Georgia Department of Transportation

Advanced Transportation and Congestion Management Technologies Deployment – Connected Vehicle Deployment

Final Report

7/29/2026

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Table of Contents

Table of Contents i

List of Acronyms and Abbreviations ii

1. Project Summary 1
- 1.1. Project Description 1
- 1.2. Technology 2
- 1.3. Project Scope 4
- 1.4. Timeline 4

2. Performance Metrics, Evaluation Methods, and Data Sources 5

3. Evaluation Results and Findings 7
- 3.1. RSU Installation 7
- 3.2. RSU Operations 10
- 3.3. Emergency Vehicle Preemption (EVP) Application 12
- 3.4. Transit Signal Priority (TSP) Application 13
- 3.5. Data Portal 16

4. Lessons Learned 16

5. Recommendations 17

6. Conclusion 17

List of Acronyms and Abbreviations

CV .... Connected Vehicle

FAST .... Fixing America's Surface Transportation

FCC .... Federal Communications Commission

GDOT .... Georgia Department of Transportation

OBU .... On-board Unit

RSU .... Roadside Unit

SPaT .... Signal Phase and Timing

V2I .... Vehicle to Infrastructure

1. Project Summary

1.1. Project Description

This project was a multi-phased approach to implement the Georgia Department of Transportation's (GDOT) connected vehicle (CV) deployment to provide for Vehicle to Infrastructure (V2I) coverage on all major arterials and interstates throughout the state. This project delivered technology that will facilitate route decision making, including facility and modal choices, provide third-party developers access to real-time data which has not been historically available, reduce congestion on regional facilities, provide new sources of traveler information, and save travelers and private sector interests time and money through congestion avoidance and crash reduction.

The goal of this project was the broad installation of roadside units (RSU) and supporting infrastructure to support V2I applications that improve safety and mobility. The project's purpose was to deploy RSUs at intersections throughout Metro Atlanta as shown in Figure 1. This will develop a CV ecosystem across the Metro Atlanta region that enables the future use of safety and mobility applications such as red-light warning, green speed, emergency vehicle preemption, and transit priority, as well as implementing traveler information messages.

RSUs were installed at signalized intersections on existing infrastructure and connected to the existing GDOT network. Prior to installation, RSUs were configured to transmit Signal Phase and Timing (SPaT) and MAP messages. Installed RSUs were validated and tested using an on-board unit (OBU) in the field to confirm SPaT and MAP messages were being transmitted and received correctly or pinged from a remote location to confirm operations. Additional tasks included field data collection to support the installation of RSUs, creation of MAP files, and filing of licenses to the Federal Communications Commission (FCC). As part of this project, GDOT partnered with local agencies to pilot emergency vehicle preemption for a fire station in Gwinnett County as well as Transit Signal Priority along a bus route in Atlanta.

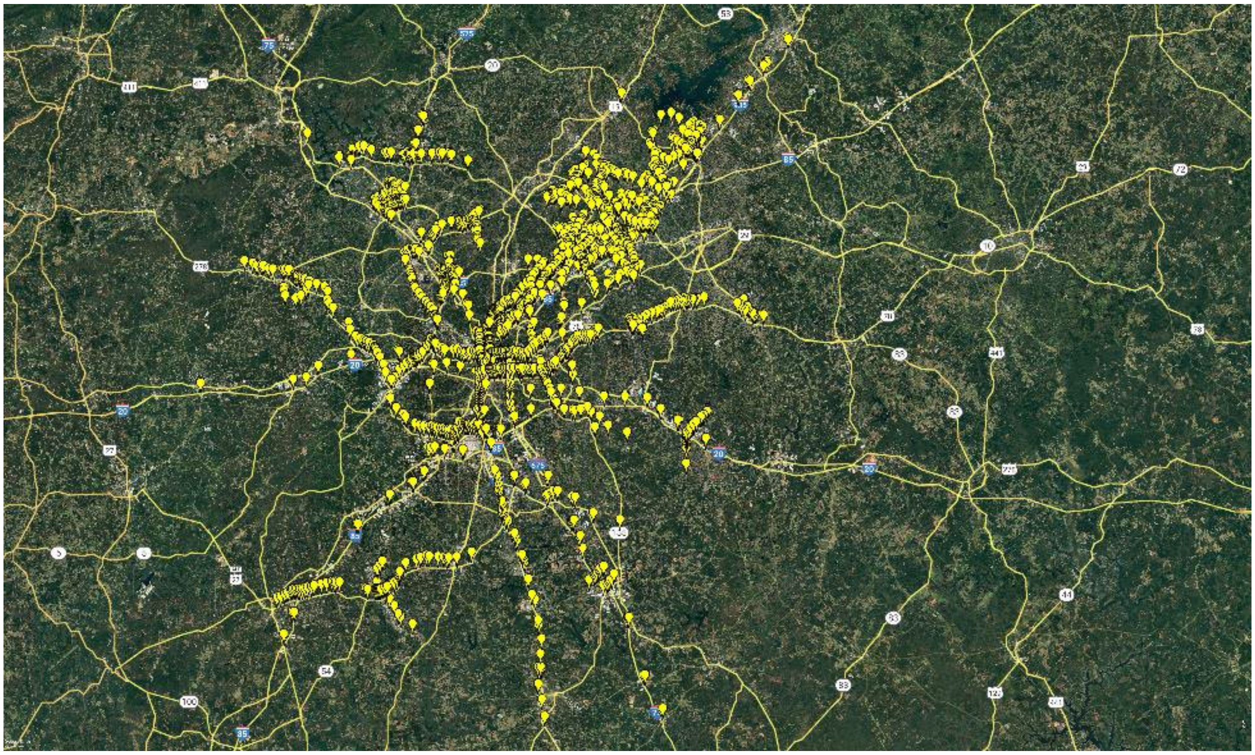

Figure 1: Map of RSUs

1.2. Technology

GDOT utilized dedicated short range communication technology (DSRC) for this deployment. These RSUs are short to medium range wireless communication devices, designed to conform to applicable Institute of Electrical and Electronics Engineers standards and operate between and among RSUs and OBUs in vehicles. Figure 2 shows an example of DSRC RSU installed under this project.

GDOT currently operates Q-Free's MAXTIME signal and ramp meter software; thus, the hardware and software applications must be integrated into the existing infrastructure to ensure seamless integration of SPaT and MAP applications. Figure 3 shows the signal software dashboard which informs the end user that the RSU is connected to the controller.

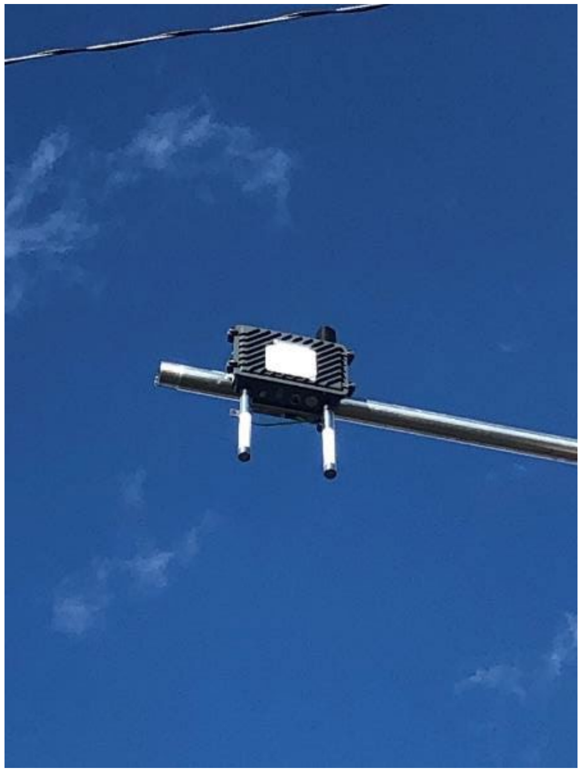

Figure 2: RSU

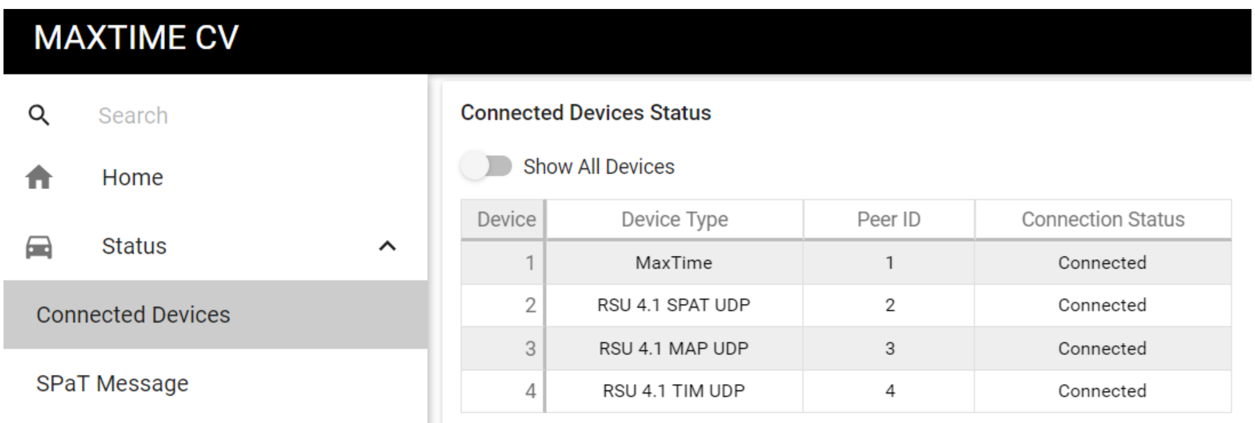

Figure 3: Maxtime Connected Vehicle Dashboard

1.3. Project Scope

- Installation of RSU devices
  - Procuring equipment for installation of devices
  - Configuring devices for communications
  - Traffic control required for installation of devices
- Support testing of the identified intersections for deployment
  - Testing using an OBU
  - Testing via remote ping to confirm operations
- Develop test tool(s) used to execute testing of the intersections in the field
  - Add detailed logging capabilities
  - Add visualization of connections and associated SPaT phase state
  - Add filters for visualized text and data
  - Add location-based filters to minimize “noise” in the visualized data
  - Add caching and storing of the phase time remaining over extended periods
  - Add plotting of phase time per signal group at each intersection
  - Add automated error/discrepancy checking of the MAP messages
  - Add form for user input to note observations while recording tests
  - Add output report generation
  - Add ability to record raw data to file
  - Add an option to record each intersection’s data to a unique file
  - Add an ability to relay recorded data into the test tool
- Develop a high-level user manual for the test tool(s)
- Dry run the test tool(s) while testing the initial corridors

1.4. Timeline

The schedule for the project is outlined in Figure 4. The evaluation period occurred during the RSU field deployment, OBU field deployment, and testing and operations tasks.

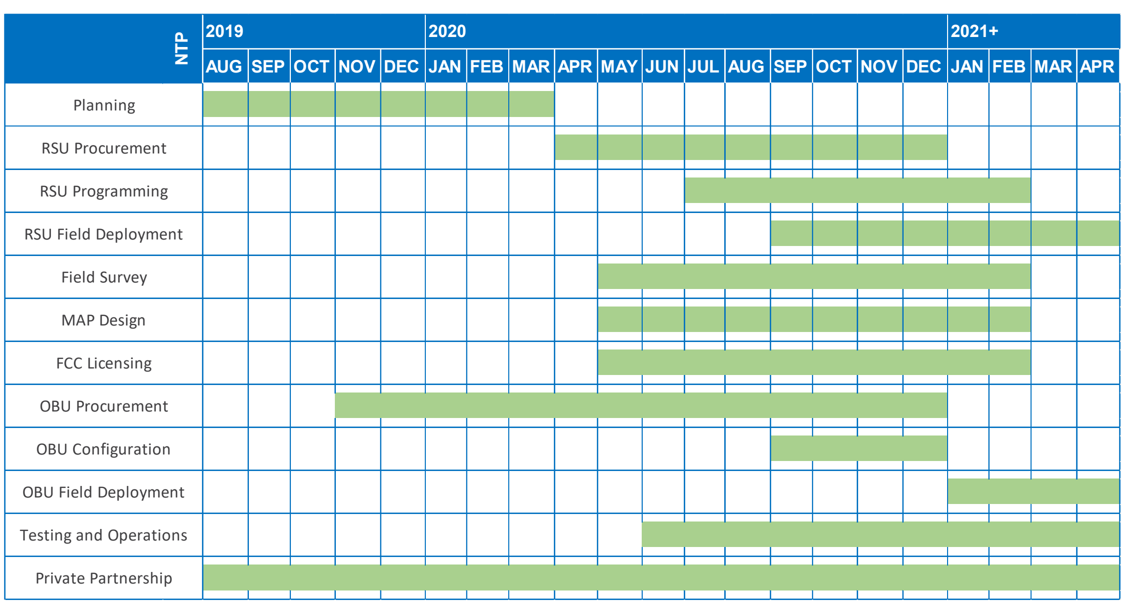

Figure 4: Schedule

2. Performance Metrics, Evaluation Methods, and Data Sources

The objective of this project was to install RSUs that will provide the foundation of CV equipment to support future CV technology and applications which will meet the goals outlined in Section 6004 of the Fixing America's Surface Transportation (FAST) Act. The following best represent GDOT's long-term goals for full implementation of a CV ecosystem.

- Improved safety
- Reduced congestion and/or improved mobility
- Reduced environmental impacts
- Improved system performance/optimized multimodal system performance
- Effectiveness of providing integrated real-time transportation information to the public to make informed travel decisions
- Reduced costs
- Institutional or administrative benefits

As the foundation of the ecosystem, the goal for this project is to implement and validate technology that supports SPaT and MAP and is scalable for use of future CV applications. To evaluate this goal the following criteria were measured.

- Number of RSUs installed
- Number of RSUs operational
- RSUs configured to transmit SPaT and MAP data
- RSUs configured to receive Transit Signal Priority (TSP) requests
- RSUs configured to receive Emergency Vehicle Preemption (EVP) requests

Table 1 outlines the evaluation method and performance measures identified for this project.

Table 1: Evaluation Method and Performance Measures

Evaluation Question	Performance Measure	Information Source/Method	Data Element	Limitations/ Constraints
Does the project support the installation of RSUs that will provide the foundation of a CV ecosystem?	Installation of RSUs	Installation of equipment by project team.	Installation dates.	Installation issues regarding existing equipment or active construction projects.
Are RSUs configured to broadcast SPaT and MAP data that can be used in conjunction with future applications?	Successful configuration of RSUs	Configuration by project team of RSUs ensured that the RSUs had SPaT and MAP enabled for broadcasting.	Configuration tool display showing SPaT and MAP applications were set to broadcast and received by the OBU.	RSUs must have GPS signal; Network information; operational hardware

Evaluation Question	Performance Measure	Information Source/Method	Data Element	Limitations/ Constraints
Are the RSUs receiving the EVP requests and transmitting to the controllers?	Signal controller received the request for EVP	GDOT/Local Agency signal controller data; Field test with OBU and test tools prior to implementation in emergency vehicles	Signal controller logs	Controller logs unavailable
Are the RSUs receiving the TSP requests and transmitting them to the controllers?	Is the signal controller receiving the TSP request	GDOT signal controller data; Field test with OBU and test tools prior to implementation in transit vehicles	Signal controller logs	Conditions did not warrant the need for using the application; ; GPS issues along corridors in Atlanta
Does the project support the installation of RSUs that can be integrated into an information sharing portal that provides information to GDOT and third parties for further research and development?	Subscribers to access data from portal	Procurement of a data portal and the input of CV data	Portal for GDOT to access and share CV data	Network outages, Incomplete or insufficient data from devices to provide meaningful data outputs

3. Evaluation Results and Findings

This section provides the results of the evaluation questions outlined in Chapter 2. The following sections outline the different evaluation methods used during the project deployment and summarizes the results and findings.

3.1. RSU Installation

RSUs were installed at existing signalized intersections along corridors throughout Metro Atlanta shown in Figure 1. The objective of this project was to install RSUs that will provide the foundation of a CV ecosystem; therefore, tracking of installation dates was used for evaluation. Table 2 shows a summary of the number of RSUs installed per year. In 2020 there was a decline in RSU installations per year due to the COVID-19 pandemic and the introduction of supply chain issues. These impacts continued through 2021; however, by 2022 supply chain issues were lessening and installation numbers started increasing again with minor impacts from weather delays.

Table 2: Installed RSUs

Installation Year	Count of RSUs Installed
2018	20
2019	344
2020	202
2021	126
2022	218
2023	18
Total	928

In addition to recording the installation dates, onsite inspections of the RSU installations were conducted. Figure 5 shows the completed installation of an RSU on an existing traffic signal pole. Each RSU is connected to the signal controller at the intersection and powered by the equipment installed in the signal cabinet as shown in Figure 6. Figure 7 shows the active installation of an RSU where the contractor is installing the wire for the connection to the signal cabinet.

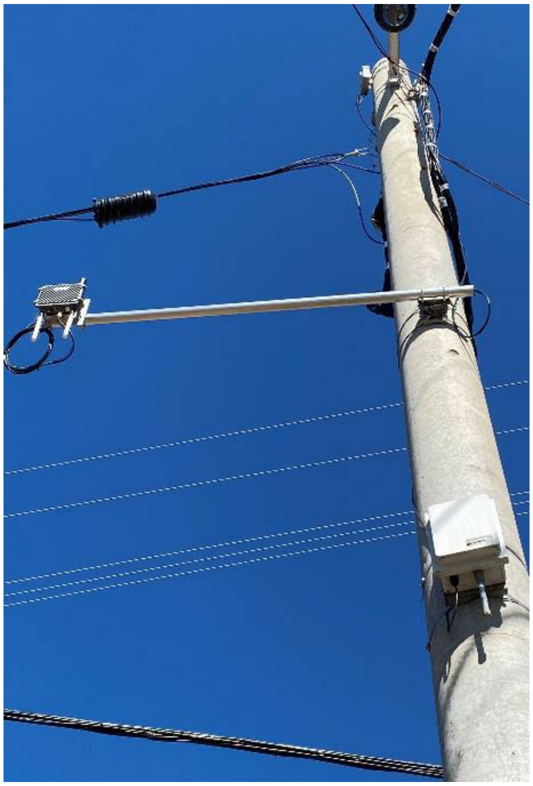

Figure 5: RSU Installation

Figure 6: RSU and Cabinet Installation

Figure 7: RSU Construction

Upon completion of the RSU installation the devices were powered on once the corresponding FCC licenses were approved. The dates were recorded to confirm the operational status of the RSUs, and the testing or evaluation phase of the project could begin. Table 3 shows the number of installed and operational RSUs per year. While some locations presented challenges for the installation team, if it was infeasible to install an RSU at a particular location an alternative location was identified and the RSU was installed. This led to 100% of the RSUs being installed.

Table 3: Operational RSUs

Year	Count of RSUs Installed	Count of RSUs Powered-On
2018	20	0
2019	344	198
2020	202	257
2021	126	214
2022	218	208
2023	18	51
Total	928	928

3.2. RSU Operations

RSUs installed as part of this project were configured to transmit SPaT and MAP data, receive basic safety messages, and configured to support future CV applications. Each intersection required the creation of a MAP message; an example is shown in Figure 8.

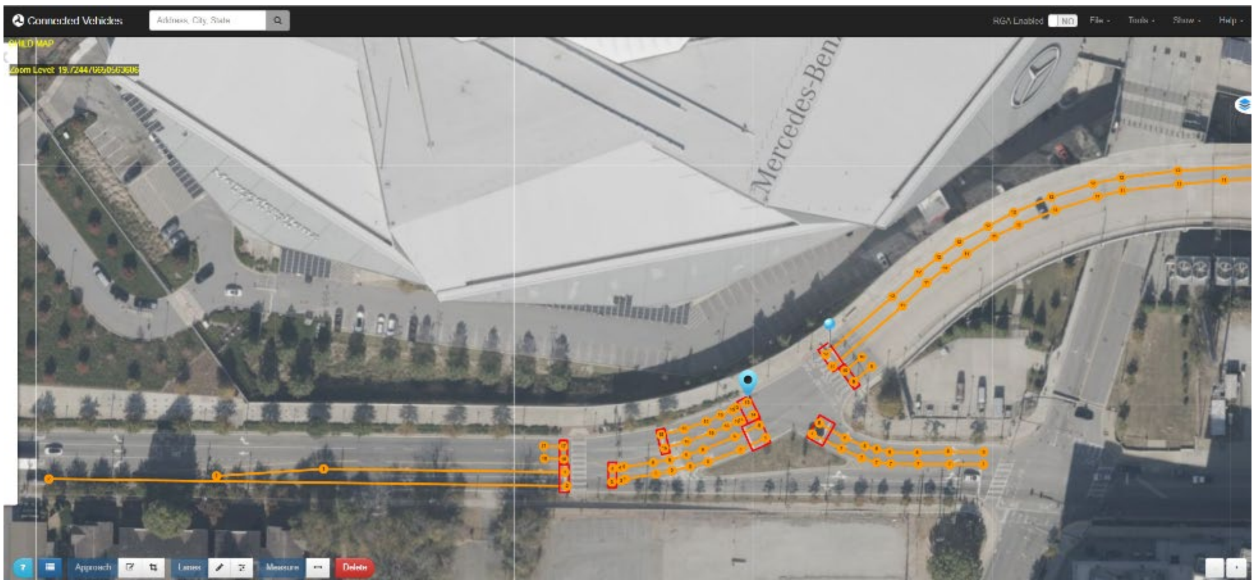

Figure 8: MAP

After installing the RSU and uploading the corresponding MAP message, an OBU was used to verify successful reception of the RSU output. Additionally, specialized test tools validated that the RSUs were transmitting both SPaT and MAP data correctly. Results from the OBU field test, presented in Figures 9 and 10, indicate that MAP messages were received at 92% of the intersections, while SPaT messages were received at 96%.

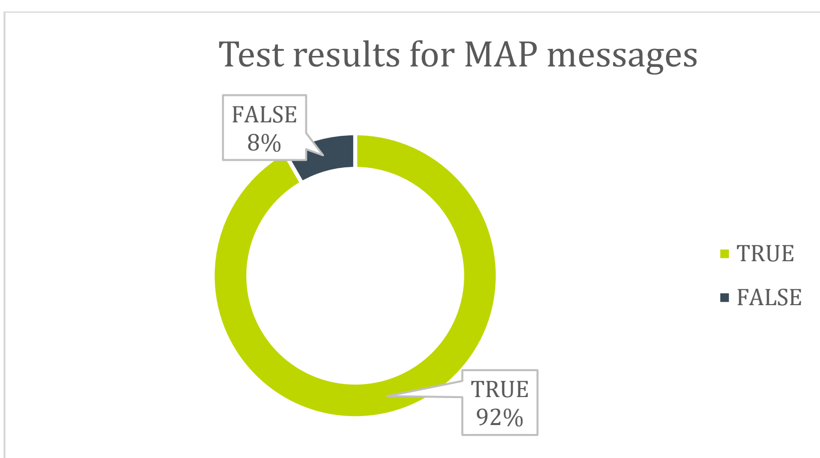

Figure 9: Field test results for MAP messages

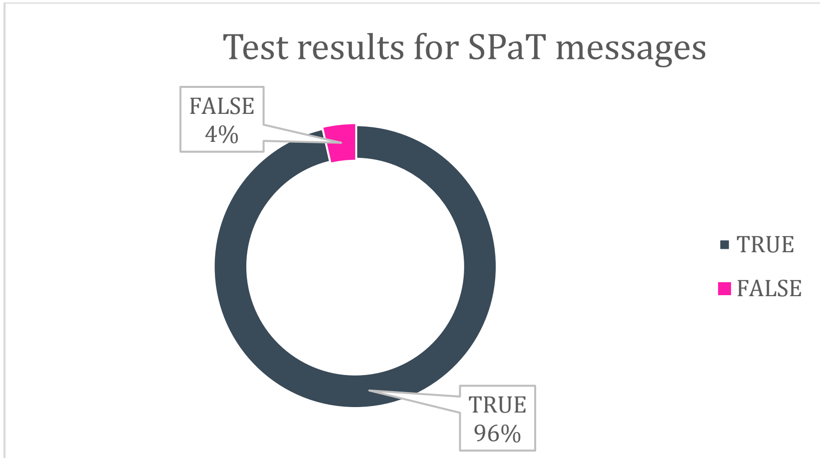

Figure 10: Field test results for SPaT messages

In addition to the field test, the RSUs are connected for remote monitoring via the network through the existing signalized infrastructure allowing the operational status of the RSUs to be monitored. Monitoring the status was conducted by performing a ping test on each RSU to determine the communication status, an example of the ping test results are shown in Figure 11. The example shown are the RSUs along Georgia State Route 154, green indicates the RSU is communicating and transmitting data while the red identifies potential issues for the team to troubleshoot and address. If an RSU was not communicating a technician would troubleshoot the RSU in order to return it to operational status. Various reasons can affect the operational status of an RSUs, such as network issues, construction at or around the intersection, changes to the IP address or network; therefore, at any given time there is the potential for RSUs to not be operational.

During this phase of the project, the network revealed limitations to remote testing. For example, when segments of the network along a specific corridor were down, the RSUs were unable to communicate or respond to ping tests. To address these issues, coordination with GDOT enabled timely notifications of such occurrences. These instances were documented during the ping test to support troubleshooting.

ːUManager - SPaT PH 2.0_Corridor C_SR154_10.csv

dor

ID	Descriptive name	Manufacturer	IP Address	Status	Network Uptime	System Uptime	SNMP Description	Serial #	TX Bytes	RX Bytes
165	Memorial Dr / Ca...	Cohda	10.251.43.104	Timeout	00:00:00	00:00:00			0	0
7684	SR 154 / Fraser ...	Cohda	143.100.212.68	Active	1 days, 16:41:30	1 days, 16:41:30	Road Side Unit		1351301394	214121807
7671	SR 154 / Martin ...	Cohda	143.100.212.69	Active	1 days, 16:41:30	1 days, 16:41:30	Road Side Unit		1351304870	2828596206
7672	SR 154 / Connall...	Cohda	143.100.212.116	Active	237 days, 06:23:40	237 days, 06:24:33	Road Side Unit		738676042	3804005740
7673	SR 154 / Hill Street	Cohda	143.100.212.117	Timeout	00:00:00	00:00:00			0	0
7674	SR 154 / Grant S...	Cohda	143.100.212.118	Active	1 days, 16:41:30	1 days, 16:41:30	Road Side Unit		1351305624	325571882
7675	SR 154 / Cherok...	Cohda	143.100.212.119	Active	56 days, 02:06:58	56 days, 02:07:50	Road Side Unit		174618410	2532559277
7676	SR 154 / Park A...	Cohda	143.100.180.198	Timeout	00:00:00	00:00:00			0	0
7677	SR 154 / Boulev...	Cohda	143.100.180.199	Active	17 days, 04:14:27	30 days, 04:16:16	Road Side Unit		93950766	2298595684
7678	SR 154 / Pearl S...	Cohda	143.100.180.248	Active	17 days, 04:14:13	30 days, 04:16:15	Road Side Unit		93950030	2322102302
7679	SR 154 / Chester...	Cohda	143.100.180.249	Active	30 days, 04:15:41	30 days, 04:16:19	Road Side Unit		94125498	2356903043
7680	SR 154 / Billy Ke...	Cohda	143.100.180.251	Active	29 days, 21:46:05	29 days, 21:47:03	Road Side Unit		93109424	2214102084
8163	SR 154 /Gibson ...	Cohda	143.100.180.246	Active	17 days, 04:11:58	30 days, 04:16:15	Road Side Unit		93927888	2328911739
7681	SR 154 / Stovall ...	Cohda	143.100.180.252	Active	85 days, 03:35:45	85 days, 03:36:56	Road Side Unit		265095636	14205684
7716	SR 154 / Whitef...	Cohda	143.100.180.253	Active	17 days, 04:11:29	54 days, 17:31:49	Road Side Unit		159743572	361137944
7718	SR 154 / Maynar...	Cohda	143.100.180.132	Active	54 days, 17:30:16	54 days, 17:31:56	Road Side Unit		170389030	1871353517
7719	SR 154 / Clifton ...	Cohda	143.100.180.133	Active	17 days, 04:11:11	54 days, 17:32:00	Road Side Unit		170389424	1844529920
7720	SR 154 / Wilkins...	Cohda	143.100.180.134	Active	54 days, 17:31:12	54 days, 17:32:00	Road Side Unit		170389906	1859573032
7721	SR 154 / Warren...	Cohda	143.100.180.153	Active	54 days, 17:31:10	54 days, 17:32:01	Road Side Unit		170389960	1856374226
7722	SR 154 / East La...	Cohda	143.100.180.158	Active	17 days, 04:10:17	30 days, 01:40:43	Road Side Unit		93614658	2309056019
7723	SR 154 / 2nd Av...	Cohda	143.100.180.163	Active	17 days, 04:08:41	48 days, 12:28:07	Road Side Unit		151053256	3019341139
7724	SR 154 / 4th Av...	Cohda	143.100.180.168	Active	17 days, 04:09:40	98 days, 07:59:22	Road Side Unit		101950733	1617223004
7725	SR 154 / East La...	Cohda	143.100.180.180	Active	17 days, 04:09:39	98 days, 08:00:40	Road Side Unit		306138316	2382228097
7726	SR 154 / Candler...	Cohda	143.100.180.188	Active	17 days, 04:09:31	143 days, 20:39:18	Road Side Unit		149152927	1910569676
7758	SR 154 / Line Str...	Cohda	143.100.178.43	Active	4 days, 14:23:35	4 days, 14:25:08	Road Side Unit		14321188	2319048716
7759	SR 154 / Carter ...	Cohda	143.100.178.48	Active	00:04:09	4 days, 14:25:04	Road Side Unit		4769905	884356380
7760	SR 154 / Rupert ...	Cohda	143.100.178.57	Active	4 days, 14:24:16	4 days, 14:25:11	Road Side Unit		14322126	2322703597
7761	SR 154 / Hooper...	Cohda	143.100.178.58	Active	4 days, 14:32:04	4 days, 14:32:49	Road Side Unit		14338786	2324186720

Figure 11: Communications Ping Output

3.3. Emergency Vehicle Preemption (EVP) Application

A singular test of the implementation of an emergency vehicle preemption application was conducted under this project with Fire Station 15 of Gwinnett County to test the ability of future applications. An RSU was installed at an intersection north of the fire station and an OBU was installed in a fire engine that could request preemption from the signal adjacent to the fire station prior to leaving the station. The Preempt Service Request and Preempt Service data for the test period of October 21, 2021, are displayed in Figures 12 and 13. The Preempt Service Request shows a dot for each request received by the controller over a 24-hour period. On the date of the test the signal controller received five preempt service request at 07:00, 07:30, 09:15, 16:00, and 18:15. The Preempt Service chart shows that each of the requests received by the controller were serviced. In addition to confirming the preemption requests from the OBU the team collected Preemption Details of each service request, which are shown in Figure 13. This chart provides details for each of the service calls from Figure 12, such as Time to Service (the amount of time in seconds that elapsed from the controller receiving the request to servicing the request), the Dwell Time (the amount of time the signal was servicing the call), and the Input Off (the amount of time until the service request was terminated).

For example, the yellow bar for the 07:00 call represents the Time to Service was approximately 7-seconds, the green bar represents the Dwell Time or duration of the service call which was 73-seconds, and the black dot represents the Input Off at 80-seconds. On the day of testing the average response time of the calls was 7-seconds, average dwell time was 65-seconds, with each call terminated promptly after the preemption was serviced. The scope of the test was to test the ability and functionality of the EVP system using connected vehicle technology which was proven successful.

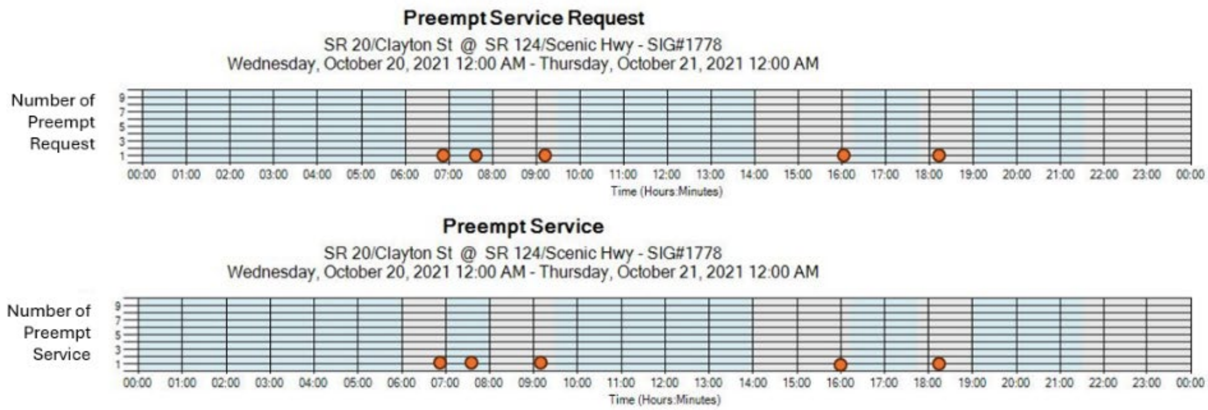

Figure 12. Preempt Service Request for EVP test

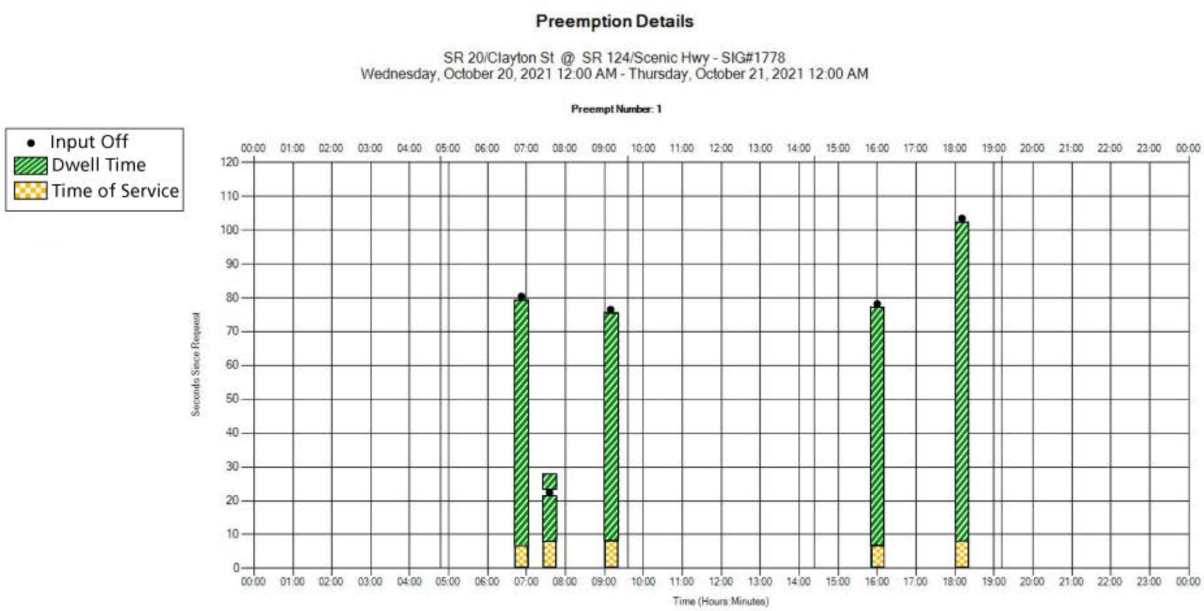

Figure 13: Preemption Request Details from EVP test

3.4. Transit Signal Priority (TSP) Application

During the timeline of this project, a pilot of transit signal priority was implemented on a downtown Atlanta transit route to test the ability and scalability of future transit applications. RSUs were configured at 26 intersections to receive priority requests from OBUs that were installed on ten transit buses and configured to request priority from a defined set of intersections if the buses were five minutes behind schedule. Figure 14 shows the bus route chosen for the pilot with the signalized intersections which have an RSU, as well as the two transit stops along the route. Figure 15 shows a summation of priority requests received by the controller during a test run on April 21, 2021, a total of

25 transit priority calls were made at 13 different intersections along the route. A limiting factor during the period of the TSP pilot was significantly low ridership and decreased traffic volumes following COVID-19. The green arrow in Figure 15 indicates the bus route direction and signal ID with the time of day that priority was requested by an OBU installed in a transit bus. Please note that the signal ID numbers in Figure 15 correspond with Figure 14.

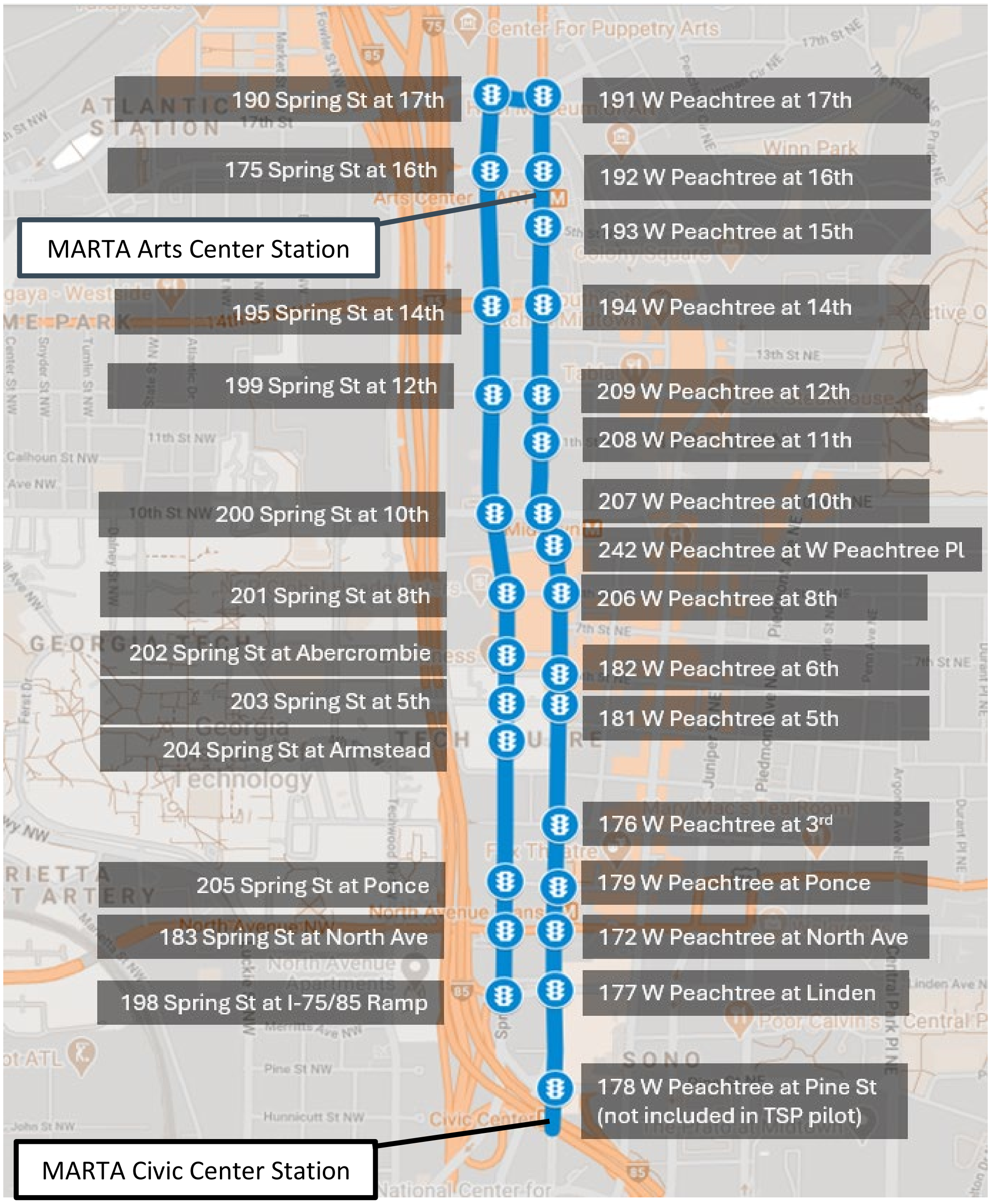

Figure 14: Transit Bus Route

4/19/2021										5:25:22 PM	5:24:27 PM	5:24:04 PM	5:23:17 PM		
				198	183	205	204	203	202	201	200	199	195	175	190
	177	172	179	176	181	182	206	242	207	208	209	194	193	192	191
	4:00:45 PM		4:01:34 PM			4:03:40 PM	4:03:59 PM	4:04:00 PM		4:06:08 PM		4:06:44 PM	4:08:20 PM	4:08:21 PM	
	5:10:38 PM		5:11:40 PM			5:15:24 PM	5:15:42 PM	5:15:43 PM		5:16:24 PM		5:16:58 PM	5:18:39 PM	5:18:40 PM	
			5:13:07 PM					5:16:03 PM				5:17:55 PM			

Figure 15: Priority Requests

The TSP pilot ran approximately from November 2021 through August 2022. There were 96 recorded trips that received priority and 513 recorded trips that did not receive priority. It should be noted that TSP requests are triggered only when a bus is running more than five minutes late. Figure 16 displays the average AM and PM travel time for both the northbound and southbound routes. The data collected during the pilot is too limited to analyze and determine any actionable results and/or benefits but show potential for future implementation and reaching GDOT's long term goals of CV infrastructure. The purposes and goals of this project were to test the feasibility of using CV technology and equipment to implement TSP for transit agencies and that was proven successful.

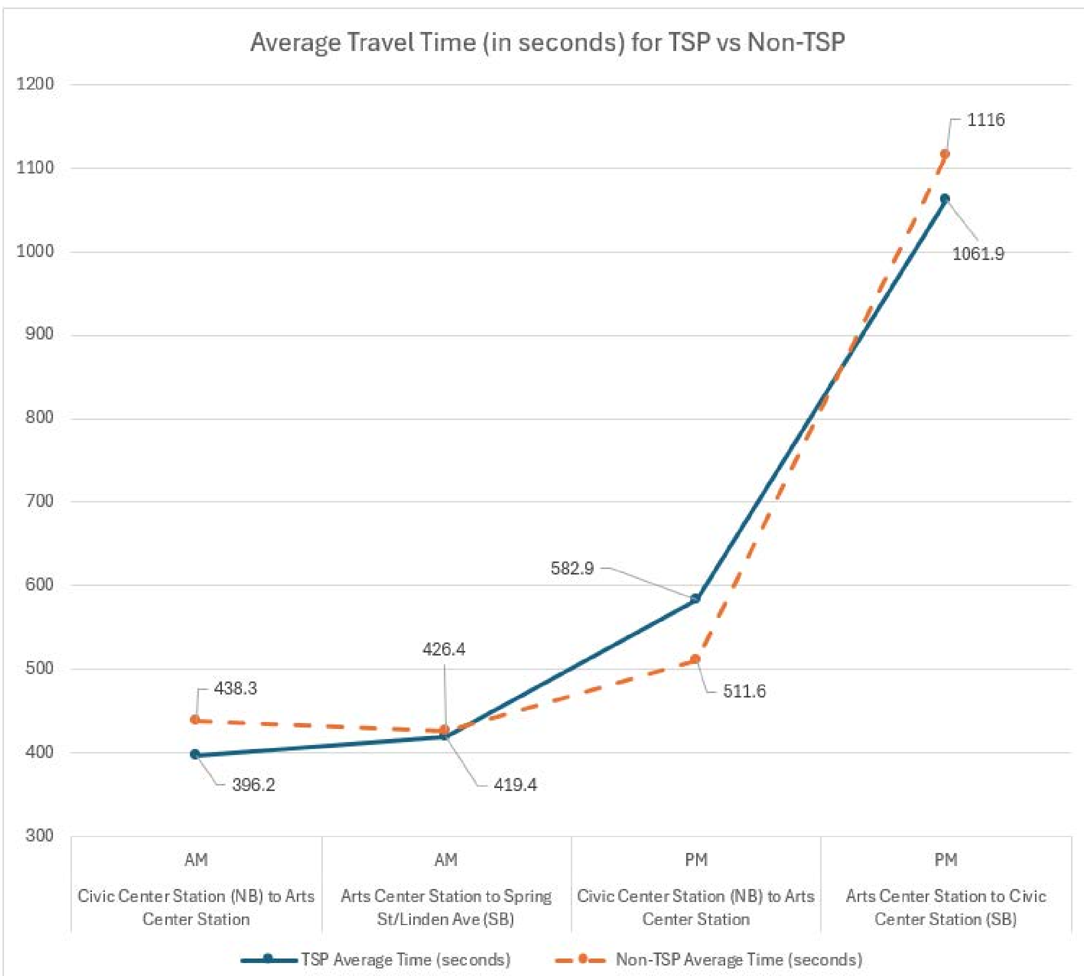

Figure 16: Travel Times recorded during test

3.5. Data Portal

GDOT procured a data portal for this deployment, the service provided a near-real time Application Programming Interface (API) to certain elements of the SPaT messages for the intersections such as minTime, maxTime, and confidence.

The purpose of this portion of the project was to implement and test the scalability and usability of a portal. GDOT found the portal to be a successful way to maintain and test the status of the RSUs. The preferred outcome of procuring the portal was to allow third parties to access the data to further develop and expand the uses of the CV technology. Throughout the course of the project subscribers to the portal included TTS (now Miovision), research institutions as well as a large web development and data company (covered under an NDA), their access to the portal allowed these subscribers to conduct research and development efforts for future use and applications. The overall purpose and goal of the portal were achieved.

4. Lessons Learned

All projects and deployments, regardless of the size, have lessons that are learned and can be applied to the next project or deployment. The following are some challenges that were encountered under this project and deployment.

Installation issues. All RSUs were installed at existing signalized intersections varying in range of age and equipment standards. The RSUs are installed on a gusseted tube which is banded to an existing signal pole, then the CAT6 cable is run to the cabinet preferably through the pole. However, there were some instances when the pole was at capacity, and we had to mitigate by installing a pole riser to complete the installation. On the cabinet side, a Power over Ethernet (POE) and surge must be installed; however, some cabinets did not have available power or were already full of existing signal equipment. Our team worked with GDOT/SigOps/local agencies to install additional power outlets or remove equipment no longer in use to provide room for the CV equipment.

Network Issues. Due to the nature of the infrastructure, network variability will be an ongoing point of attention. This can be mitigated by communication and coordination within the Department and project teams. Being aware of upcoming or ongoing network outages the monitoring of the RSU communication status can be more efficient.

Supply Chain Issues. Manufacturing was impacted due to the COVID-19 pandemic which resulted in delays in RSU hardware and RSU mounting hardware. These delays were mitigated by implementing batch shipments instead of waiting for the entire order to be ready and while waiting on the hardware the team worked on field surveys for MAP messages and FCC licenses.

Flashing Yellow Arrow. An ongoing challenge is aligning how signal controllers manage overlap phases, in particular flashing yellow arrows for left turn movements, and how they are represented in the V2X standards. The V2X standards assume that a single signal head is represented by a single "signal group" or phase. Internal to the controller, 4-section and 5-section signal heads are driven by two or more phases. Signal controller vendors are continuing to work on software solutions to address this; however, there are still some issues representing the phase correctly.

MAP Message Creation. When creating a message, it must accurately represent the existing intersection geometry and signal phasing. During the deployment, we discovered the USDOT MAP tool satellite imagery base map did not always accurately depict the lane geometry. Through the support of a .KML in the USDOT tool, a more current satellite image could be traced and inserted into the tool. Additionally, plans under development can be used to create MAPs. CAD files can be transferred into a KML file, and transferred into the USDOT tool, thus ensuring that MAP messages are created with the highest known level of detail. Incorporating these various techniques resulted in an up-to-date, accurate, and precise MAP message.

Federal Communications Commission. The recent ruling by the FCC to limit the 5.9-GHz DSRC band available to CV applications to a specific number of channels resulted in impacts to the project schedule of this deployment. GDOT made the determination to continue with the installation of the DSRC units which communicate on channel 180.

5. Recommendations

The Department recommends continued deployment of infrastructure and contributing to the advancement of technology to further accelerate benefits envisioned for CVs. Prior to beginning any application development or deployment, it is recommended to identify all stakeholders and understand the needs and goals each have for the proposed application. Stakeholder meetings and data gathering were crucial pieces to the success of the pilot. Following the completion of the pilots the Department will be identifying more stakeholders to partner with to implement EVP and TSP through the state. A phased CV implementation approach was successful, having a foundation of technology prior to implementing the EVP and TSP applications was essential. Understanding how the CV equipment integrates within existing signal systems and ensuring that the signal software is set up to push the data to the RSU is integral to correctly transmit the SPaT and MAP data and promote scalability. Once the foundation is set the implementation of applications such as EVP and TSP can begin.

6. Conclusion

The Connected Vehicle Deployment program has been marked with overall success. Throughout this project the team avoided deviations and changes to the original scope. This was accomplished by meeting the project objective of installing the necessary equipment that provide the foundation for a connected vehicle ecosystem and to support future CV technology and applications which will meet the goals outlined in Section 6004 of the Fixing America’s Surface Transportation (FAST) Act. The key takeaway from this deployment is to understand that technology is ever evolving, and the deployment teams must be adaptable and able to react to changing circumstances. Through the implementation of this project, we have witnessed a global pandemic which resulted in limited travel and exposure to people, supply chain issues resulting in delayed manufacturing of RSUs, OBUs, and standard mounting hardware which impacted schedules, the FCC ruling on the spectrum for transportation safety, and inflation resulting in increased costs of all equipment. Despite these challenges, we were still able to install devices to meet the goal of the project of installing a total of 928 RSUs configured to transmit SPaT and MAP data with 26 of the RSUs configured to receive TSP and one RSUs configured to receive EVP requests.

Because GDOT was an early adopter of CV technology and infrastructure, the benefits of this project will not be realized until well into the future. GDOT is strategically positioned for broad implementation and adaptation of future CV technology by having a built-out ecosystem. As CV technology advances and new capabilities emerge, GDOT will be able to implement CV projects in the future at a lower cost and more efficiently due to having this CV infrastructure in place.