

Located along the Gulf of Mexico, Corpus Christi, Texas, the anticipated Stage 2 location, had a 2022 population of 316,239. The city has a large Hispanic population. Approximately 17 percent of the population are below the poverty level, which is about 1.4 times higher than the U.S. rate of 12.6 percent. The CCRTA provides regular route, paratransit, rideshare, and other services in the Corpus Christi area. The Stage 2 at-scale project would include signalized intersections along the Staple Street and Ayres Corridors, as well as possible stand-alone intersections with safety concerns. These corridors focus on lower income areas with large numbers of households without a motor vehicle available.

The Stage 1 pilot project included equipping 5 intersections with RSUs and other equipment and equipping 49 buses with on-board units (OBUs). The cost of the Stage 1 project was approximately \$1.9 million, with \$481,155 for equipment (\$316,155 for the intersection RSUs and \$165,000 for the OBUs). The actual equipment expenditures were slightly lower as fewer bus signs were purchased due to the final intersection selected. The Stage 2 project in the Corpus Christi estimated to include equipping 12-15 intersections with RSUs and 118 buses (83 fixed route buses and 35 paratransit minibuses) with OBUs. It is anticipated that the cost will be in the range of \$10 to \$12 million.

The *Smarter* Intersections Pilot Project deployed and tested smart infrastructure technology in College Station to achieve two main goals: 1) improve intersection safety and mobility for pedestrians, bicyclists, and those using other mobility devices, including people with mobility and visual disabilities; and 2) demonstrate that the technology functions as proposed. Technologies being used in the project fall within the categories of connected vehicles, intelligent sensor-based infrastructure, and smart technology traffic signals. The project used cellular vehicle-to-everything (C-V2X) units at five intersections in tandem with OBUs in transit vehicles to do the following:

- Alerted pedestrians and bicyclists using crosswalks and bike lanes of approaching and/or turning transit and emergency response vehicles. This alert was provided through the use of auditory and visual cues from pole-mounted devices that received information from the C-V2X RSUs.
- Explored the feasibility of incorporating that vehicle information into a smartphone application (app) that blind/low-vision (B/LV) people could use to navigate the intersections.
- Communicated with automated shuttles to alert them of turning transit and emergency response vehicles at the intersection.

The goals and desired outcomes for the at-scale deployment build on the Stage 1 activities. As described in more detail in Section 3, these goals focus on increasing safety, reliability, resiliency, and accessibility by reducing crashes at intersections, and providing more accessible information about the status of the intersections. The at-scale deployment will also support mobility options, and multi-group partnerships, as well as enhancing integration of data and operations at complex intersections.

The goals and outcomes of the at-scale deployment address the statutory language focusing on “improve the safety and integrating transportation facilities and systems for pedestrians, bicyclists and the broader traveling public and promote connectivity between and among connected vehicles, roadway infrastructure, pedestrians, bicyclists, the public, and the transportation system”

Smarter Intersection Pilot Project Stage 1 Activities

The partners in the *Smarter* Intersections Pilot Project included TxDOT, the grant recipient, with TTI conducting the project. Other public and private sector partners were the City of College Station, Texas

A&M University Transportation Services, the Brazos Transit District (BTD), and Beep, an automated shuttle operator.

As the grant recipient, TxDOT executed the contract with the USDOT and the interagency agreement with TTI, completed the financial submissions and reviewed deliverables prepared by TTI before submission to the USDOT. TTI was responsible for conducting all aspects of the project including finalizing the five pilot intersection, procuring and testing the equipment, assisting with installing the RSUs and OBUs, and monitoring and evaluating the operations at the intersections. TTI also developed and tested the B/LV app and conducted the interviews with pedestrians and bicyclists, and the surveys with the bus operators. Further, TTI researchers simulated communicating the intersection information with an automated shuttle and a fire truck. TTI organized and facilitated the Project Advisory Committee (PAC) and completed all required deliverables and participated in online and in-person SMART Grant meetings.

The City of College Station installed the RSUs at the five intersections, assisted with ongoing monitoring and evaluation activities, and participated in the PAC meetings. The City of College Station Fire Department assisted with simulating the communication with a fire truck and participated in PAC meetings. Texas A&M University Transportation Services installed the RSUs on 49 buses, assigned the instrumented buses to routes operating through the intersections, assisted with the surveys of bus operators, and participated in the PAC meetings. Brazos Transit participated in the PAC meetings. Beep assisted with simulating the communication with an automated shuttle and participated in the PAC meetings.

The *Smarter* Intersections Pilot Project was conducted over an 18-month period from September 15, 2023, to March 15, 2025. Initial project tasks included establishing the PAC and holding initial meetings, reviewing and finalizing the pilot intersections, and updating the equipment requirements. TTI researchers also developed protocols, scripts, recruitment processes, and other items for the interviews and surveys to be conducted throughout the project, as required with research involving human subjects. This information was submitted to the Texas A&M University Institutional Review Board (IRB) via the Huron online portal. The protocol was approved.

The project was not able to move forward with purchasing equipment until the National Environmental Policy Act (NEPA) review was completed and approval provided. It was anticipated that this review would be completed by the start of the project or during the initial months. USDOT notified TxDOT on January 30, 2024, that the NEPA review had been completed and that the pilot met the definition contained in 23CFT2 771.117(c)(1) for a categorical exclusion. Based on this approval, TTI began the procurement process. The later than anticipated approval did delay the project and resulted in a four-month demonstration period, rather than the initially anticipated six-month demonstration.

One of the first tasks conducted in the project was establishing the PAC. Representatives from all these partners were members of the PAC, including representatives from both the City of College Station Traffic Engineering, Signs and Markings Division and the Fire Department. The PAC also included representatives from the Texas A&M University Department of Disability Services and the Bryan/College Station Metropolitan Planning Organization (BCSMPO).

Six meetings of the PAC were held over the course of the project – September 12 and November 30, 2023, and March 7, June 27, and November 7, 2024, and January 30, 2025. The hybrid meetings were hosted by Transportation Services at their on-campus offices with online links. The meetings covered the key activities of the project and discussions on different topics. The PowerPoint presentations used at the meetings were distributed to PAC members. The March 7, 2024, meeting also included a tour of the City of College Station Fire Station #6 hosted by the fire department.

The Smarter Intersections Pilot Project proposal included five possible pilot intersections. These intersections were identified based on an initial review of bus routes, the traffic signal technology, pedestrian and bicycle activity, and the surrounding areas. Three of the initial intersections were found to have limitations in the traffic signal hardware or supporting elements after further onsite inspection by TTI researchers and discussion with the City of College Station and TxDOT personnel. Additional intersections were considered and analyzed. These intersections were discussed at the September 12 and November 30, 2023, meetings of the PAC. Figure 1 presents the final five pilot intersections agreed upon by the PAC for the project.

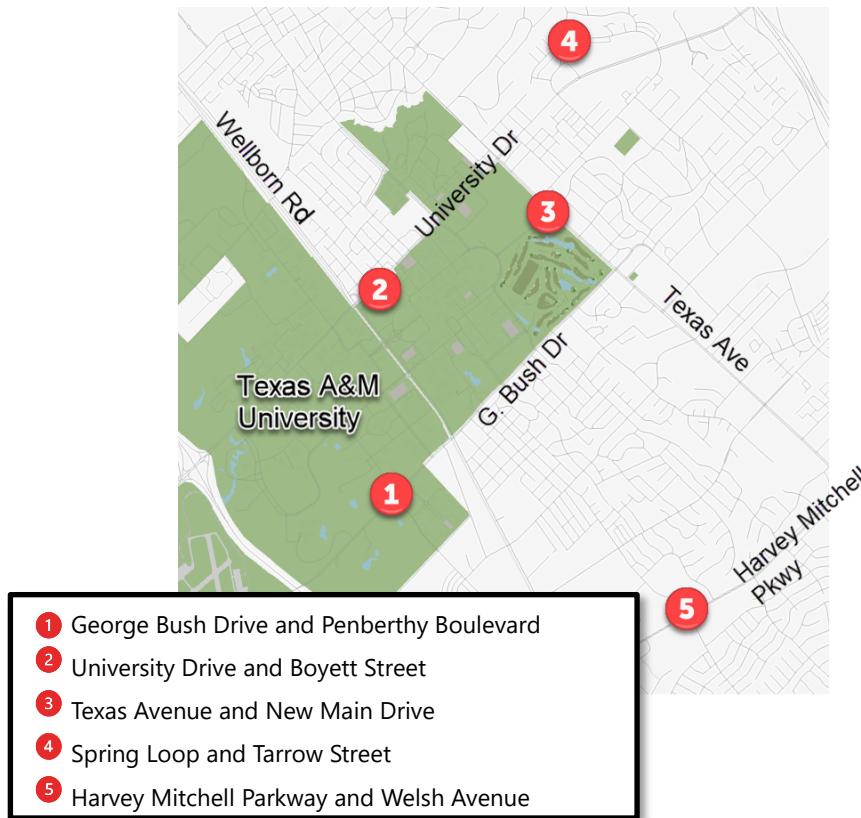


Figure 1. Final Pilot Intersections

TTI researchers conducted detailed assessments of the existing traffic signal system and pedestrian equipment at each of the five intersections. The need for new and upgraded C-V2X equipment was identified, based on the bus turning movements at each intersection. As an example, Figure 2 illustrates the Texas A&M University bus turning movements (yellow arrows) and the location of existing (black text) and new (red text) equipment needed at the University Drive and Boyett Street intersection. The

equipment included RSU, the bus sign, the Polara pedestrian system, the Bosch camera, and the traffic signal controller (TSC). A similar analysis was conducted at the other four intersections.



Figure 2. University Drive and Boyett Street – Bus Turning Movement and Existing and New Equipment

The initial equipment list contained in the proposal was updated early in the project. New quotes were obtained from various vendors. Based on the USDOT notification on January 30, 2024, that the NEPA review on the Smarter Intersections Pilot Project had been completed and the pilot project met the definition contained in 23CFT2 771.117(c)(1) for a categorical exclusion, TTI initiated the procurement process for the C-V2X equipment needed for the project. The delay in receiving NEPA approval did delay the procurement process and the installation of equipment at the intersection.

The equipment needs identified from the analysis at each intersection were used in the procurement process. The equipment was ordered in phases following TTI guidelines as a part of the Texas A&M University System. The equipment included RSUs, OBUs, Polara pedestrian detection system, LED Bus signs, traffic signal controllers, Bosch cameras, and other equipment. Two Iteris RSUs and three Yunex RSUs were procured. TTI researchers worked with the RSU vendors and the City of College Station on the installations. The City staff completed the field work for the equipment installations.

The following C-V2X messages are generated by the RSUs and are used in the description of the communication protocol, as well as the discussion of simulating communications with an automated vehicle and a fire truck.

- A Basic Safety Message (BSM) is broadcast by equipped vehicles, and contains the location, direction of travel, and speed of the equipped vehicle.
- A MAP message is broadcast by the RSU and defines the topology of an intersection including the approaches at the intersection, the stop line for each approach, the lanes available in each approach, and the movements available from each lane at the stop line.
- A Signal Phase and Timing (SPaT) message is broadcast by the RSU and complements the MAP message by providing the status (green, yellow, or red) for each lane movement defined in the MAP message and the time remaining in the status for that movement.

- A Signal Request Message (SRM) is broadcast by an approaching emergency vehicle or transit vehicle and provides information about the request for preemption or priority.
- A Signal Status Message (SSM) is broadcast by the RSU and contains information sent back to an emergency or transit vehicle to indicate that the preemption or priority request has either been granted or denied.
- The Personal Safety Message (PSM) is usually broadcast by an equipped pedestrian and contains their location, direction of travel and speed, like the BSM. However, since pedestrians' mobile phones are not ready yet to broadcast a PSM, this project used a Bosch camera to detect pedestrians at the intersection. The camera sends the information to the RSU, and the RSU generates and broadcasts a PSM to equipped vehicles to alert drivers about the presence and locations of pedestrians at the intersection.
- The Traveler Information Message (TIM) is broadcast by the RSU and is used to send information (advisory and road sign) to equipped devices. TIMs are activated for a specific start and duration period.

TTI researchers developed the communication protocol for the different RSUs. Figure 3 illustrates the protocol developed on a previous TxDOT research project using dedicated short range communication (DSRC) technologies to communicate between an intersection and approaching bus. An equipped bus with an OBU broadcast a BSM 10 times a second when approaching the intersection. The RSU at the intersection receives the BSM and sends it to the TTI personal computer (PC). The TTI PC communicates with the TSC to obtain signal status, and detector status and to activate the BUS sign as a visual alert. The TSC also communicates with the cabinet to activate the audio alert in the Polara pedestrian equipment.

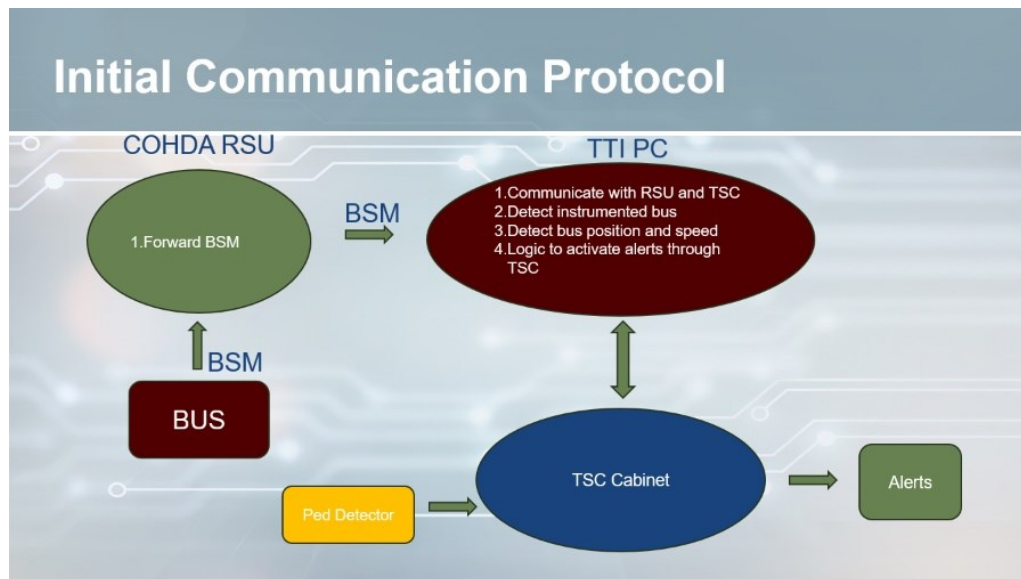


Figure 3. Initial System Communication Protocol

To take advantage of the latest C-V2X equipment and capabilities TTI used RSUs from both Iteris and Yunex systems in this project. Yunex RSUs were installed at the University Drive and Boyett Street, Texas Avenue and New Main Drive, and Harvey Mitchell Parkway and Welsh Avenue intersections. Iteris RSUs were installed at the George Bush Drive and Penberthy Boulevard, and Spring Loop and Tarrow Street intersections. Figure 4 illustrates the communication protocol using Iteris equipment.

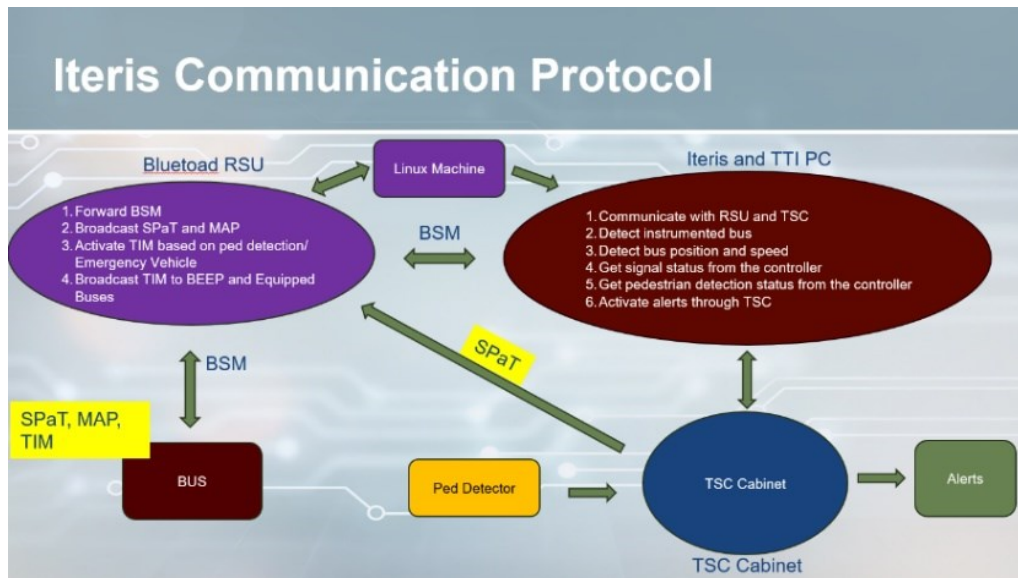


Figure 4. Communication Protocol Using an Iteris RSU

An equipped bus with an OBU broadcasts a BSM 10 times a second when approaching the intersection. The RSU at the intersection receives the BSM and sends it to a TTI PC and a Iteris PC. The Iteris RSU, as well as the TTI PC, communicates with the TSC. The RSU receives the SPaT data from the TSC, formulates a SPaT message and broadcasts the SPaT message over the air 10 times a second. The RSU also broadcasts the MAP message, which is stored on the RSU, once a second. The RSU can also broadcast a TIM based on certain criteria. The TTI PC hosts the project application to initiate the visual alert and the audio alert based on signal status, detector status, and the bus position. The TSC also communicated with the TSC to activate the audio alert. The Bosch camera is connected to the pedestrian input panel in the cabinet and the Iteris computer monitors these inputs. When a pedestrian is detected it generates a TIM message on the presence of a pedestrian.

Yunex RSUs were used at the University Drive and Boyett Street, Texas Avenue and New Main, and Harvey Mitchell Parkway and Welsh intersections. Figure 5 illustrates the architecture using the Yunex equipment.

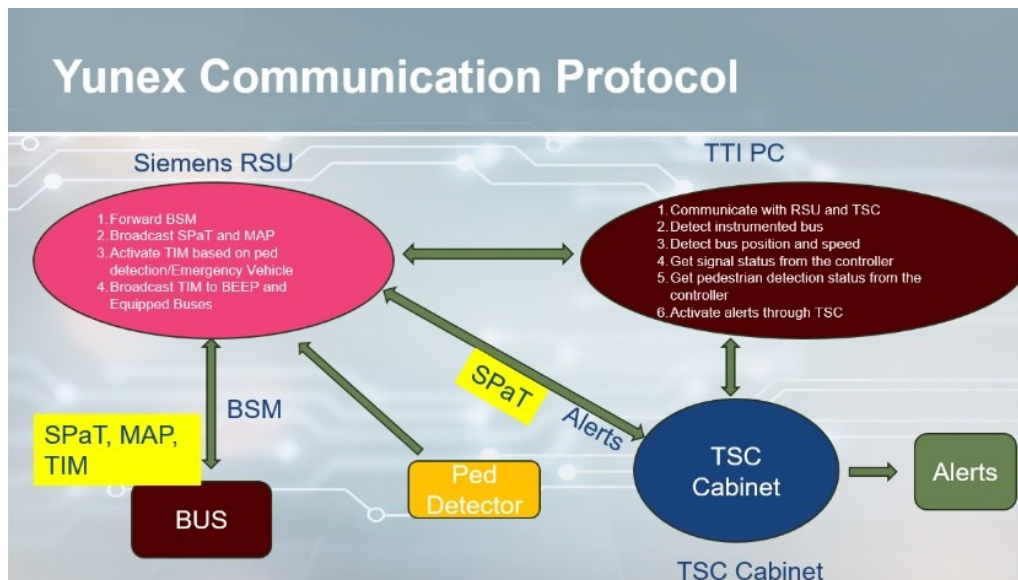


Figure 5. Communication Protocol Using a Yunex RSU

An equipped bus with OBU broadcasts a BSM 10 times a second when approaching the intersection. The Yunex RSU at the intersection receives the BSM and processes it. The RSU receives the SPaT data from the TSC, formulates a SPaT message and broadcasts the SPaT message over the air ten times a second. The RSU also broadcasts the MAP message which is stored on the RSU, once a second. The RSU can also broadcast a TIM based on certain criteria. The TTI PC hosts the project application to initiate the visual alter and audio alert, based on the signal status, detector status, and the position of the bus. The RSU is also directly communicating with the Bosch camera, generating and broadcasting a PSM 10 times a second.

The bus signs, Bosch cameras, and Polara pedestrian systems were also installed at the intersections. The installation, testing, and full operation of the intersections involved TTI researchers, City of College Station traffic signal personnel, and staff from Iteris and Yunex. Figure 6 highlights the installation of equipment at George Bush Drive and Penberthy Boulevard. It typically took two to three days to install the equipment, with additional time for configuring and testing the systems, as well as addressing any issues. The systems at all five intersections were fully operational in late November 1, 2024.

A total of 49 Texas A&M University buses were equipped with OBUs as part of the project. TTI procured 10 Yunex OBUs and 43 Iteris OBUs. TTI also purchased 50 antennas for the buses. TTI configured and tested the OBUs and antennas and delivered them to Texas A&M University Transportation Services.

Figure 7 shows an antenna being installed on the Texas A&M buses. The OBUs were installed behind the destination sign panel above the windshield on the front of the buses. The placement of the OBUs was selected to ensure no distraction to bus drivers or impact on bus operations. It was also selected due to ease of removing the panels for the initial installation and for ongoing maintenance and troubleshooting. The radio antennas were installed on the roof of the buses, taking advantage of an existing opening in the bus roof.

TTI researchers configured the MAPs for the five pilot intersections. The MAPs constitute the MAP message being broadcast by the RSUs using C-V2X communication. The MAPs were created using the Guidance Document for MAP Preparation prepared for the Connected Vehicle Pooled Fund Study in March 2024.

The application resides on an edge computer in the traffic signal cabinet at an intersection. The RSU was configured to forward any BSM it received from buses equipped with an OBU to the edge computer. The application includes a configuration file with all the possible bus turning movements at the intersection and information about the entry heading and exit heading of the buses making a turn at the intersection and other related information.

Once the application started receiving BSMs from the RSU of a bus approaching the intersection, the application checked the heading of the bus received in the BSM and indicated the direction of travel of the bus and compared it to the possible turning movements at the intersection. If the bus heading matched one of the possible turning movements at the intersection, the application continuously monitored the distance of the bus from the center of the intersection. Once the bus location was detected within a turning movement bay at the intersection, the system checked the status of the traffic signal phase that controlled the turning movement lane and if the phase status was green and the bus could proceed, the application turned on the bus sign at the intersection and started playing the audio message at the intersection to warn pedestrians, bicyclists, and other users of the turning bus. Figure 8 illustrates the bus sign at Texas Avenue and New Main Drive. The system continued to monitor the location of the turning bus and once it was past the exit location at the intersection, the system turned off the bus sign and stopped playing the audio message.



Figure 6. City of College Station Installing Equipment



Figure 7. Installing OBU on a Texas A&M University Bus



Figure 8. Illuminated Bus Signal at Texas Avenue and New Main Drive

The Smarter Intersection Pilot Project included the development and testing of a beta version of an Apple smartphone app to assist B/LV individuals crossing at the pilot intersections. TTI researchers completed a review of other similar projects developing intersection navigation apps for B/LV individuals and conducted initial online interviews with B/LV individuals to gauge possible interest in an app. TTI researchers developed the beta app and tested it at the George Bush Drive and Penberthy Boulevard and the Texas Avenue and New Main Drive intersections. Three B/LV individuals and three typical vision individuals tested the app at the George Bush Drive and Penberthy intersection and provided feedback to TTI researchers.

As required with research involving human subjects, the protocols, scripts, recruitment process, and other items for the interviews and surveys to be conducted throughout the project were developed and submitted to the Texas A&M University Institutional Review Board (IRB) via the Huron online portal. The necessary information on the blind/low vision focus group and online interviews, the intercept surveys with pedestrians and bicyclists at the pilot intersections, the online bus operator surveys, and the interviews with team members on the lessons learned and best practices were developed and submitted. All protocols were approved by the IRB.

TTI recruited B/LV individuals through contacts with the Texas A&M University Transportation Services and the Department of Disability Services, Blinn College Disability Services, the Brazos Valley Council of Governments Aging and Disability Resource Center, the Brazos Transit District, private non-profit organizations, and businesses focusing on services to B/LV people. Participants were paid \$40 for participating in the online interviews (via Venmo, PayPal, or Amazon gift card).

Four interviews were conducted in June 2024, with B/LV individuals, including two men and two women. All four participants had vision limitations that affect their daily lives, ranging from partial to full blindness. All indicated that they do some walking as part of day-to-day transportation but do so generally over short distances (such as to reach a transit stop or a convenience store). The results from the four interviews were summarized and were used in the development of the beta smartphone app.

TTI researchers developed a beta version of an Apple smartphone app for B/LV individuals. Figure 9 illustrates the approach used in developing the communication from the traffic signal to the app. TTI researchers installed and configured a microcontroller in the signal cabinet that queries the signal controller for SPaT status messages that are relevant to pedestrian safety. The microcontroller broadcasts queried messages in the form of Bluetooth low energy beacons. The smartphone app detects beacon messages from the intersection signal cabinet. The smartphone app relays alert information to B/LV pedestrians approaching a crosswalk in audible and tactile form.

TTI researchers developed a geofence around the George Bush Drive and Penberthy Boulevard intersection to target the communication with the app. The app was developed using a traffic signal controller in the Houston TTI office. The app was tested successfully at the George Bush Drive and Penberthy Boulevard intersection using a Bluetooth device added to the traffic signal pole. A geofence was also developed at the Texas Avenue and New Main Drive intersection and the app was successfully tested at that location.

TTI researchers demonstrated the app at the January 30, 2025, PAC meeting. The functions and development of the app were discussed. The app was displayed on a smartphone and triggered at the meeting using a Bluetooth device. PAC members were able to hold the smartphone and experience the vibration and verbal message.

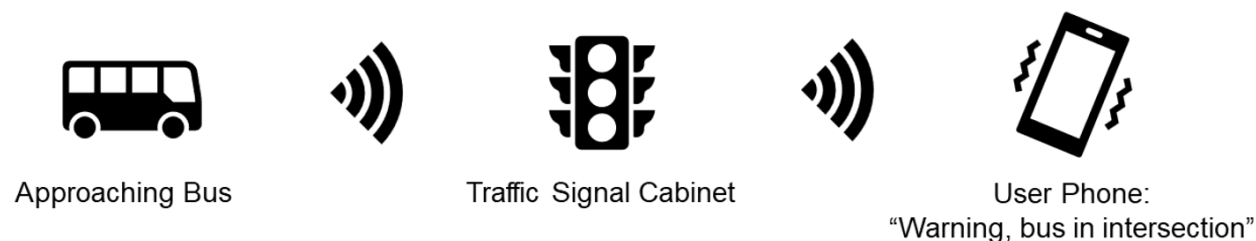


Figure 9. B/LV Smartphone App Process

The B/LV app was tested by three B/LV individuals and three typical-vision individuals on Saturday, February 1, 2025. The test and interviews with the participants were conducted at the George Bush Drive and Penberthy Boulevard intersection on a sunny, warm afternoon. Two of the B/LV individuals had participated in the earlier online interviews. The third volunteered to participate after hearing about the test from one of the initial test participants. The other three individuals were TTI staff not involved in the project who volunteered to participate.

Each participant tested the app individually while standing on the sidewalk at one end of the intersection's signalized crosswalk. Ambient roadway traffic was present on both of the intersecting roads throughout the testing process. TTI researchers at the traffic signal cabinet activated the illumination of the bus sign and the audible announcement when notified by the TTI researchers conducting the interviews. The following steps were taken in conducting the test of the beta app:

- TTI researchers explained the features of the app and the process for the test.
- The participant was handed an iPhone with the app activated.
- In the first case, the signal was activated simulating the entrance of a bus into the intersection. the simulated bus active both the phone app (vibration and verbal announcement) and the bus sign and verbal announcement.
- In the second case, the signal was activated simulating the entrance of a bus into the intersection, but the verbal announcement was not activated. The phone app was activated (vibration and verbal announcement) and the bus sign was activated.
- Participants were able to repeat either of the test cases.
- TTI researchers walked the participant back to the parking area and asked questions about their experience of the app.

Overall, feedback on the app was positive. All of the B/LV participants and two of the three typical-vision participants said that this type of app would provide useful information and make them feel safer at intersections. B/LV participants noted that both the audible alert and the vibration was beneficial.

The ability of the *Smarter* Intersection to send a message to an automated shuttle and to an emergency vehicle was simulated during the project. Similar approaches were used in both simulations. Since there is not an automated shuttle in College Station, TTI researchers worked with Beep personnel to develop and conduct a simulation with a TTI vehicle equipped with an OBU acting as an automated shuttle. It was not possible to equip an emergency vehicle with an OBU, so a TTI vehicle with an OBU led a College Station fire truck through one of the intersections to simulate the communication capabilities. Both approaches and the simulation results are discussed next.

TTI researchers and Beep personnel held online meetings to discuss the process for simulating the communication of turning buses from the traffic signal to an automated shuttle approaching the intersection. TTI researchers summarized the capabilities of the traffic signal controllers and the types of messages that can be sent to vehicles, and Beep personnel explained the sensors and OBUs used on automated shuttles during these meetings. Beep personnel described some of the messages that are currently being received from traffic signals on some projects.

The simulation included a TTI vehicle equipped with an OBU attached to a tablet acting as an automated shuttle approaching the George Bush Drive/Penberthy Boulevard intersection. The vehicle traveled south bound on George Bush Drive approaching the intersection. The *Smarter* Intersection sent a message to the OBU that a turning bus was approaching the intersection with the time of the OBU receiving the information being documented.

The SPaT message was broadcast at 10 Hz, i.e., 10 times a second, while the MAP message was broadcast at 1 Hz, once every second. The RSA message was broadcast continuously at 1 Hz, i.e., once a second, while the bus was making the turn at the intersection. Additional messages about the presence of pedestrians in the crosswalk if detected by the infrastructure was also broadcast as a TIM message at a frequency of 1 Hz.

A TTI vehicle with an OBU connected to a tablet led a fire truck (not in emergency operations) through the Texas Avenue and New Main intersection. The OBU in the TTI vehicle (acting as a fire truck) sent and received messages from the traffic signal system at the intersection. The system triggered an

announcement and illuminated the sign to alert pedestrians and bicyclists at the intersection. The system broadcast SPaT, MAP, and other messages to the TTI vehicle on the status of the intersection. The system also received a SRM from the OBU in the TTI vehicle simulating a request from a fire truck and then broadcast a TIM alerting pedestrians and bicyclists of a fire truck traveling through the intersection.

This process was used on two tests through the intersection. In the first case, the fire truck activated a signal preemption message, which the signal system received and gave a green signal phase indication. In the second case, the fire truck did not activate the signal preemption message. In both cases, the system was triggered by the OBU in the TTI vehicle simulating a fire truck.

The results from the simulations were captured on a video recording of the tablet screen and the automated shuttle messages were documented in a .PCAP file. The results from the simulations of communicating with an automated shuttle and a fire truck were similar. The video and data file documented the SPaT, BSM, TIM, and PSM messages.

The results of the simulated communication with an automated shuttle were discussed with Beep personnel after they reviewed the information in the video and the .PCAP file. Beep personnel indicated that the results aligned with their experience to date and would add value, in combination with existing capabilities, to safely operate automated shuttles at signalized intersections.

The results also highlight the benefit of using C-V2X to communicate with fire trucks and other emergency vehicles. Currently, responding emergency units from different jurisdictions may not use the same technology to request preemption. C-V2X provides a uniform standard resulting in rapid and uniform service to all emergency vehicles irrespective of their jurisdictions. Further, conventional emergency responders do not get an active acknowledgement when their request for service is being provided or denied. This situation could result in crashes when emergency responders approach an intersection from two directions. C-V2X provides an acknowledgement of the request for service with the responding units knowing whether they are being provided a preemption service or not. In addition, the range for C-V2X is approximately 1,500 feet from an intersection. The service request accompanies the BSM, which also provides the location of the emergency vehicle, allowing the signal controller to respond in a timely manner to the emergency vehicle.

TTI researchers developed the following required documents and reports on the *Smarter* Intersections Pilot Project. The documents were submitted on-time to the USDOT after review by TxDOT.

- July 1, 2023 – September 30, 2023, Quarterly Progress Report – submitted to USDOT on October 24, 2023
- Evaluation Plan – submitted to the USDOT on December 14, 2023
- Data Management Plan – submitted to the USDOT on December 13, 2023, updated and resubmitted to the USDOT on April 14, 2025
- October 1 – December 31, 2023, Quarterly Progress Report – submitted to USDOT on January 5, 2024
- Grantee Profile Form and Partner Logos – submitted to USDOT on March 22, 2024
- January 1 – March 31, 2024, Quarterly Progress Report – submitted to USDOT on April 16, 2024
- Draft Implementation Report – submitted to the USDOT on September 11, 2024
- July 1 – September 30, 2024, Quarterly Progress Report – submitted to USDOT on October 30,

2024

- October 1 – December 31, 2024, Quarterly Progress Report - submitted to USDOT on January 29, 2025
- Final Implementation Report, submitted to USDOT on June 27, 2025.

TTI researchers participated in the online SMART Grant meetings and the 2023 and 2024 SMART Grant Summits. As discussed in the next section, TTI researchers also participated in media interviews on the project and gave presentations at conferences and webinars.

Project Media Coverage and Presentations

The Smarter Intersections Pilot Project has been the focus on media coverage and information sharing at conferences and online webinars. Table 1 lists these events and activities.

Table 1. Smarter Intersection Pilot Project Presentations and Media Coverage

Date	Event	Format
April 27, 2023	ITS America, Grapevine, TX, Committee Meeting	In-person
May 2, 2023	KAGS Television, College Station, TX	In-person interview at one of the Smarter Intersections
April 24, 2024	ITS America Conference & Expo, SMART Grant Traffic Signal Panel, Phoenix, AZ	In-person
April 30, 2024	SMART Grant Peer Exchange	Online
May 8, 2024	News 4, San Antonio, TX	Online interview, aired on May 24, 2024, accompanied by an on-line article
July 24, 2024	Transportation Research Board (TRB) Traffic Signal Committee Mid-Year Meeting, Institute of Transportation Engineers (ITE) Annual Meeting, Philadelphia, PA	In-person
September 19, 2024	ITE Webinar	Online
March 14, 2025	C-V2X and Road User Safety – Yunex	Online
Ongoing Presentations as part of Visits to TTI	Honeywell, Nuro, Pusan National University, Boldly and the University of Tokyo, the University of Minnesota Center for Transportation Studies	In-person

There were no deviations in the Stage 1 Smarter Intersections Pilot Project. As noted previously, there has been a deviation in the Stage 2 at-scale project focusing on Corpus Christi rather than Houston.

Section Three: Stage 1 Prototype Evaluation Findings

TTI researchers monitored the operation of the five pilot intersections over the four-month period from November 1, 2024, to February 28, 2025. Daily log files on the operation of the systems were recorded and analyzed. Intercept interviews were conducted with pedestrians and bicyclists at selected intersections and an online survey was conducted with Texas A&M University bus operators to obtain their perspectives of the bus signs and audible messages. Crash data for the five pilot intersections was examined for a year before the pilot project and for the four-month demonstration. The results of these activities are summarized in this section.

Evaluation Questions, Performance Measures, and Performance Targets

The Evaluation Plan and the Data Management Plan were used to guide the analysis, evaluation, and documentation process for the *Smarter* Intersections Pilot Project. This section highlights the results of the evaluation based on the questions included in the Evaluation Plan.

Does the technology and system detect turning buses and activate the visual and audio alerts?

TTI visually monitored the operation of the system on an ongoing basis. Daily log files were created and maintained on the operation of the system. The log files included the time stamp of approaching buses, the status of the traffic signal cycle, the start and end time of the audio alert, and the start and end of the bus sign illumination.

TTI researchers worked with the Texas A&M University Transportation Services to ensure that the OBU-equipped buses were assigned to the routes traveling through the pilot intersections. Due to issues with the structural integrity of the other buses in the fleet, Transportation Services was not always able to assign the equipped buses to the routes serving the pilot intersections. In addition, due to lower ridership non-OBU equipped paratransit minibuses were sometimes assigned to Route 34 serving the Harvey Mitchell Parkway and Welsh Avenue intersection. These two issues caused the system to not be fully operational at all five intersections over the four-month demonstration. The daily logs indicated the days and times when non-OBU-equipped buses traveled through the intersections. These occurrences were not included in the assessment of the system performance. Overall, the system performed as anticipated, with a 99 percent accuracy rate of detecting the equipped buses and activating the illuminated bus sign and the audio alert.

Do pedestrians and bicyclists perceive benefits from the system?

TTI researchers conducted intercept interviews with pedestrians, bicyclists, and other individuals crossing the pilot intersections to gain feedback on the illuminated bus sign and the audio alert. The interview procedures and questions were approved by the Texas A&M University IRB.

TTI researchers tested the interviews at the University Drive and Boyett Street and the Texas Avenue and New Main Drive intersections on November 19 and November 20, 2024, shortly after the intersections became fully operational. TTI researchers conducted the interviews at the George Bush Drive and Penberthy intersections on February 12 and February 17, 2025, after the system had been operational for almost four months.

As illustrated in Figure 10, TTI personnel were stationed at the sidewalk at the intersections. TTI researchers approached pedestrians, bicyclists and scooter users waiting to cross the street and asked if they would complete a brief interview. The participant's verbal responses were entered into a handheld tablet computer. After thanking the participants, TTI personnel entered observations relating to their gender, approximate age, if a phone or mobile device was visible, and if the individual was wearing headphones or earbuds.



Figure 10. TTI Researchers Conducting Intercept Interviews at University Drive and Boyett

A total of 292 interviews were conducted in November, with approximately 70 percent completed at University Drive and Boyett and 30 percent conducted at Texas Avenue and New Main Drive. Pedestrians accounted for 58 percent of the respondents, with 22 percent bicyclists, 19 percent scooter users, and 1 percent other. The majority of respondents, 60 percent, reported using the intersections multiple times a day, with 24 percent using it at least daily. A total of 66 percent of the respondents indicated they had noticed the illuminated bus sign and heard the bus turning announcement, and 52 percent reported they found it helpful for themselves. In a separate question, 88 percent responded that the bus sign and verbal message would be helpful for all or helpful for some people crossing the street. Some of the individuals at the University Drive and Boyett Street intersection noted that they thought the system was less beneficial since the intersection has a pedestrian crossing only phase, with all vehicle traffic stopped. They noted that the system would be beneficial at intersections without this feature.

A total of 69 interviews were conducted at the George Bush Drive and Penberthy Boulevard intersection on February 12 and February 17, 2025. The composition of individuals crossing the intersection was different from the interviews conducted in November, with 42 percent scooter users, 30 percent bicyclists, and 28 percent pedestrians. A total of 42 percent of the individuals reported using the intersection multiple times a day, with 36 percent using it at least once a day and 22 percent using it at least once a week. A total of 77 percent of the individuals reported noticing the illuminated bus sign and hearing the announcement, and 62 percent responded that they found it helpful. In the separate question, 86 percent responded that the bus sign and announcement would be helpful for all or helpful to some people crossing the intersection.

Do bus operators perceive benefits from the system?

An online survey of Texas A&M University bus operators was conducted to obtain their perspectives on the pedestrian and bicyclist visual alerts at the pilot intersections. The survey was included in the approved IRB application. The survey was pre-tested in late November 2024, shortly after the system became operational. The online survey was conducted the week of March 17 and March 24, 2025,

focusing on bus operators driving on Route 8 through the George Bush Drive and Penberthy Boulevard intersection.

The November survey focused on the illuminated bus sign at all five intersections. Only half the respondents indicated they had noticed the bus signs. The format may have caused some confusion given the multiple intersections involved and the potential for duplicate responses. Of the 57 responses, the illuminated bus signs at George Bush Drive and Penberthy Boulevard and Harvey Mitchell Parkway and Welsh Avenue were the most noticed and most identified as beneficial.

A total of 10 bus operators responded to the March online survey which included questions on both the illuminated bus signal and audio alert. One operator reported that they were not aware of either the bus sign or the audible announcement at the intersection. Nine (90 percent) of the operators reported they were aware of the sign and the announcement, 7 (78 percent) responded that they thought the bus sign helps alert pedestrians and bicyclists that a bus is turning at the intersection, while 2 (22 percent) were not sure. A total of 6 (67 percent) of the operators reported that they thought the audible announcement helps alert pedestrians and bicyclists that a bus is turning at the intersection, while 3 (33 percent) were not sure.

Do B/LV individuals perceive benefits of beta app?

The B/LV beta Apple app was tested with three B/LV individuals and three-typical vision individuals at the George Bush Drive and Penberthy Boulevard intersection. The feedback from the six participants was positive. All of the B/LV participants and two of the three typical-vision individuals said the app provided useful information and will make them feel safer at intersections.

Is the system able to communicate with automated shuttle?

Working with Beep personnel, TTI researchers simulated communication with an automated shuttle. The simulation successfully communicated SPaT, BSM, TIM, and PSM messages to an OBU in a TTI vehicle acting as an automated shuttle. Beep personnel indicated the results aligned with their experience to date and would add value in combination with existing capabilities to safely operate automated shuttles at signalized intersections.

Crash Data

Data from the TxDOT Crash Records Information System (CRIS) was examined in the project. Data on crashes involving buses and bicyclists or pedestrians were obtained from CRIS for a year before the pilot project and for the four months of the demonstration (November and December 2024 and January and February 2025). There were no reported crashes involving buses, pedestrians, and bicyclists during either the before period or the four-month demonstration.

Overall Summary

The results of monitoring and evaluating the *Smarter* Intersection Pilot Project indicated that the system functioned as designed and that the illuminated bus sign and audio alert were perceived as beneficial by pedestrians, bicyclists, scooter users, and bus operators. The system met performance targets with a 99 percent accuracy rate. A majority (52 percent in November 2024 and 62 percent in February 2025) of pedestrians, bicyclists, and scooter users reported that they found the system helpful, with 88 percent and 86 percent responding that the bus sign and announcement would be helpful for all or some people

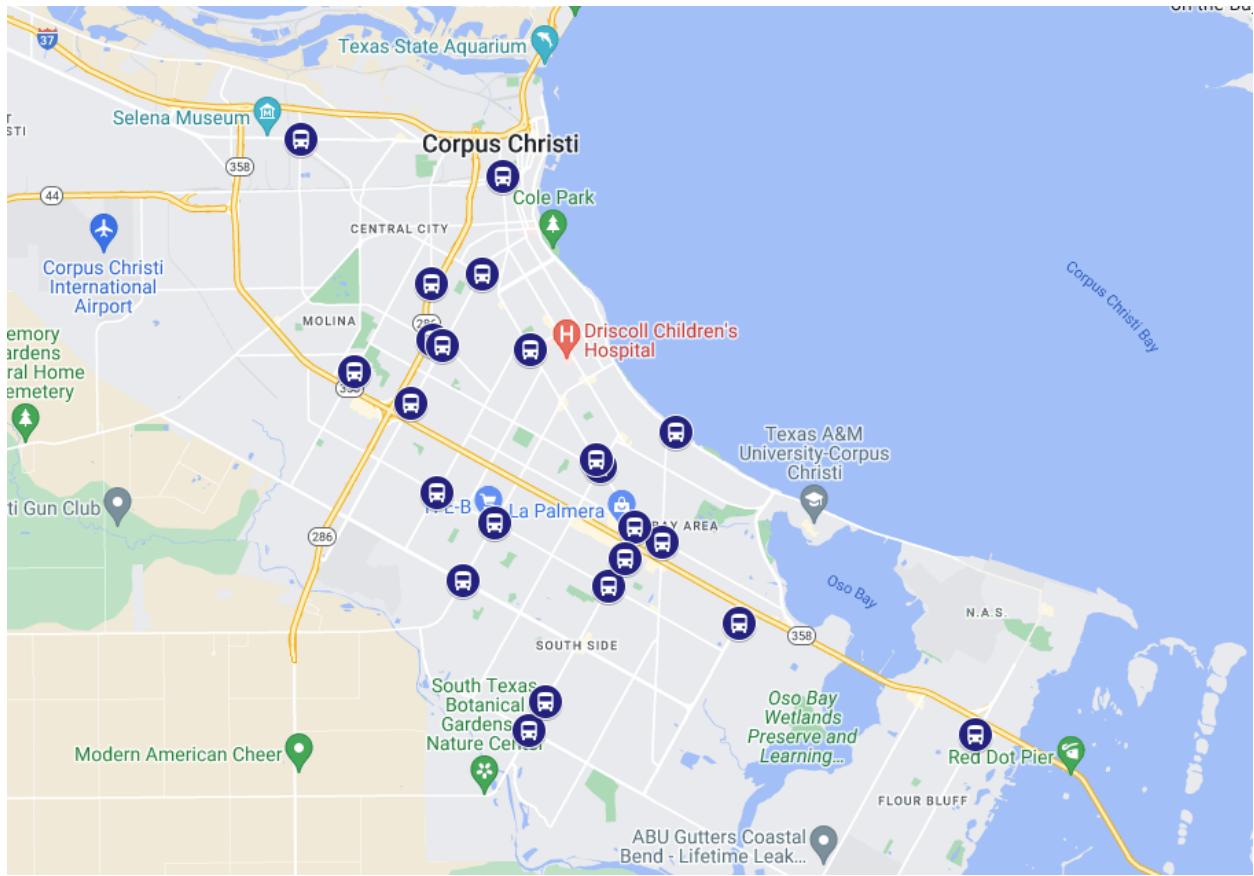
crossing the intersection. Bus operators also provided positive feedback, with 78 percent indicating they thought the bus sign helped alert pedestrians and bicyclists to turning buses and 67 percent responding that the audio message was beneficial. The project results support the statutory areas relating to improving the safety and integration of transportation facilities and systems for pedestrians, bicyclists, and the broader traveling public and promoting connectivity between and among connected vehicles, roadway infrastructure, pedestrians, bicyclists, the public, and transportation systems.

Section Four: Anticipated Costs and Benefits of At-Scale Implementation

As noted previously, the cost of the Stage 1 prototype project was \$1.9 million, and the anticipated cost of the Stage 2 at-scale project is anticipated to be in the range of \$10 to \$12 million. The benefits are anticipated to exceed the costs. The Stage 2 evaluation will follow the format used in Stage 1. A more detailed assessment will be made of the improvements in safety using the CRIS database to determine baseline crashes and monitor changes over the at-scale deployment. In addition, the at-scale deployment will promote connectivity between and among connected vehicles, roadway infrastructure, pedestrians, bicyclists, and other road users.

TxDOT and TTI worked with the CCRTA and the City of Corpus Christi, the owner and operator of the traffic signals in the city, to develop an approach for a potential Stage 2 proposal. Numerous online meetings were held between September 2024, and January 2025, and an onsite meeting and tour was conducted on December 18, 2024. The CCRTA identified intersections with high crash rates and bus routes with turning buses. Figure 11 illustrates the location of these intersections. Table 2 provides more information on the intersections, including the routes traveling through the intersections and the bus turning movements.

TxDOT and TTI personnel made a site visit to Corpus Christi on December 18, 2024. The visit included a tour of selected intersections and the City of Corpus Christi Traffic Management Center. TTI, TxDOT, city, and CCRTA personnel examined the traffic signal cabinets and watched buses turning at the intersections. The potential locations for the illuminated bus signs and RSUs were discussed. Following the tour, TTI, TxDOT, CCRTA and City staff met to discuss possible approaches and next steps.



Source: CCRTA, mapped by TTI

Figure 11. Location of Possible Intersections in Corpus Christi

Table 2. Possible Intersections, Bus Routes, and Bus Turning Movements in Corpus Christi

Intersection Number	CCRTA Bus Routes	# of Bus Routes @ Intersection	Intersection Cross Street Names and Bus Turning Movement
1	15, 32	2	Weber Rd @ Saratoga Blvd (Left Turn)
2	29, 37	2	S Staples St @ Everhart Rd (Right and Left Turn)
3	6, 26, 37, 65	4	Airline Rd @ McArdle Rd (Right and Left Turn)
4	6, 17, 24, 26, 37, 65	6	S Staples St @ McArdle Rd (Right and Left Turn)
5	19, 21, 23, 25, 32, 37	6	Horne Rd @ S Port Ave (Right and Left Turn)
6	12, 23, 37	3	S Port Ave @ Tarlton St (Right and Left Turn)
7	15, 19, 21, 23, 32, 37	6	Ayers St @ Horne Rd (Right and Left Turn)
8	3, 4, 29F, 65, 90, 93	6	Waldron Rd @ Compton Rd (Right Turn)
9	6	1	Ocean Dr @ Airline (Right and Left Turn)
10	15	1	Holly Rd @ Kostoryz Rd (Left Turn)
11	24	1	S. Staples @ Yorktown Blvd (Right Turn)
12	15,32	2	Weber Rd @ Holly Rd (Right Turn)
13	29	1	S Staples St @ Williams Dr (Right and Left Turn)
14	12, 19	2	Ayers St @ Baldwin Blvd (Left Turn)
15	29,37	2	S Staples @ Gollihar Rd (Right and Left Turn)
16	24,26	2	S Staples @ Lipes Blvd (Right and Left Turn)
17	29,93	2	Rodd Field Rd @ Williams (Right and Left Turn)
18	17,29	2	S Staples @ Texan Trl (Right and Left Turn)
19	19	1	Ayers St @ McARdle Rd (Right and Left Turn)
20	27,28	2	Leopard St @ N Navigation Blvd (Left Turn)
21	16,29	2	S. Staples @ Laredo St (Right Turn)
22	19,25	2	Greenwood Dr @ Trojan Dr (Right and Left Turn)

Source: CCRTA

The proposed Stage 2 at-scale project would include intersections along the Staple Street and Ayres Corridors, as well as possible stand-alone intersections with safety concerns. These corridors focus on lower income areas with large numbers of households with no vehicle available. The selection of the final intersections will be based on the traffic signal hardware, the number of bus routes, the number of turning buses, bus headways and the span of service.

It is estimated that 12-15 intersections would be equipped with RSUs, and 118 buses (83 fixed route buses and 35 paratransit minibuses) would be equipped with OBUs. It is anticipated that the cost of the Stage 2 project would be within the range of \$10 to \$12 million.

Based on discussions at the December 18, 2024, meeting in Corpus Christi, and follow up communication from the City of Corpus Christi providing their commitment, a general approach was developed along with the anticipated roles and responsibilities of the various agencies. The anticipated roles and responsibilities presented in Table 2 were developed by TTI and TxDOT personnel and discussed in an online meeting to guide the Stage 2 project. The roles and responsibilities are outlined by four-time frames – notice from the USDOT that additional Stage 2 Notice of Funding Opportunity (NOFO) will be issued, developing a proposal in response to a Stage 2 NOFO, conducting the project if the proposal is selected, and post-project. It is also anticipated that a PAC will be used, similar to the Stage 1 project. A Stage 2 PAC would include the team members, the Corpus Christi Metropolitan Planning Organization, and other appropriate groups.

Table 3. Agency Roles and Responsibilities with Possible Stage 2 project in Corpus Christi

Team Member	Notice from USDOT—Add'l Stage 2 NOFO Will Be Issued	Proposal Development on Issued NOFO	Conducting Project If Selected	Post-Project
TxDOT	Work with team members to further develop the scope of a proposal	<ul style="list-style-type: none"> • Lead the proposal development and submission process 	<ul style="list-style-type: none"> • Complete a contract with USDOT • Complete an interagency contract (IAC) with TTI • Complete financial submissions • Review all deliverables prepared by TTI before submission to USDOT • Oversight responsibility 	Assist with questions on maintaining equipment for useful life and proper disposition or retiring
TTI	Work with team members to further develop the scope of a proposal	<ul style="list-style-type: none"> • Assist with the proposal • Provide the letter of commitment 	<ul style="list-style-type: none"> • Complete an IAC with TxDOT • Lead conducting project • Working with the City of Corpus Christi, review the capabilities of the identified intersection to accommodate the needed equipment • Procure all equipment based on A&M System procedures • Configure and deliver equipment to the City of Corpus Christi and CCRTA • Oversee installation of equipment including contracting with vendors, the city, CCRTA, or other groups • Test the system and monitor the system • Conduct any evaluation elements, including completing baseline and after implementation data collection and conducting any interviews and surveys • Complete and submit all reporting requirements and deliverables to USDOT after TxDOT review and any TxDOT deliverables • Participate in online and in-person meetings with USDOT and other groups • Assist with other activities as appropriate 	Assist with any questions on maintaining equipment for useful life and proper disposition of retiring equipment
City of Corpus Christi	Work with team members to further develop the scope of a proposal, including assessing the capabilities of the potential intersections	<ul style="list-style-type: none"> • Assist with the proposal • Provide the letter of commitment 	<ul style="list-style-type: none"> • Finalize the equipment for each of the traffic signal systems at identified intersections • Assist with installing the RSUs, supplemental bus signs, camera, and other equipment at the identified intersections (TTI will contract with vendors, the city, or others to install the equipment) • Operate and maintain the RSUs and other equipment for their useful life • Assist with monitoring and evaluating the system • Assist with other activities as appropriate 	Maintain equipment for useful life based on determination of useful life and proper disposition of retiring equipment
CCRTA	Work with team members to further develop the scope of a proposal	<ul style="list-style-type: none"> • Assist with the proposal development • Provide a letter of commitment 	<ul style="list-style-type: none"> • Install the OBUs on the bus fleet (check if financial assistance is needed) • Operate the equipped buses on the routes traveling through the intersections • Maintain the OBUs for their useful life • Assist with monitoring and evaluation elements • Assist with other activities as appropriate 	Maintain equipment for useful life and proper disposition of retiring equipment

The following highlights the anticipated impacts of Stage 2 at-scale deployment in the six goal areas of the SMART Grant Program outlined in the proposal. Available historical data that may be used to assess these goals are noted. The cost estimates for Stage 1 and Stage 2 are also presented.

- **Safety and Reliability**
The project increases the actual safety of pedestrians, bicyclists, and other road users by reducing crashes at intersections as well as providing more accessible information about the status of intersections, supporting better mobility. CRIS data will be used to assess changes in crashes involving buses, pedestrians and bicyclists. Intercept surveys of pedestrians and bicyclists at the intersections will be used to assess perceptions about the improvements in safety and mobility.
- **Resiliency**
The project increases the resiliency of the information technology system by employing open-source platforms and data formats. The use of historical data is not anticipated.
- **Access**
The project enhances the accessibility of the road system by pedestrians and bicyclists by creating a safer environment and creating useful features for mobility-impaired and B/LV users. The use of historical data is not anticipated.
- **Partnership**
The Stage 1 project expanded partnerships between multiple public entities (including Texas A&M University, the City of College Station, and BTD) as well as privately operated automated vehicles, such as Beep. Stage 2 will expand this partnership to include CCRTA, the City of Corpus Christi, and other groups. The use of historical data is not anticipated.
- **Integration**
The project improves the integration of all road users at intersections and creates new data paradigms that allow for complex intersection information to be shared and used by different platforms. The use of historical data is not anticipated.

Section Five: Challenges and Lessons Learned

The lessons learned and tips for other areas interested in similar projects were collected across the project team and partners using three primary methods. First, these items were discussed at the PAC meetings, especially the final meeting on January 30, 2025. Second, TTI researchers conducted online information exchanges with the PAC members and other key individuals participating in the project. Finally, TTI researchers discussed and documented these items during their regular team meetings. The common themes relating to lessons learned from these activities are summarized in this section.

- A strong working relationship among project partners is critical to a successful project. There is a strong working relationship among the City of College Station, TxDOT, Texas A&M University, BTD, and TTI. These agencies have worked in partnership on numerous projects and programs, including the initial testing of smart intersection technologies. Representatives from the College Station Traffic Engineering, Signals, Signs, and Markings group in the Public Works Department have been the major participants from the city. The importance of this partnership was key to installing the RSUs and the OBUs. Strong partnerships among the owner/operator of the traffic signals and the operator of the bus services key to success of this type of project.

- Another lesson learned was expanding the partnership to other city departments. The College Station Fire Department participated in the *Smarter* Intersection Pilot Project. Representative from the Fire Department were actively engaged in meetings of the PAC, hosted a tour of Fire Station #6 after the March PAC meeting, and participated in the simulation and testing of two fire trucks operating through one of the *Smarter* Intersections. Their interest in the *Smarter* Intersection has grown as they learned more about the capabilities of the technologies. This project has been instrumental in expanding the involvement of all the groups needed to improve the safety of all roadway users.
- Project partners noted that the PAC meetings were very beneficial and that it would be good for other areas to consider using a PAC. The regular updates helped with ongoing communication and provided all partners with the opportunity to discuss project elements and provide input.
- Installing the C-V2X equipment, working with vendors, and testing the various components takes time and resources. Providing resources to the agencies responsible for the activities would be beneficial to support their time. Some elements of the project may be new to the project partners. It was noted that learning about these technologies and their capabilities was very beneficial. Safety is job number one, so addressing any issues quickly is important.
- Preplanning for the equipment needs, determining if there is adequate room in the traffic signal cabinets, and addressing any potential limitations early is beneficial. Using the piggyback cabinets for the project equipment was also good, given the space is limited in the signal cabinets. The delay in the NEPA approval process resulted in a more condensed schedule for installing, testing, monitoring and evaluating the system, adding pressure to all groups.
- While numerous approaches were used and contacts made with different groups, recruiting B/LV individuals to participate in the online interviews and the actual testing of the B/LV app was challenging. Working to establish and maintain ongoing relationships with the different groups providing services to B/LV would be beneficial. PAC members noted that exploring future applications of the B/LV beta app and use by all individuals using different communication methods would be beneficial.
- What can appear to be small changes, such as restricting the live feed from the Texas A&M University transit app, can have impacts on a project. Identifying any challenges early in the development process and working on solutions is important.
- Considering how the system will work in the future and how the pilot project fits into a longer-term vision would be beneficial. Given limited resources, maximizing the use and benefits of the technology is important.

Measuring the impact of a four-month pilot project can be challenging. Further, the pilot intersections were selected based on bus turning movements and the capabilities of the traffic signal system, not crashes involving buses and bicycles and pedestrians. Measuring the safety benefits was difficult. There were no crashes involving buses, pedestrians, and bicyclists in either the before period or the four-month demonstration. Obtaining feedback from the different intersection user groups was also challenging given the four-month demonstration period. The demonstration also corresponded with the end of the fall semester, winter break, and the start of the spring semester for Texas A&M University students. A longer demonstration period and focusing on intersections with previous bus, pedestrian, or bicycle crashes would provide an opportunity for a more robust evaluation.

The lessons learned related to the specific items identified by the USDOT are highlighted below:

- Legal, Policy, and Regulatory Requirements - The delay in the NEPA review process caused a delay in the implementation of the Stage 1 project. While regular contacts were made with the USDOT checking on the status, contacting the TxDOT Environmental Division earlier for assistance would have been beneficial. There were no issues associated with the Build America/Buy America in Stage 1.
- Procurement and Budget – Procurement of the needed equipment began once the NEPA approval was provided. No issues were encountered with the procurement process, with delivery of the equipment occurring in a reasonable timeframe. Actual Stage 1 expenditures were slightly lower than budgeted. The equipment costs were lower due to the purchase of fewer bus signs than anticipated. Staff costs were slightly lower due primarily to less time spent on the B/LV app due to fewer than expected B/LV participants in the initial interviews and the testing the app.
- Partnerships – As noted previously, one key factor in the successful deployment of the Smarter Intersections was the interest and support of the City of College Station, Texas A&M University Transportation Services, BTM, and other groups. The project was able to expand on the strong existing partnerships.
- Technology Suitability/Integration with Incumbent Systems – The testing and evaluation of the Smarter Intersection Pilot Project indicates that the technologies, including the RSUs and OBUs, are suitable for the goals of both the prototype and the at-scale projects. The Smarter Intersections technology was integrated into the incumbent traffic signal system.
- Data Governance – The Data Management Plan was used to guide the data governance. The data generated by the Smarter Intersections is used to generate the alerts. While it is being stored to ensure the system is working correctly, there is little value associated with the data. Following the approach outlined in the Data Management Plan, it is not envisioned that data governance will be a major issue with the Stage 2 project.
- Workforce Capacity – As discussed in more detail later in Section Five, the Smarter Intersections Pilot Project did not replace jobs. The use of smarter intersection technologies will increase the need for skilled, high-paying jobs related to traffic signal operation and bus on-board technologies.
- Internal Project Coordination – Project coordination within the implementing agencies and across agencies is a key to the success of the Stage 1 project. Continuing this coordination after the completion of the pilot project will be a focus for all groups with continued operation of some of the intersections anticipated. Project communication among TxDOT, CCRTA, the City of Corpus Christi, TTI, and other groups will continue to be a priority in a Stage 2 project.
- Community Impact – The Stage 1 project did not examine the impact of the intersections on the surrounding areas to a great extent due to the short duration of the demonstration. It is anticipated that community impacts will be evaluated more thoroughly in a Stage 2 project in Corpus Christi.
- Public Acceptance – The intercept surveys conducted as part of the project at the Smarter Intersections in College Station indicated public acceptance and support of this approach for altering pedestrians and bicyclists of turning buses.
- Cybersecurity – The Smarter Intersections Pilot Project followed the security protocols used by the City of College Station Public Works Department. The traffic signal equipment was always accessed under the supervision of the Public Works Department. TTI researchers employed

procedures to remotely access the system while maintaining security, including configuring the firewall on the cellular router used to access the edge processor in the traffic signal cabinet. The processor accesses the traffic signal controller and runs the application to detect the equipped buses and provide the visual and audio alerts. The firewall restricted access to the field edge processor to only computers running within the TTI network. The BeyondTrust Remote Support tool was used by TTI researchers to remotely access the field edge processor in each cabinet, which required a username and password to access each machine.

Section Six: Deployment Readiness

As outlined in the USDOT guidance, the following topics were examined associated with deployment readiness of the Smarter Intersections.

- Legal, Policy, and Regulatory Requirements – Ensuring that the NEPA review for the at-scale deployment is completed in a timely manner will be important. Contacts with the TxDOT Environmental Division can be made as needed to assist with the review. There were no issues associated with the Build America/Buy America in Stage 1. It is not anticipated to be a concern in Stage 2 at-scale deployment.
- Procurement and Budget – Based on the experience in Stage 1 with the procurement process, it is not anticipated that there will be any issues with the procurement process and budget in the at-scale project. Given the larger scale of the procurement process, it will be important to closely monitor the status of each step in the process.
- Partnerships – As noted previously, one key factor in the successful deployment of the Smarter Intersections is the interest and support of the owner and operator of the traffic signal system and the partnerships with the transit operators, MPOs, and other groups. Nurturing these partnerships in Corpus Christi will be an important element to ensuring a successful at-scale project.
- Technology Suitability – The deployment and evaluation of the Smarter Intersection Pilot Project indicates that the technologies, including the RSUs and OBUs, are suitable for the goals of the proposed at-scale project in Corpus Christi.
- Data Governance – The Data Management Plan will continue to be used to guide data governance in the Stage 2 project. Following the approach outlined in the Data Management Plan, it is not envisioned that data governance will be a major issue.
- Workforce Capacity – As discussed in more detail later in this section, at-scale deployment of the Smarter Intersections would harness the benefits and negate potential negative impacts of technologies on good paying jobs with free and fair choice to join a union. The Smarter Intersections do not replace jobs, rather they add skilled, high-paying jobs related to traffic signal operation and bus on-board technologies.
- Internal Project Coordination – Project coordination within the implementing agencies and across agencies is a key element to a successful at-scale deployment. Enhancing the coordination that exists in Corpus Christi will be an important focus for the at-scale deployment.
- Community Impact – Examining the impact of the Smarter Intersections on the communities and areas around the intersections in Corpus Christi will be important during the more detailed planning, development, and operation stages of the at-scale deployment.
- Public Acceptance – The results from intercept surveys at the Smarter Intersections in College

Station indicate support for this type of system. It provides a model for use in Corpus Christi. Changes can be made as needed, with similar surveys being conducted as part of the Stage 2 at-scale deployment.

- Cybersecurity – The at-scale deployment will build on the approach used in the *Smarter Intersections Pilot Project* and will employ the Security Credential Management System for the deployment of CV2X equipment.

The development of the *Smarter Intersections Pilot Project* has provided a good understanding of the maintenance and operating requirements for at-scale deployment. The systems at the pilot intersections are able to accommodate updates as C-V2X technologies continue to evolve. The capacity exists in the College Station area to provide ongoing maintenance and improvements to prevent technical debt. These same capabilities for ongoing maintenance and enhancements exists in a Stage 2 at-scale deployment in Corpus Christi.

The *Smarter Intersections Pilot Project* was included in a workforce development workshop on Connected Vehicles and Applications in the Bryan/College Station Area. The other co-sponsors included TTI's 21st Century Mobility Test Bed and Saving Lives with Connectivity: Accelerating V2X Deployment: The Texas TRUST Project. The Texas CAV Task Force was also a co-sponsor. The 4-hour workshop components focused on the connected vehicle ecosystem and connected vehicle messages. The *Smarter Intersection Pilot Project* and the TRUST project were highlighted. The workshop was piloted on February 6, 2025, at the TTI Headquarters Building on the RELLIS Campus with representatives from TxDOT, the City of College Station, and the City of Bryan participating.

The at-scale operation of the *Smarter Intersections* would harness the benefits and negate potential negative impacts of new technologies on good-paying jobs with a free and fair choice to join a union. The deployment of the *Smarter Intersections* adds skilled, high paying jobs, without having any negative impacts on existing staff. Individuals with skills in traffic signal design, timing, and operations are needed for at-scale implementation. Many communities, counties, and state departments of transportation who own and operate traffic signals systems are looking for individuals with these skills. Individuals at transit agencies with skills associated with installing and maintaining the OBUs and other technologies are also needed. Opportunities exist for workforce development related to upskilling existing employees and training new workers. Outreach to universities, junior colleges, and technical schools would be beneficial to develop and offer courses, certificates, and degrees related to traffic signal system design and operation, as well as technologies for transit applications.

Section Seven: Wrap Up

The development, testing, operation, and evaluation of the five *Smarter Intersections* met expectations. Based on the experience, no major changes would be suggested for the at-scale implementation. As noted, the coordination and partnerships among the agencies responsible for owning and operating the traffic signal systems and operating the transit service, along with outreach to the local community, is important to a successful at-scale deployment.

Technical Terms and Acronyms

Table 4. Acronyms and Technical Terms

B/LV	Blind/Low Vision
BCSMPO	Bryan/College Station Metropolitan Planning Organization
BSM	Basic Safety Message
BTD	Brazos Transit District
CRIS	Crash Records Information System
C-V2X	Cellular-Vehicle-to-Everything
CCRTA	Corpus Christi Regional Transportation Authority
DSRC	Dedicated Short Range Communication
IRB	Institutional Review Board
ITS	Intelligent Transportation Systems
MPO	Metropolitan Planning Organization
NOFO	Notice of Funding Opportunity
OBU	On Board Unit
PAC	Project Advisory Committee
PC	Personal Computer
RSA	Roadside Alter
RSU	Roadside Unit
SPaT	Singal Phasing and Timing
TIM	Traveler Information Message
TSC	Traffic Signal Controller
TTI	Texas A&M Transportation Institute
TAMU	Texas A&M University
TxDOT	Texas Department of Transportation
USDOT	U.S. Department of Transportation