Connected Vehicle Pilot Deployment Program Independent Evaluation

Public Agency Efficiency Impact Assessment—Tampa (THEA)

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16. Abstract

This report contains the finding of the public agency efficiency impact assessment associated with the Tampa Hillsborough Expressway Authority (THEA) Connected Vehicle Pilot Deployment (CVPD). In this report, the Texas A&M Transportation Institute (TTI) assesses how the deployment impacted stakeholders' ability to improve their operational efficiency and situational awareness. TTI used data provided to the THEA CVPD team as well as supplemental interviews with impacted stakeholders. Because of issues associated with the deployment, TTI was only able to provide a qualitative analysis. The analysis found that the biggest impact on public agency efficiency came from the performance monitoring tool developed by the Center for Urban Transportation Research. The tool uses data collected from onboard units and roadside units to monitor the status of the deployment and provide insight into the locations and time frames where warning alerts and messages were provided to equipped vehicles. The tool allows stakeholders to monitor the operational heath of the system by monitoring the status of the field devices and providing stakeholders with performance indicators on the effectiveness of the applications. The tool allows stakeholders the ability to monitor system performance at individual intersections or on system-wide basis. Stakeholders can aggregate performance statistics over time and by individual sites. This tool provides a solid foundation for the agencies to build upon as they enter future deployment phases.

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Executive Summary

One potential benefit of connected vehicle (CV) technologies is that they can provide data and information that agencies can use to improve their efficiencies. The extent to which an agency can use this data to assess its efficiencies can depend upon an agency's policies that limit or constraint the data. For this evaluation, public agency efficiency also refers to the agency's ability to respond to changing conditions or unexpected events occurring in the deployment area. Public agency efficiency can also refer to data and information that agencies can use to better understand the performance of their system. The Texas A&M Transportation Institute assessed public agency efficiency impacts from two perspectives:

- Improved operating efficiencies.
- Improved situational awareness.

Examples of performance measures that agencies typically use to quantify improved operating efficiencies include improved signal timing responsiveness, improved percent arrival on green, improved travel time reliability, and improved percent on-time performance. Examples of improved situational awareness might include detections of unexpected congestion due to weather events and incidents, improved detection of equipment or device outages, and better understanding of system bottlenecks or independencies.

Originally, the Tampa Hillsborough Expressway Authority (THEA) team had planned to demonstrate public agency efficiencies through its mobility, safety, and customer satisfaction analyses. However, because of unexpected delays in the deployment and because of unforeseen external factors (e.g., the COVID-19 pandemic), the THEA Connected Vehicle Pilot Deployment (CVPD) team was unable to deploy several of its planned mobility applications, which would have allowed the team to quantify public agency efficiencies. Market penetration issues and reduced evaluation periods also impacted the ability to quantify public agency benefits resulting from safety applications (e.g., reduction of vehicle collisions and crash potentials).

One positive outcome of the deployment that proved to be valuable from a public agency efficiency standpoint was the performance monitoring tool developed to track the deployment. The tool uses data collected from onboard units (OBUs) and roadside units (RSUs) to monitor the status of the deployment and provide insight into the locations and time frames where warning alerts and messages were provided to equipped vehicles. The tool, developed by the Center for Urban Transportation Research, allows stakeholders to monitor the operational heath of the system by displaying the number of fully operational RSUs and OBUs. The tool also provides stakeholders with performance indicators that provide information on the effectiveness of the applications. The tool allows stakeholders the ability to monitor system performance at individual intersections or on a system-wide basis. Stakeholders can aggregate performance statistics over time and by individual sites. This tool provides a solid foundation for the agencies to build upon as they enter future deployment phases.

Key findings and lessons learned related to public agency efficiencies include the following:

- One of the primary motivating factors for public agencies to participate in projects like the CVPD is the opportunity to work with and potentially shape emerging technologies. The experiences gained by implementing 'shelf-ready' technology, getting it operational, and generating results is invaluable when it comes to planning, designing, deploying, and managing advance technology projects.
- Participants acknowledged that the experimental design at the beginning of the project assumed that the technology would be fully ready, out on the road, and operational. It turned out that the technology was not fully ready as originally assumed. The deployment team had to make changes to those assumptions.
- With respect to the technology, the market in which the technology development was taking place was small-sized research and development businesses, some of which almost disappeared from the market. Regarding the deployment, the market around the technology was in rapid development, and there were significant growing pains associated with the technology.
- The THEA CVPD provided the local stakeholders with valuable knowledge and experience in deploying and testing CV applications in the corridor and measuring their benefits.

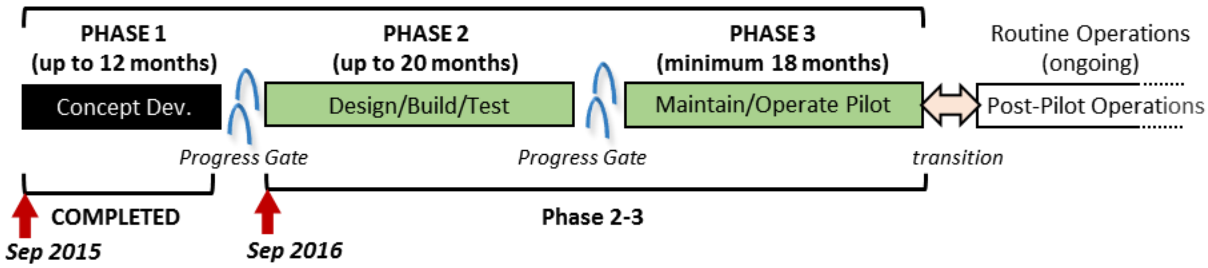
Chapter 1. Introduction

The United States Department of Transportation (USDOT) connected vehicle (CV) research program is a multimodal initiative that aims to enable safe, interoperable networked wireless communications among vehicles, transportation infrastructure, and travelers' personal communications devices. CV research is being sponsored by USDOT and others to leverage the potentially transformative capabilities of wireless technology to make surface transportation safer, smarter, and better for the environment. Concurrent Federal research efforts have developed critical cross-cutting technologies and other enabling capabilities required to integrate and deploy applications. Descriptions of the relevant research products, developed by the component CV research programs, are available at www.its.dot.gov/pilots. The programs seek to identify, develop, and deploy applications that leverage the full potential of trusted communications among CVs, travelers, and infrastructure to better inform travelers, reduce environmental impacts, enhance current operational practices, and transform surface transportation systems management.

Connected Vehicle Pilot Deployment

Through the Connected Vehicle Pilot Deployment (CVPD) Program, the USDOT Intelligent Transportation Systems Joint Program Office (ITS JPO) wanted to spur innovation among early adopters of CV application concepts. The pilot deployments were expected to integrate CV research concepts into practical and effective elements, enhancing existing operational capabilities. The pilot deployments included site-tailored collections of applications that addressed specific local needs while laying a foundation for additional local/regional deployment. ITS JPO also expected each deployment to provide transferable lessons learned for other prospective deployers across the Nation. The ITS JPO expected the deployments to encourage partnerships of multiple stakeholders (e.g., private companies, State and local agencies, transit agencies, commercial vehicle operators, and freight shippers) to deploy applications using data captured from multiple sources (e.g., vehicles, mobile devices, and infrastructure) across all elements of the surface transportation system (e.g., transit, freeway, arterial, parking facilities, and tolled roadways). The sites were expected to demonstrate improved performance in one or more of the following areas: safety, mobility, public agency efficiency, or reduced negative environmental impact. Pilot deployers identified key quantitative performance measures and implemented a system that supports continuous monitoring of observed data capable of quantifying the measures. Deployed technology was expected to become part of a permanent CV capability that was fully integrated into routine operational practice at the pilot site and created a foundation for expanded and enhanced deployments. Each site was expected to identify and implement institutional and financial models that would enable long-term sustainability without the need for dedicated Federal funding.

On September 14, 2015, the CVPD Program initiated the pilot deployments of CV applications that synergistically capture and use new forms of CV, mobile device, and infrastructure data to improve multimodal surface transportation system performance and enable enhanced performance-based systems management. [(1)] The Intelligent Transportation Systems Joint Program Office (ITS JPO) selected three locations as pilot deployment sites: Wyoming, New York City, NY, and Tampa, FL. Each deployment represents different potential settings for CV technologies and was comprised of different applications that address vastly different problems. For example, the Wyoming deployment focused on better dissemination of travel information during winter weather events to reduce the potential of multi-vehicle collisions involving trucks. The New York deployment focused on improving safety and traffic flow in a very dense urban environment, while the Tampa deployment focused on improving safety and mobility in a typical central business district (CBD) of a smaller community. As illustrated in Figure 1, each deployment went through a similar life cycle. In Phase 1 of the life cycle, each site developed and refined the concepts behind its deployment. In Phase 2, each site, following the systems engineering approach, designed, built, and tested its deployment. In Phase 3, each site was responsible for managing and operating its deployments under actual traffic conditions.



Source: Federal Highway Administration

Figure 1. Flow chart. Three phases of a connected vehicle pilot deployment. [1]

Independent Evaluation

ITS JPO selected the Texas A&M Transportation Institute (TTI) CVPD evaluation team to be the independent evaluator for the mobility, environmental, and public agency efficiency benefits for the CVPD. An *independent* evaluation by a third party who has no vested interest or stake in the project will eliminate potential bias in the findings. USDOT has sponsored an independent evaluation of CVPD to help inform USDOT of the following:

- The extent to which the CVPD Program was effective in achieving its goals of transformational safety, mobility, public agency efficiency, and environmental improvements.
- The lessons learned that can be used to improve the design of future projects.
- The institutional and financial impacts of the CVPD.
- How resources should be applied in the future.

In parallel, the independent evaluation will help the deployment sites with the following:

- Identifying the impacts of their pilot deployments by complementing the sites' performance measurement effort.
- Determining if their actions achieved desired objectives.
- Extracting lessons that can be used to improve the continued operation of their deployments.

This report provides an independent assessment of the impact of the Tampa-Hillsborough Expressway Agency (THEA) CVPD on public agency efficiency. For this analysis, public agency efficiency relates to how the deployment impacted the agency's ability to manage and operate the transportation resources in the deployment area. Public agency efficiency also refers to the agency's ability to respond to changing conditions or unexpected events occurring in the deployment area. TTI assessed public agency efficiency impacts from two perspectives:

- Improved operating efficiencies.
- Improved situational awareness.

Because of delays in the deployment and because of unforeseen external factors (e.g., the COVID-19 pandemic), FHWA revised TTI's evaluation scope to include only data collected by the sites during their evaluation. TTI did not perform an *extensive* quantitative analysis of the data collected by the THEA CVPD team. Instead, TTI's evaluation is primarily qualitative in nature, with some supporting explanatory quantitative analyses appropriately scoped to reduce technical risk and consistent with the nature, quality, and quantity of underlying data. To complete the analysis, TTI used materials and information provided through published information and outcomes of other evaluation efforts, including the following:

- Performance measurement activity performed by the sites.
- The Volpe Center's safety impact assessments.
- Site-generated dashboards and lessons-learned logbooks.
- Survey and interview outputs from the Connected Vehicle Pilot Deployment Program Independent Evaluation: User Acceptance and Stakeholder Satisfaction (Task C) analysis.

Organization of the Report

The organization of this report is as follows:

- Chapter 2 provides an overview of the THEA CVPD in Tampa. The chapter provides a summary of THEA's goals and objectives associated with the deployment. Chapter 2 also includes a description of the applications planned and deployed through Phase 3 of the deployment.
- Chapter 3 summarizes the sources and availability of evaluation data available to conduct the public agency efficiency impact assessment.
- Chapter 4 provides an overview of the approach the TTI team used to assess the public agency efficiency impacts of the deployment.
- Chapter 5 summarizes stakeholder feedback on the value of the deployment in improving public agency efficiency.
- Chapter 6 includes a summary of the findings and lessons learned from the public agency efficiency impact assessment.

Chapter 2. THEA Tampa Connected Vehicle Pilot System Overview

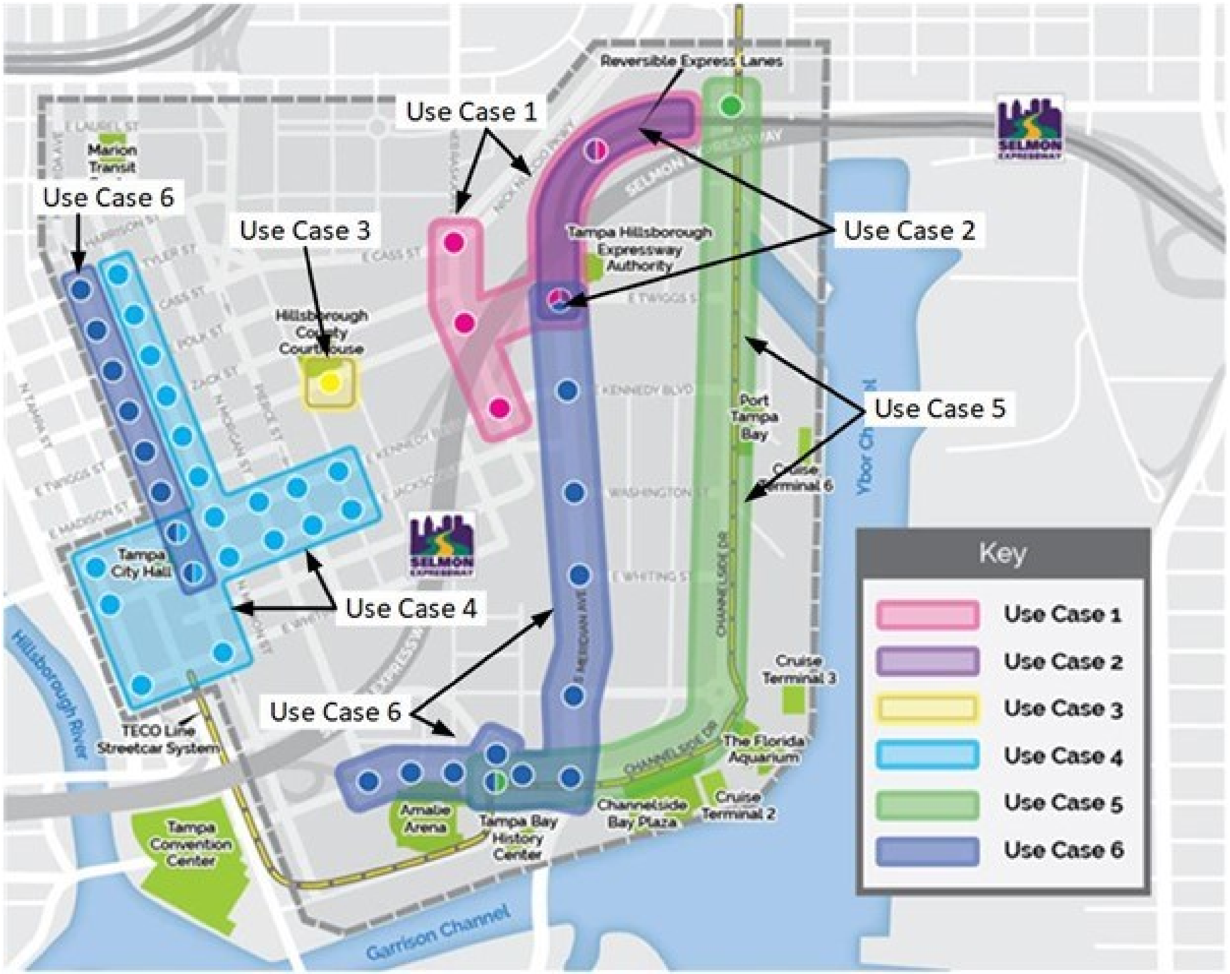
This chapter describes the deployer's goals and objectives for the pilot deployment site. This chapter also summarizes the set of applications chosen by the local stakeholders to meet the objectives. Finally, the chapter summarizes the metrics and data to be used by the THEA CVPD team to measure and monitor performance of the deployment.

Site Description and Transportation Issues

Figure 2 shows the THEA CVPD site in downtown Tampa, FL, which is bordered by the Ybor Channel (a cruise ship and commercial port channel) to the east, the Garrison Channel (a local waterway) to the south, Florida Avenue to the west, and Scott Street to the north.(2,2) In terms of transportation features of the Tampa downtown area, THEA owns and operates the Selmon Expressway and the REL. The Selmon Expressway is an elevated reversible and all-electronic toll facility that serves as a main commuter route, connecting the community of Brandon (a large residential area with a population of 103,000) and I-75 with downtown Tampa, the Tampa cruise and commercial port, and McGill Air Force Base (MAFB). MAFB is located 8 mi south of downtown Tampa adjacent to the western terminus of the Selmon Expressway. The base has a transportation incentive program in which about 1,450 base personnel use express buses or vanpools to commute to the base. The program provides monthly Hillsborough Area Regional Transit (HART) express bus passes to commuters who live in suburban areas east of Tampa. The vanpool program provides commuters, in groups of five or more, funding to secure a passenger van for their daily commute. The Tampa downtown area has a high volume of pedestrian activity around the courthouse, convention center, and arena. In addition to HART buses, streetcar lines connect downtown Tampa with neighboring Ybor.

Tampa Deployment Goals and Objectives

The THEA CVPD site was one of the first CV pilot sites selected to showcase the value of CV technology and to spur its adoption in the United States. The overall goal of the THEA CVPD was to improve the overall quality of life for Tampa Bay residents by creating a connected urban environment through the deployment of several CV applications. These applications were meant to mitigate several existing transportation challenges in the CBD of Tampa. (2)



Source: Center for Urban Transportation Research, 2020

Figure 2. Map. THEA CVPD site. (3)

The area encapsulated by the THEA CVPD experiences several different mobility and safety issues daily.(3) For example, in the morning commute, the REL toll lanes end at the signalized intersection of East Twiggs Street and Meridian Avenue. East Twiggs Street and Meridian Avenue are also major routes for HART buses into and out of downtown Tampa. Drivers experience significant delay during the morning peak, resulting in numerous rear-end crashes and red-light-running collisions. Also, Meridian Avenue and West Kennedy Boulevard experience transit signal delay, pedestrian conflicts, red-light running, and signal coordination issues. At the Hillsborough County Courthouse on East Twiggs Street, there is significant competing vehicular and pedestrian traffic during the morning peak. Similarly, commuters to MAFB who travel through the downtown area on the Simmons Expressway often encounter queues and delays where the REL exits into downtown. Also, during the morning peak, THEA is concerned with wrong-way entries into the REL in the downtown area. To improve mobility, enhance safety, mitigate the environmental impacts of queuing, and enhance agency efficiency, the THEA CVPD deployed several CV applications and technologies to address the following operational issues in the deployment area:

- Congestion reduction and collision avoidance due to queuing on the exit ramp from the REL during the morning peak (Use Case 1).

- Wrong-way entries into the REL entrance/exit ramps during all hours of the day (Use Case 2).
- Pedestrian safety on East Twiggs Street near the George E. Edgecomb Court House (Use Case 3).
- TSP on the Marion Street Transitway (Use Case 4).
- Vehicle and pedestrian conflicts with the Tampa historic streetcars on Channelside Drive (Use Case5).
- Traffic flow optimization and signal progression on Meridian Avenue, Nebraska Avenue, Channelside Drive, and Florida Avenue (Use Case 6).

Table 1 shows the issues (in the form of Use Cases) the THEA CVPD team planned to address through the deployment. In a few of these Use Cases, the THEA CVPD team planned to deploy multiple applications to address these issues.

Deployed Equipment

Table 2 summarizes the number and type of devices that the THEA CVPD originally planned to deploy and that were deployed.

Between March and December 2018, installation teams equipped 1,020 private vehicles with aftermarket onboard units (OBUs).[2] Certified technicians and student trainees at Hillsborough Community College installed the OBUs on participant vehicles. All vehicles equipped with OBUs recorded all received and transmitted data from interaction with nearby vehicles and roadside units (RSUs) in range via an OBU data log recording protocol. OBU data logs contain various data elements, falling into one of the following categories:[2]

- WAVE Short Messaging Protocol messages sent or received.
- Warnings issued to the driver.
- Internal system monitoring events (e.g., Secure Digital card space and security audits).

Table 1. Summary of use cases addressed by the THEA CVPD. [2,3]

Use Case	Condition	Description of Issues to Be Addressed	Applications
1	Rush-hour collision avoidance	As drivers approach the end of the Selmon Expressway Reversible Express Lanes (REL), drivers enter a curve where the speed limit reduces from 70 miles per hour (mph) to 40 mph. During morning rush hour, as vehicles exit the REL onto Meridian Avenue to make a right turn onto East Twiggs Street, the right-turn lane backs up. An additional issue is that many of these drivers then want to make a right turn onto Nebraska Avenue, which is an immediate right turn after turning onto East Twiggs Street. The combination of these issues causes the queue to back up onto the REL. This backup causes exiting vehicles turning right to use the shoulder as part of the right-turn lane. As drivers approach the REL exit, they may not be able to anticipate where the end of the queue is for the right-turn lane, potentially causing them to brake hard or attempt a rapid lane change	• End of Ramp Deceleration Warning (ERDW) • Electronic Emergency Brake Light (EEBL) • Forward Collision Warning (FCW) • Intelligent Traffic Signal System (ISIG)
2	Wrong-way entry prevention	At the exit of the REL onto East Twiggs Street, there is a relatively easy opportunity for a driver to become confused and attempt to enter the REL going the wrong way. There are no gates or barriers at the westbound downtown terminus of the REL to prevent drivers from entering the REL going the wrong way. Drivers who are traveling on East Twiggs Street approaching the intersection where the REL ends, and Meridian Street begins can mistakenly (or knowingly) enter the REL going the wrong way. Drivers approaching this intersection coming from downtown can inadvertently (or knowingly) make a left turn onto the REL exit. Conversely, drivers on East Twiggs Street approaching this intersection going toward downtown can inadvertently make a right turn onto the REL exit. Finally, drivers approaching the intersection on Meridian Avenue can potentially veer slightly to the left onto the REL exit. Each of these possibilities is a safety concern.	• Wrong-Way Entry (WWE) • ISIG
3	Pedestrian conflicts	At the George E. Edgecombe Hillsborough County Courthouse, there is one primary crosswalk for pedestrian access to the main parking garage. The crosswalk is marked and has a yellow flashing beacon to warn drivers that they are approaching a crosswalk. This crosswalk is the primary route for jurors, lawyers, and other people to get to and from the courthouse. During morning rush hour, there is significant pedestrian traffic as potential jurors unfamiliar with the area attempt to arrive on time. This significant pedestrian traffic is compounded on Mondays and Tuesdays when new juror pools of up to 400 persons are required to report during rush hour. Lack of attention by drivers causes a safety concern for pedestrians trying to reach the courthouse.	• Pedestrian Collision Warning (PCW)

Use Case	Condition	Description of Issues to Be Addressed	Applications
4	Transit signal priority	Two express bus routes (24LX and 25LX) use the Selmon Expressway to connect the east and west sides of the metropolitan area and exit the expressway to serve a stop in downtown. There are large residential communities in the areas of Brandon, Riverview, and Fish Hawk to the east of downtown. Aside from the employment center associated with the CBD, MacDill Air Force Base (MAFB) is situated close to the western or southern terminus of the Selmon Expressway. CV technologies were deployed to attempt to create a virtual transit connection between the two portions of the expressway by providing more reliable transit mobility using transit signal priority as the express buses negotiate the surface streets of downtown in the morning and evening peak hours.	• Transit Signal Priority (TSP)
5	Streetcar conflicts	The Tampa Electric Company (TECO) Streetcar runs along Channelside Drive from the Amalie Arena area up Channelside Drive, north, and past the Selmon Expressway. The streetcar is a steel-wheel-on-steel-rail fixed-guideway system in a dedicated right-of-way. An overhead catenary powers it, and the streetcar crosses intersections at grade. As a result, at various stops along the streetcar route, vehicles may have to turn right in front of a stopped or moving streetcar. As pedestrians disembark the streetcar and the streetcar prepares to depart, a vehicle may turn right in front of the streetcar. This situation occurs at signalized and non-signalized intersections, none of which have a right-turn protected movement. CV technology was used to provide information to streetcar operators and drivers to improve safety around these locations.	• Vehicle Turning Right in Front of a Transit Vehicle VTRFTV)
6	Traffic progression	Meridian Avenue has significant congestion and delay during morning peak-hour periods. This congestion is due to many MAFB commuters exiting the Selmon Expressway downtown and traveling through downtown arterial routes to reach the base's entrance. As some of these commuters use surface roads through downtown, they interact with other traffic and pedestrians, increasing the likelihood of conflicts. In addition to Meridian Avenue, Florida Avenue (sections within the study area) experiences similar issues for downtown commuters.	• EEBL • FCW • Intersection Movement Assist (IMA) • ISIG

Source: Texas A&M Transportation Institute based on information contained in reference 1 and 2, 2022

Table 2. Summary of devices for deployment.

Device Category	Tampa (THEA) Devices	Planned Number to Be Deployed	Actual Number Deployed
Infrastructure	RSUs at intersections	40	49
Infrastructure	Light detection and ranging (LiDAR)–equipped pedestrian detection systems	2	2*
Vehicle	Light vehicles equipped with OBUs	1,600	1,020
Vehicle	HART transit buses equipped with OBUs	10	0**
Vehicle	Tampa historic streetcars equipped with OBUs	10	7
Vehicle to everything	Pedestrians equipped with the app on personal information devices (PIDs)	500+	0***

*THEA determined that the operational reliability of the LiDAR sensors was not adequate to support the Pedestrian in Crosswalk application and replaced them with video and thermal imaging sensors.
** Only deployed on a limited number of vehicles as a test.
***During the deployment, Pedestrian Crossing (PED-X) portion of the applications was implemented due to issues associated with the GPS accuracies in the PIDs.

Source: Texas A&M Transportation Institute based on information contained in references 2 and 3, 2022

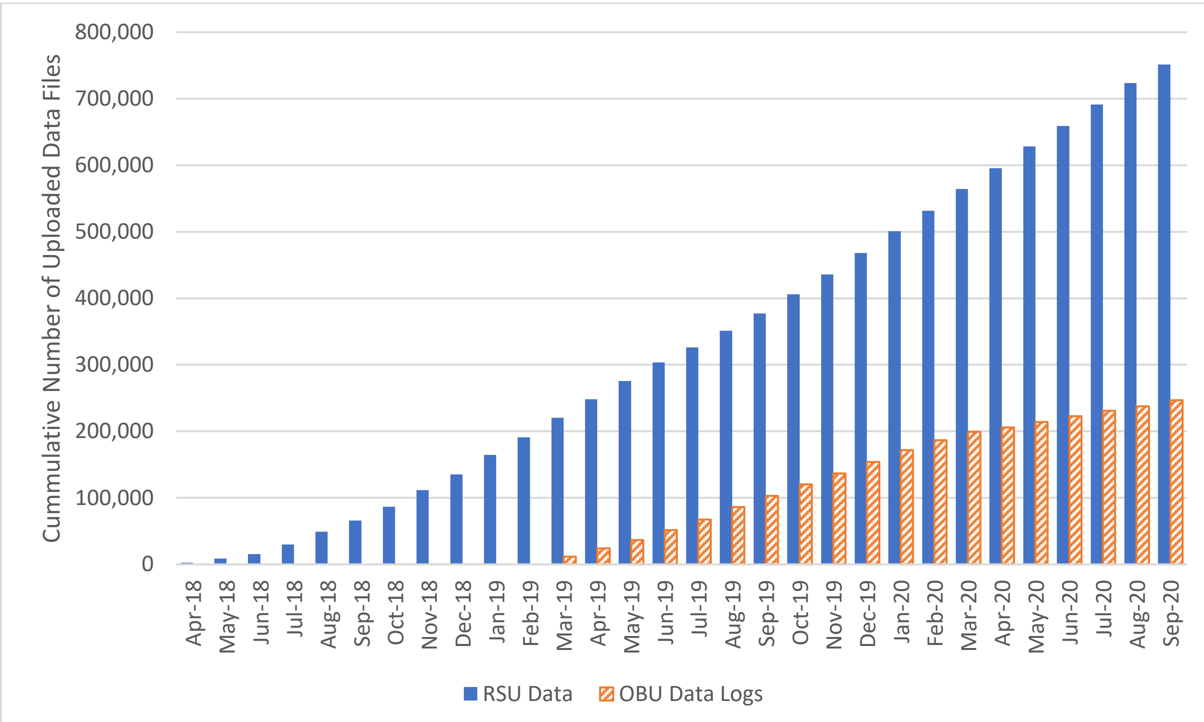
THEA installed 49 RSUs in the deployment area. (2) Each RSU transmitted and collected the following data: (2)

- Basic Safety Messages (BSMs) from the participant and public transit vehicles (up to 10 Hz), also called "sniffed" BSMs or BSMs collected by a vehicle operating in range of an RSU.
- Signal Phase and Timing Message (SPaT) from RSUs (10 Hz).
- Map Data Message (MAP) from RSUs (1 Hz).
- Traveler Information Message (TIM) from RSUs at 1 Hz.
- Signal Request Message (SRM) transmitted by OBUs within range of the dedicated short-range communication (DSRC) radio of an RSU.[1]
- Signal Status Message (SSM) broadcast by RSUs for conveying back to OBUs the status of its SRM.
- Multimodal Intelligent Traffic Signal System (MMITSS) Java Script Object Notation (JSON)–formatted Siemens-MMITSS calculated metrics.
- PED-X JSON–formatted structure with the element "psm" containing the Pedestrian Safety Message (PSM) that triggered the collision alert as J2735 Message Frame.

The circles shown in figure 2 identify the locations where the THEA CVPD team installed RSUs.

[1] While the RSUs are capable of logging SRMs, SSMs, MMITSS, and PSMs, the applications that generate these data sources were <u>not</u> active during the phase 3 evaluation.

Over the course of the deployment, the THEA CVPD team uploaded over 750,000 highly compressed RSU and over 246,000 OBU data logs to the Secure Data Commons (SDC). [3] Figure 3 shows the volume of data files transferred to the SDC during the deployment. The OBU files began logging beginning in March 2019 (at the beginning of the pre-deployment period), whereas the RSU data were available at the beginning of Phase 2 (the design, build, and test phase). The THEA CVPD uploaded all the raw data into USDOT's SDC. [4]



Source: Center for Urban Transportation Research, 2021

Figure 3. Bar chart. Volume of RSU and OBU data files generated by the THEA CVPD. [3]

Applications

The THEA CVPD team originally intended to deploy 13 different CV applications in the deployment;[2] however, due to installation delays and equipment issues, the THEA CVPD team was unable to deploy all the planned applications during Phase 3. [3] Table 3 shows the list of final applications deployed by the THEA CVPD team in each Use Case.[3] Appendix A provides a summary description of the applications. As part of Phase 4 activities, the THEA CVPD team is currently working on deploying several of its planned applications (specifically, the I-SIG and TSP applications) that were not fully operational during the Phase 3 operational evaluation period.

Table 3. Applications deployed in each use case in the THEA CVPD. [3]

Application	Use Case 1 Morning Backups	Use Case 2 Wrong-Way Entries	Use Case 3 Pedestrian Conflicts	Use Case 4 Transit Signal Priority	Use Case 5 Streetcar Conflicts	Use Case 6 Traffic Progression
EEBL	Deployed	NA	NA	NA	NA	Deployed
ERDW	Deployed	NA	NA	NA	NA	NA
FCW	Deployed	NA	NA	NA	NA	Deployed
IMA	NA	NA	NA	NA	NA	Deployed
PCW	NA	NA	Deployed	NA	NA	NA
VTRFTV	NA	NA	NA	NA	Deployed	NA
WWE	NA	Deployed	NA	NA	NA	NA
TSP	NA	NA	NA	Planned but not deployed	NA	NA
I-SIG	Planned but not deployed	NA	NA	NA	NA	Planned but not deployed

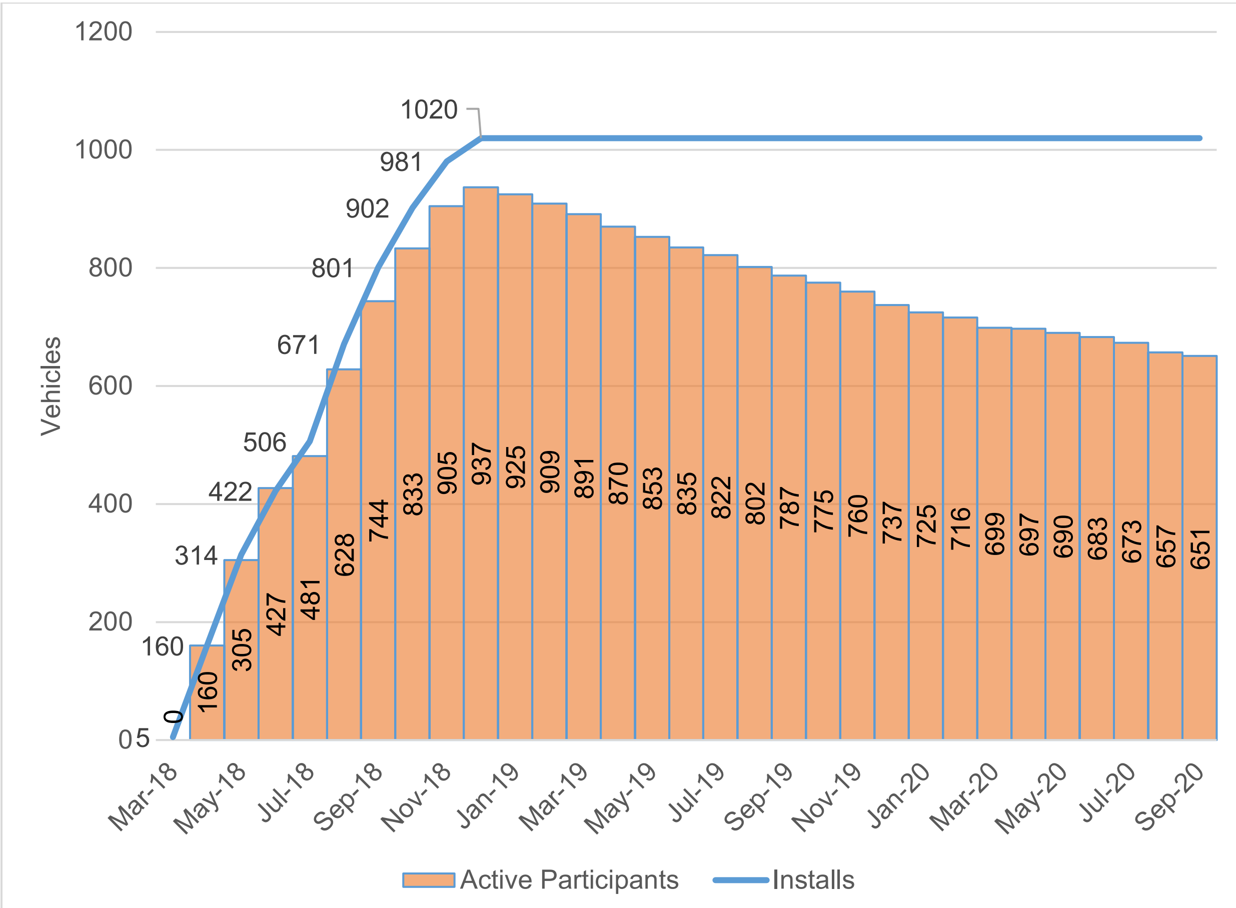
NA = not applicable to use case.
Source: Texas A&M Transportation Institute based on information contained in reference 2, 2022

The applications were developed and deployed by aftermarket vendors using Society of Automotive Engineers (SAE) International standards and application specifications. [5] Driver warning event records are created whenever one of the applications triggers a warning. The OBU creates a unique warning ID used to identify multiple records belonging to the same warning event. [3] The OBU creates a set of records per warning. Each record of the set represents a point in time before, during, and after the warning triggered. A record always contains the host vehicle's (hv) BSM at a given point in time within "hvBSM." Warnings that result from receiving a remote vehicle's (rv) BSM populate the "rvBSM" field with the BSM of that vehicle. Before and after data records for the warning populate the "rvBSM" field with BSMs received from the same vehicle. The remote vehicle is identified by its temporary ID contained within the BSM. Likewise, warnings triggering the pedestrian collision warning that result from receiving a vulnerable road user personal safety message (vruPSM) populate the "vruPSM" field. Due to their size and complexity (i.e., embedding several payloads), OBU data logs are Extensible Markup Language (XML) encoded and compressed as flat files for upload by the University Center for Urban Transportation Research (CUTR) server to the SDC, along with a separate data dictionary.

Participants

Participants in the CV pilot study included drivers, pedestrians, and bus/streetcar drivers. The THEA CVPD team began recruiting and training participants from the pool of existing THEA customers beginning in 2018. As an incentive for participating in the project, THEA provided a discount on tolls. [2,3]

Figure 4 shows the number of total installations and the number of active participants per month through the duration of the phase 3 deployment. A total of 1,020 private vehicles were equipped with aftermarket OBUs beginning in March 2018 through December 2018. The maximum number of participants was 937, occurring in December 2018. THEA defined an active participant if the OBU generated at least one BSM during a month.



Source: Center for Urban Transportation Research, 2021

Figure 4. Bar chart. Number of OBU installations and monthly active participants. [3]

For evaluation purposes, the THEA CVPD team assigned each participant to either a treatment group or control group using a randomized two-to-one matching (two treatments to one control) stratified by gender, age, income, and education. [3] In the end, THEA assigned 621 participants to the treatment group, while 391 participants were assigned to the control group. Only those participants in the treatment group actively received warnings and alerts through the devices. For the control group participants, the applications generated the appropriate alert based on the condition, but the alert would not be displayed to drivers. The intent behind this was to allow a comparison of driver responses to the alert messages generate by the applications.

Other demographic information about the THEA CVPD participants includes the following:(3)

- 43.5 percent of the participants self-identified themselves as female, while 54.3 percent self-identified themselves as male.
- Over half of the participants were between the ages of 36 and 55. Approximately 25 percent of the participants were under the age of 35, while 18.1 percent were 56 years of age or older.
- Over 60 percent of the participants reported having an education level of a bachelor's degree or higher.
- The median income group of all participants was $75,000 to $99,999.

The *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation—Tampa (THEA) CV Pilot Phase 3 Evaluation Report* provides more information on the demographics of the participants. (3)

Chapter 3. Public Agency Efficiency Impact Assessment

This chapter provides a qualitative analysis of the public agency efficiencies impact analysis. TTI defines public agency efficiency as any action or the use of data that allows the public agency to better operate its facilities and to improve its situational awareness of the performance of its systems.

Improved Operating Efficiencies

Improved operating efficiency is a direct measure of public agency efficiency. Examples of metrics that might indicate improved operating efficiencies include reductions in incident response and clearance times, improved on-time performance/schedule adherence by transit vehicles, improved compliance with speed limits, etc. For the Tampa deployment, the TTI evaluation team considered the following to be direct measures of improved operating efficiency:

- Percent arrival on green.
- Bus route travel time reliability.
- Percent arrival on schedule.

THEA was unable to deploy several of the applications (e.g., the TSP and I-SIG applications) that might have led to a direct operational efficiency benefit. Because the applications were not active during the independent evaluation period, TTI was unable to determine the extent to which operating agencies were able to improve their efficiencies as a direct result of the deployment.

One concrete example of how the deployment led to better operating efficiency is delivering updates to the OBUs remotely. The OBU vendors created a method for updating the firmware and configuration parameters over the air without having to bring participants to the study installation facility multiple times. The method allowed the THEA CVPD team to push updates to the OBU firmware and configuration parameters via the RSUs while vehicles were traveling inside the study area. The THEA CVPD team used this method successfully several times to update firmware and issue configuration changes. In some instances, however, the updates did not reach all participants. This created a challenge in the collection and over-the-air transmission of the OBU data logs. This also affected successfully updating the latest application configuration and operational parameters.

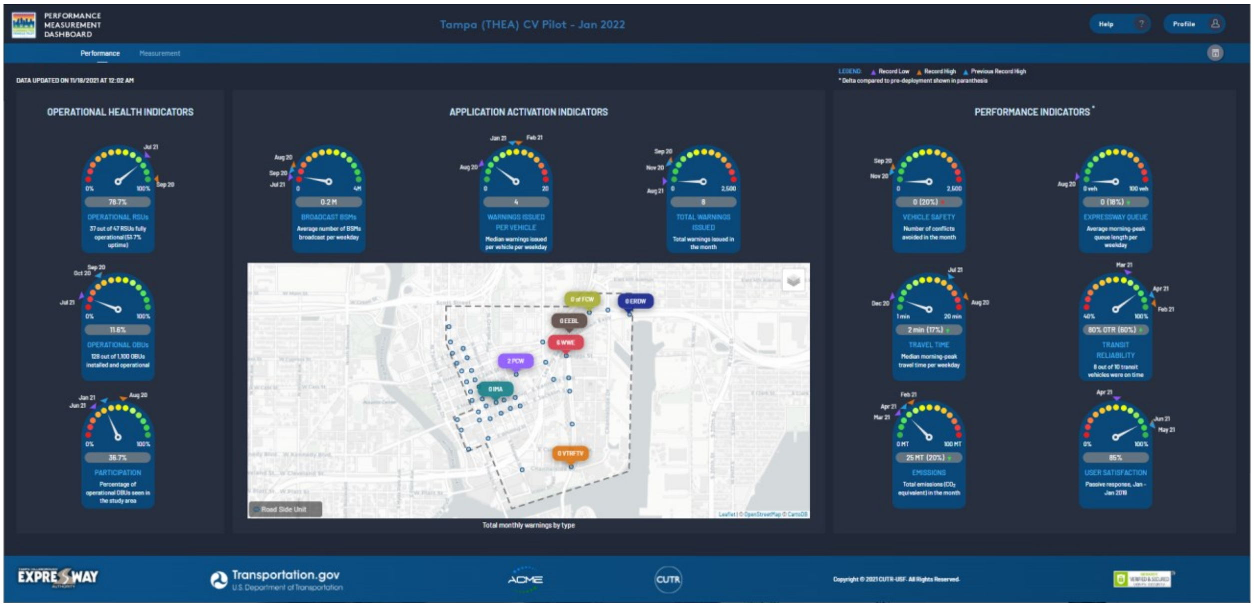
Improved Situational Awareness

Public agencies can improve their efficiencies by improving their awareness of potential situations, weather, operating conditions, and events that might degrade travel performance in the transportation network. Examples of the types of events where CVPD might improve include the following:

- Unexpected queues and queue lengths.
- Weather events.
- Incidents and collisions.
- Outages and issues associated with traffic control devices.

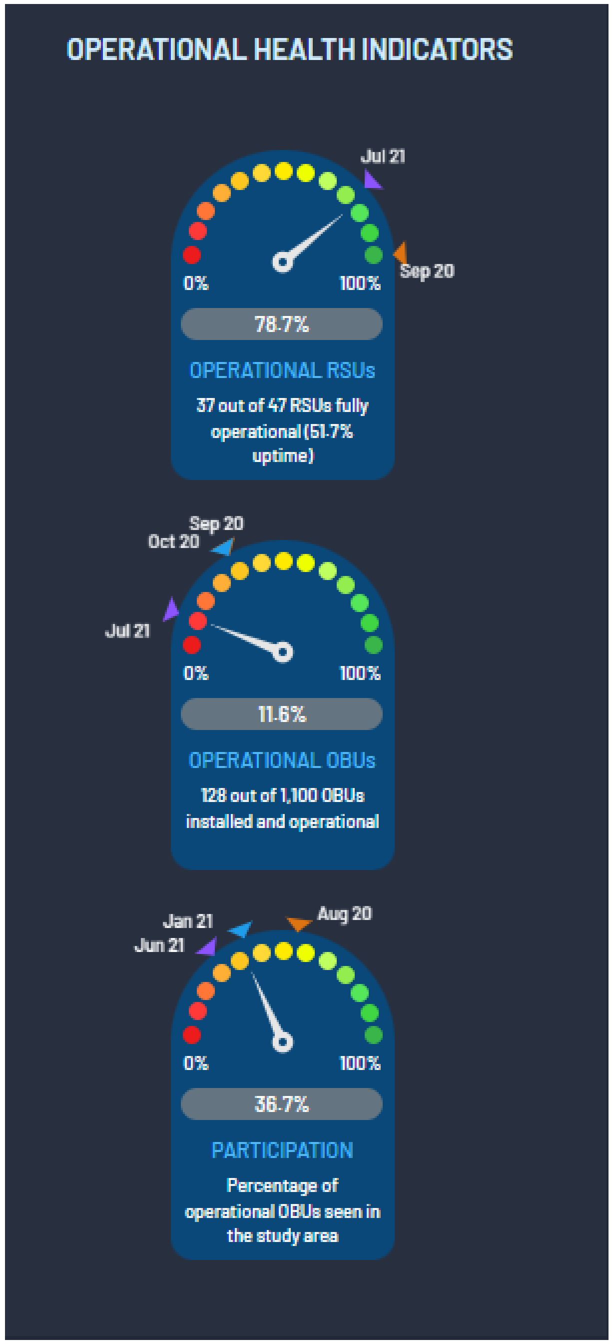
While the Tampa CVPD team did not collect performance measures on improved situational awareness explicitly, CUTR developed a series of dashboards that the THEA team used to monitor the status of the devices and the alerts produced by the applications. CUTR developed the dashboards to monitor CV devices and alerts, and to help with their performance measurement. This tool is specifically for the CVPD and was not really used by any of the key stakeholders (i.e., THEA, HART, etc.) in the dispensation of their core duties. While the tool cannot be considered as having impacts on how the stakeholders (i.e., public agencies) performed their daily duties, it was instrumental to CUTR in performing their performance measurement role. Agencies could develop similar tools for the various stakeholders to improve their situational awareness.

The design of the THEA CVPD did not specifically provide for the real-time monitoring of vehicle alerts; however, CUTR at the University of South Florida developed a performance measurement dashboard that THEA and other stakeholders could use to monitor the performance of the THEA CVPD. Figure 5 shows an example of this dashboard. The opening dashboard page allows THEA and other stakeholders to immediately assess the operational readiness of the deployment. From this dashboard, THEA CVPD stakeholders could obtain information about the operational health of the system, the frequency and types of alerts and warnings produced by various applications, and the safety and mobility, environmental, and public agency efficiency performance measures associated with the deployment. Figure 6 through figure 8 provide closer views of the operational health, application activation, and performance indicators portions, respectively, of the dashboard.



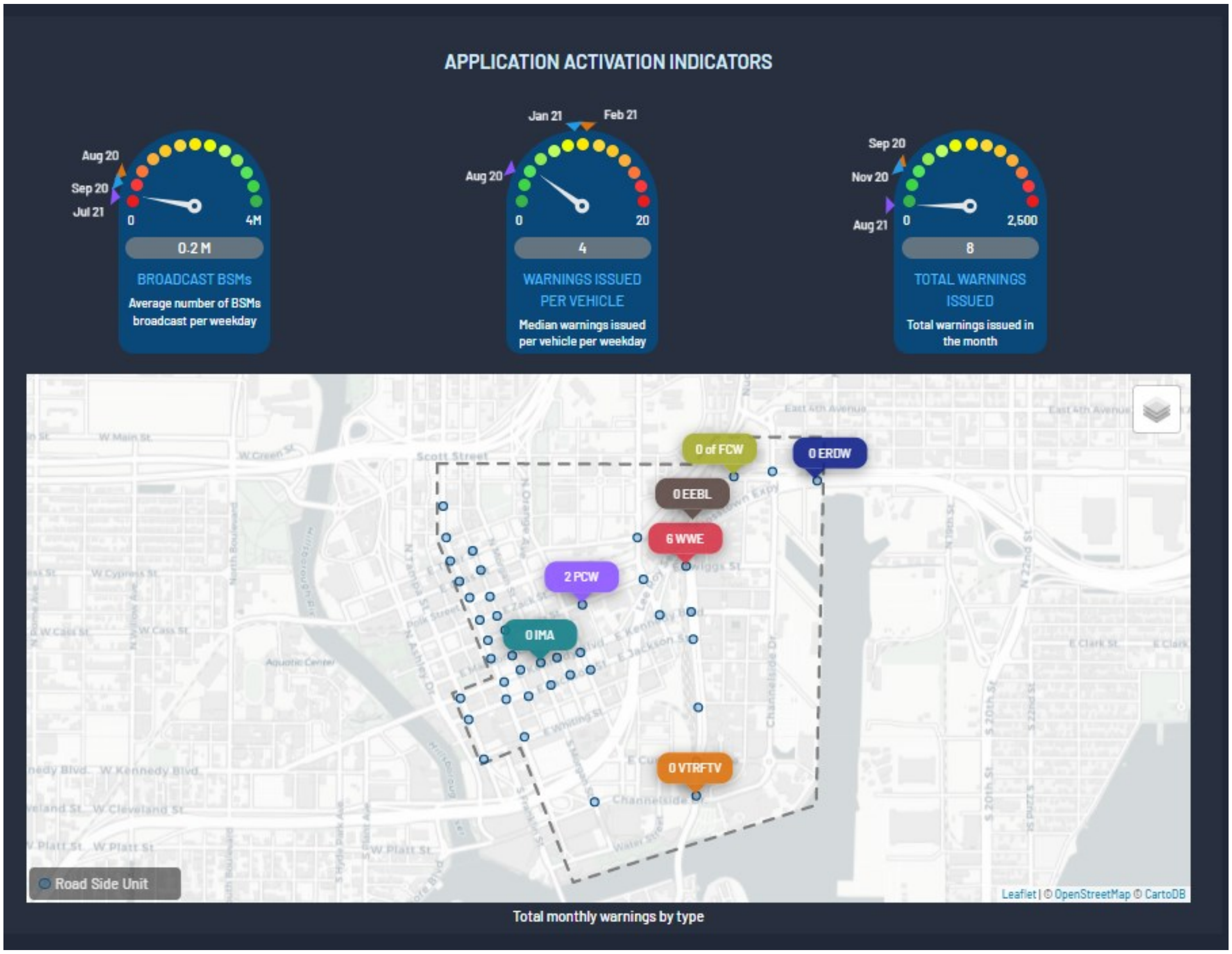
Source: Center for Urban Transportation Research, 2020 (5)

Figure 5. Screenshot. Example of the THEA CVPD Performance Measurement Dashboard.



Source: Center for Urban Transportation Research, 2020 [5]

Figure 6. Screenshot. Close-up example of the operational health performance indicators available through the THEA CVPD Performance Measurement Dashboard.



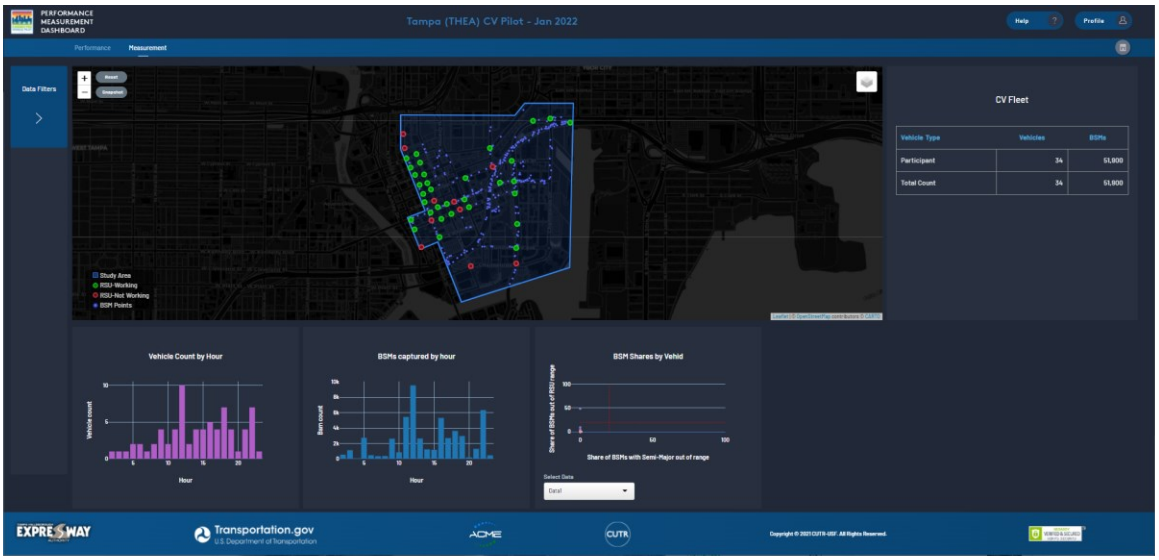
Source: Center for Urban Transportation Research, 2020 (5)

Figure 7. Screenshot. Close-up example of the applications activation performance indicators available through the THEA CVPD Performance Measurement Dashboard.

Source: Center for Urban Transportation Research, 2020 (5)

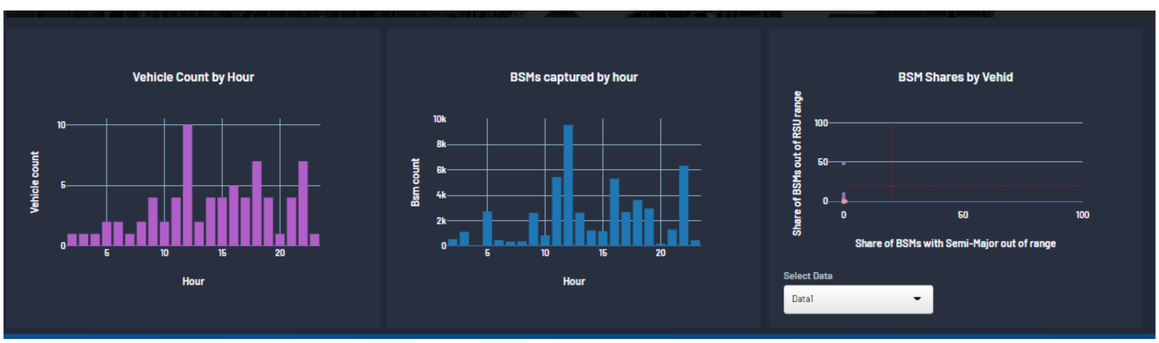
Figure 8. Screenshot. Close-up example of the system benefits performance indicators available through the THEA CVPD Performance Measurement Dashboard.

Through the performance measurement dashboard, stakeholders could examine the operational status of each RSU (see figure 9). Green circles indicate the RSUs that are operational, while red circles indicate RSUs that are not operational. The tool also displays all the BSMs (blue dots) observed during a user-selected evaluation window. Using the tool, stakeholders could obtain information about the different vehicle types, vehicle counts, and counts of observed BSMs for selected evaluation periods. Figure 10 shows an example of the details available through the dashboard.



Source: Center for Urban Transportation Research, 2020 (5)

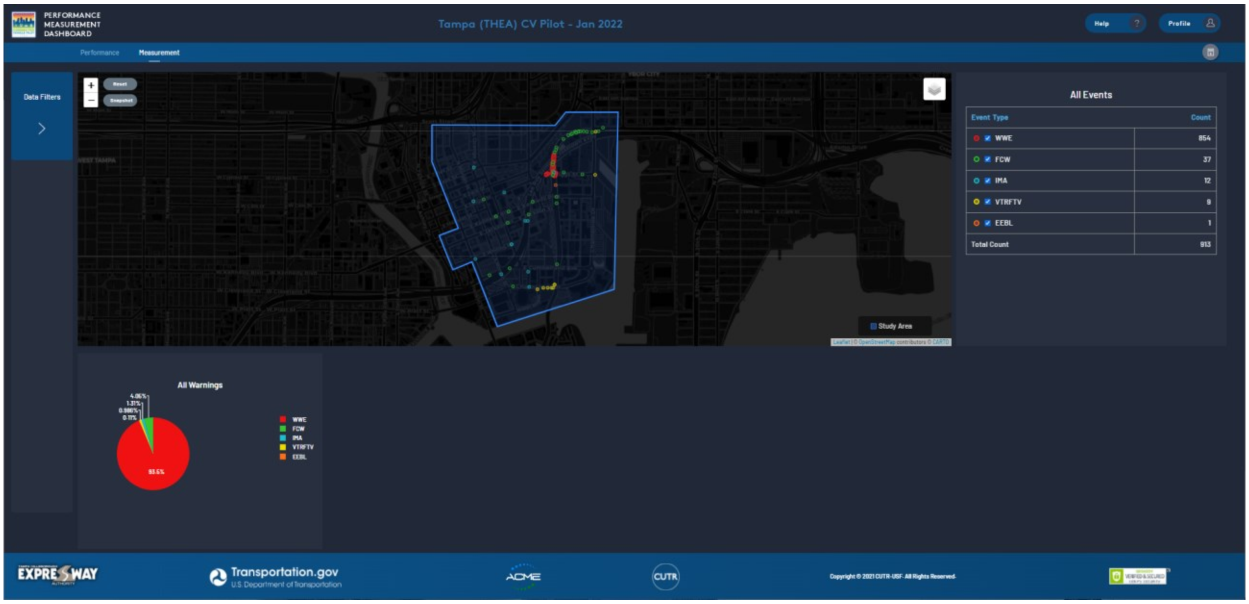
Figure 9. Screenshot. Dashboard developed by CUTR to assess device operational status in the THEA CVPD.



Source: Center for Urban Transportation Research, 2020 (5)

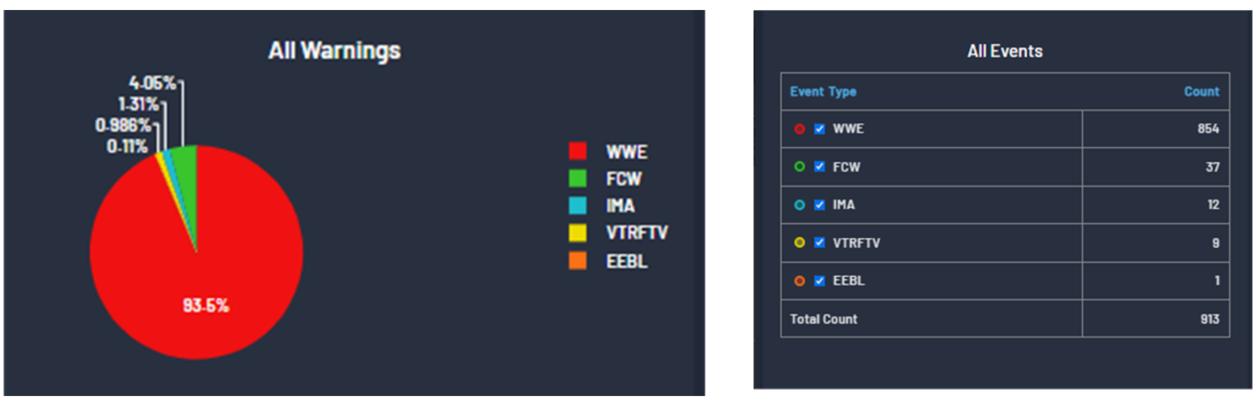
Figure 10. Screenshot. Example of details dashboard features for monitoring RSU operational status in the THEA CVPD.

CUTR also developed a dashboard that allowed selected stakeholders, such as THEA administrators, the THEA CVPD team, and USDOT analysts, to assess the types of messages and alerts generated by the different applications (see figure 11). Using various data filters, stakeholders could query the performance monitoring data to obtain the locations where different types of alert messages were generated during selected evaluation windows. The dashboard also provided frequency counts and relative percentages of different types of warning messages observed in vehicles. Figure 12 provides close-ups of the type of detailed information available through the dashboard.



Source: Center for Urban Transportation Research, 2020 [(5)]

Figure 11. Screenshot. Dashboard developed by CUTR to analyze warning messages generated by various applications deployed in the THEA CVPD.



Source: Center for Urban Transportation Research, 2020 [(5)]

Figure 12. Screenshot. Example of warning message details through the THEA CVPD Performance Measurement Dashboard.

Through this dashboard, CUTR also developed a tool that the THEA CVPD stakeholders could use to analyze events and warnings generated by vehicles. Through this tool, the stakeholder could generate a visual animation of every single event that generated a warning in the study area. Once activated, the dashboard used the BSMs to show the vehicle trajectories of the vehicles leading up to the warning event. The tool then displayed traces of the speed, longitudinal acceleration, and yaw rate of the vehicles involved in the event. The THEA CVPD team used this tool to gain a better understanding of the conditions under which a warning was triggered for calibration and verification purposes. CUTR also used this tool to analyze whether a warning was generated by a true event or was a false alarm. Figure 13 shows an example of the output of this assessment tool.

Source: Center for Urban Transportation Research, 2020 (5)

Figure 13. Screenshot. Example of a visual animation of a warning event through the THEA CVPD Performance Measurement Dashboard.

Chapter 4. Stakeholder Feedback

TTI invited four stakeholders to participate in a brief interview focusing on a series of supplemental questions regarding how the deployment impacted their ability to better operate and management operations in the deployment area. Three of the four individuals agreed to participate, and individual interviews were conducted mid-March 2022. The supplemental questions were sent to the stakeholders prior to the interview. The interview lasted approximately 45 minutes, and this chapter summarizes the responses to each question.

Responses to Interview Questions

The following provides a summary of the responses to the interview questions.

Question 1: Given your experience during the connected vehicle pilot deployment, how did the deployment improve the operating efficiency of your agency?

Two participants commented that the CVPD did not, in itself, improve agency operating efficiency. The primary reason for this was due to the fact that the goals of the CVPD were different than their agency operating goals and/or needs. One of these individuals commented that their agency did reap some benefit from the RSUs providing a cellular connection. This connection facilitated an update to the signal timing system. This was a positive ancillary benefit. Another of these individuals stated that their transit vehicles are on a fixed guideway, which largely prevents them from getting out of the way of connected passenger vehicles. The warnings that were received by transit vehicles did not come quickly enough to allow the transit vehicle to react in a timely manner.

One participant commented that the CVPD did improve operating efficiency, particularly during the peak, when 10 percent penetration rates were achieved. The CVPD helped move traffic through the system. Additionally, the ERDW anecdotally reduced collisions.

Question 2: What did the deployment allow your agency to do better from an operational perspective?

Two participants commented that the CVPD did not facilitate operational improvements in their agencies, while one participant stated that it facilitated better signal system communication.

Question 3: How might you use the results of the deployment to better operate and manage traffic conditions/situations?

One participant noted that the lessons learned regarding how to maintain the RSUs will benefit their agency as their number of RSUs increases. They also stated that the lessons learned regarding what issues arose with the various CVPD apps are of interest to their agency. How can these apps be integrated into the RSU network? How can these apps be refined for future deployments?

One participant speculated that the results could improve the movement of more traffic through the system, reduce crashes, and enhance turning movements. This participant specifically mentioned that the pedestrian warning would allow for a safer environment around the courthouse.

Lastly, one participant stated that their agency already tracks vehicle close calls and has video on the agency transit vehicles. This individual speculated that the results could perhaps be used to validate information already being collected.

Question 4: Did the deployment change how you manage system operations? If so, how?

All three participants stated that the CVPD did not change how their agencies managed systems operations. One participant stated that it did accelerate some already scheduled system infrastructure upgrades.

Question 5: Did the deployment allow you to improve your situational awareness of the performance of your system? If so, how? Did you learn about things you did not know about?

Two participants stated that the CVPD did not improve their agency's situational awareness of the performance of their system. One of these two participants stated that during the pilot there was a need to constantly remind transit vehicle operators to turn the system on. The system "beeps and chirps" were distracting to drivers.

One participant felt that their agency was able to get a better handle on vehicle throughput due to the CVPD.

Question 6: Can you provide specific examples or case studies of how the deployment (or having access to the data available from the deployment) improved your situational awareness?

Only one participant was able to provide an example. In this case, the participant lauded the utility of the dashboard in keeping tabs on the system.

Question 7: Given what you know now about the type of information and the capabilities of the technologies, how might the data/information available to you from the technology support your overall operational goals and objectives?

One participant suggested that the expansion of their RSU network and the knowledge gained by working more closely with the RSUs could be applied downstream as the size of their RSU network increased. Additionally, the CVPD helped develop/strengthen relationships with other agencies.

One participant theorized that data being collected could be used in validating data being collected by the agency's transit vehicles.

Another participant speculated that as CV market penetration increases, so will the utility of the data being harvested from them for assessing congestion and managing traffic flow.

Question 8: How did participating in the deployment better prepare your agency for future connected and automated vehicle projects?

One participant stated that, in addition to increasing the overall level of familiarity with RSUs, there was an increased level of knowledge at all staff levels about hardware issues and maintenance. Agency staff learned a good deal about various hardware functional challenges. Furthermore, the agency has been educated about the quality and quantity of human resources needed when the agency upgrades its RSUs in the future. The agency was also able to gain a deeper understanding of technical training needs.

Similarly, another participant said the CVPD helped facilitate a better understanding of future hardware needs, where it needs to be deployed, and how to deploy it. They are also now more familiar with the necessary apps.

Another participant stated that the rail side of the agency knew nothing of how CV technology worked prior to the CVPD. Now, the agency knows what to expect from future deployments. The agency also gained knowledge about hardware installation.

Question 9: From a public agency efficiency perspective, what do you know now that you wished you had known going into the deployment?

Participant responses include a wide array of responses regarding what they wish they had a better understanding of prior to the deployment:

- Better understanding of the current CV market penetration and adoption rates.
- Better understanding of the hardware maintenance challenges. These include issues with OBUs. The Institutional Review Board (IRB) required that OBUs be removable. This made installation difficult. Some of the installations included a considerable number of wires taped down.
- Better understanding of what causes communication issues with the system. On the RSU side, there were grounding issues, and the loss of communication was widespread and made things challenging. Things are made more difficult when the agency does not maintain the RSUs.

- Better understanding of the installation process. More testing prior to the installation would have been better.
- Better understanding of how immature the technology and apps were. The V2V apps were not fully vetted. The V2I apps were not even developed yet.

Question 10: What did you modify about your deployment and why?

One participant commented that some of the apps were more challenging than others. The MMITSS app is one such app. One of the initial challenges was a lack of coordination between the signals. Coordination up and down a corridor is critical. This app needs to be vetted more thoroughly. The pedestrian safety app was also problematic. There was a maintenance issue with LiDAR, which was replaced with camera technology. If participant were to deploy again, they would select different hardware.

This same participant also commented that, at the onset of the project, a pedestrian safety app that notified pedestrians via their phone was to be deployed. This was dropped, perhaps for IRB-related reasons. The participant was unsure about how much time and money were spent on this, prior to making the decision to drop the application and move on. It would have been beneficial to be able to quickly repurpose these resources after the application was tabled. At a minimum, it would have been good to have better communication about how much time/effort was spent on this before the decision was made to table it.

One participant confirmed that their deployment was modified. This modification resulted in Phase 4, which included vehicle manufacturers. This Phase 4 team developed a pre-production OBU that will be installed in select vehicles participating in Phase 4. The team is working on a red-light violation warning application.

Finally, one participant suggested it would be better to send messages from a transit vehicle to a connected passenger vehicle, as opposed to vice versa, because fixed-guideway transit vehicles cannot turn easily, and their stop times are quite long.

Key Takeaways

The following is a summary of the key takeaways from these interviews:

- Two of the three participants felt that the CVPD did not improve the operating efficiency of their agency. Improvement mentioned by a single participant included reduced collisions and increased throughput (although this improvement was not supported or confirmed by the evaluation data).
- One of the biggest benefits of the CVPD was an increased knowledge of RSU installation, maintenance, and operation. Another benefit was an increased familiarity with the CV applications. This knowledge base could be applied in the future and was deemed extremely useful.
- All three participants stated that the CVPD did not change how their agencies managed systems operations.
- Two participants stated that the CVPD did not improve their agencies' situational awareness of the performance of their system.

- In retrospect, participants would have liked a better understanding of the following prior to starting the CVPD:
    - Current CV market penetration and adoption rates.
    - Hardware maintenance challenges.
    - The root causes of signal systems communication issues.
    - The installation processes.
    - Technology and application maturity.

Chapter 5. Conclusions and Lessons Learned

This chapter provides a summary of the findings and the lessons learned associated with deployment.

Summary of Findings

One potential benefit of CV technologies is that they can provide data and information that agencies can use to improve their efficiencies. For this evaluation, public agency efficiency also refers to the agency's ability to respond to changing conditions or unexpected events occurring in the deployment area. Public agency efficiency can also refer to data and information that agencies can use to better understand the performance of their system. TTI assessed public agency efficiency impacts from two perspectives:

- Improved operating efficiencies.
- Improved situational awareness.

Performance measures that agencies typically use to quantify improved operating efficiencies include improved percent arrival on green, improved travel time reliability, and improved percent on-time performance. Examples of improved situational awareness might include detections of unexpected congestion due to weather events and incidents, unexpected speed reductions, excessive lanes changes, or unexpected changes in lane utilization, improved detection of equipment or device outages, and better understanding of system bottlenecks or independencies.

Originally, the THEA team had planned to demonstrate public agency efficiencies through their mobility, safety, and customer satisfaction analyses. However, because of unexpected delays in the deployment and because of unforeseen external factors (e.g., the COVID-19 pandemic), the THEA CVPD team was unable to deploy several of the planned mobility applications that would have allowed the team to quantify public agency efficiencies. Market penetration issues and reduced evaluation periods also impacted the team's ability to quantify public agency benefits resulting from the safety applications (e.g., reduction vehicle collisions and crash potentials).

One positive outcome of the deployment that proved to be valuable from a public agency efficiency standpoint was the performance monitoring tool developed to track the deployment. The tool uses data collected from OBUs and RSUs to monitor the status of the deployment and provide insight into the locations and time frames where warning alerts and messages were provided to equipped vehicles. The tool, developed by CUTR, allows stakeholders to monitor the operational heath of the system by displaying the number of fully operational RSUs and OBUs. The tool also provides stakeholders with performance indicators that provide information on the effectiveness of the applications. The tool allows stakeholders the ability to monitor system performance at an individual intersection or on a system-wide basis. Stakeholders can aggregate performance statistics over time and by individual sites. This tool provided a solid foundation for the agencies to build upon as they enter future deployment phases.

Lessons Learned

In addition to the interviews conducted in this work effort, the TTI CVPD evaluation team also conducted a virtual post-deployment workshop with Tampa deployment team stakeholders. The purpose of the workshop was to foster additional dialog among the deployment managers, deployment teams, and operating agencies concerning the lessons learned and major takeaways from planning and implementing the deployments. The common themes identified in the post-deployment interviews were used to frame the group discussion, which explored these and other topics in more detail. The workshop was originally planned as an in-person event but was shifted to a virtual platform because of the pandemic. The following provides a summary of the key findings and lessons learned from the workshop interviews:

- One of the primary motivating factors for public agencies to participate in projects like the CVPD is the opportunity to work with and potentially shape emerging technologies. The experiences gained by implementing in “shelf-ready” technology, getting it operational, and generating results is invaluable when it comes to planning, designing, deploying, and managing advance technology projects.
- Participants acknowledged that the experimental design at the beginning of the project assumed that the technology would be fully ready, out on the road, and operational. It turned out that the technology was not fully ready as originally assumed. The deployment team had to make changes to those assumptions.
- With respect to the technology, the market in which the technology development was taking place was small-sized research and development businesses, some of which almost disappeared from the market. Regarding the deployment, the market around the technology was in rapid development, and there were significant growing pains associated with the technology.
- One significant unmet expectation was the fact that the National Highway Traffic Safety Administration ruling was imminent when the project started. The reality that the ruling did not materialize dramatically changed the dynamics of the project, including the overall direction of the project.
- The THEA CVPD provided the local stakeholders with valuable knowledge and experience in deploying and testing CV applications in the corridor and measuring their benefits.

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Appendix A. Description of Applications Deployed in THEA CVPD

This appendix provides a brief description of the applications deployed as part of the THEA CVPD. [3]

Vehicle-to-Vehicle Safety Applications

Vehicle-to-vehicle (V2V) safety applications use the wireless exchange of data among vehicles traveling in the same vicinity to offer significant safety improvements. Each equipped vehicle on the roadway—including automobiles and transit vehicles—will be able to communicate with other vehicles. This rich set of data and communications supports a suite of active safety applications and systems. Vehicles communicate with one another and broadcast BSMs. The BSM provides basic information about a vehicle's speed, heading, and location, and is updated every 1/10th of a second. These applications will only function when the involved vehicles are both equipped with V2V devices. The THEA CVPD team deployed four V2V safety applications. These applications are described briefly as follows.

Emergency Electronic Brake Light

The EEBL application alerts drivers to hard braking in the traffic stream ahead. The warning is intended to provide the driver with additional time to look for and assess situations developing ahead. Vehicles will broadcast a self-generated emergency brake event within a BSM to surrounding vehicles. Upon receiving the event information, the receiving vehicle determines the relevance of the event and, if appropriate, provides a warning to the driver to avoid a crash. This application is particularly useful when the driver's line of sight is obstructed by other vehicles or bad weather conditions (e.g., fog or heavy rain). This application will be used to increase safety during peak traffic hours on the REL. Backup on the REL causes exiting vehicles wanting to turn right to use the shoulder as part of the right-turn lane. If a vehicle is broken down on the shoulder of the road, the EEBL application will notify vehicles that may hit the stopped vehicle.

Forward Collision Warning

The FCW application warns vehicle drivers of an impending rear-end collision with another vehicle that is ahead of them in the same lane and direction in traffic. The application uses data received from other vehicles to determine if a forward collision is imminent. The FCW application is intended to advise drivers to take specific actions to avoid or mitigate rear-end vehicle collisions in the forward path of travel. THEA expected the FCW, like the EEBL application, to increase safety by reducing accidents during peak traffic hours on the REL.

Intersection Movement Assist

The IMA application produces a warning when two or more vehicles are approaching one another by using the relative position, speed, and heading of those vehicles. The IMA application receives BSMs from approaching vehicles adjacent to the vehicle equipped with IMA. If IMA determines there is a high probability of a collision, the application warns the driver. THEA expected the application to improve safety at intersections where there might be potential conflicts between equipped vehicles.

Vehicle Turning Right in Front of a Transit Vehicle

The VTRFTV application determines the movement of vehicles near a stopped transit vehicle and provides an indication to the transit vehicle operator that a nearby vehicle is pulling in front of the transit vehicle to make a right turn. This application will help the transit vehicle determine whether the area in front of the vehicle will be occupied as it begins to pull away from a transit stop. The Tampa historical streetcar line, which runs along Channelside Drive from the Amalie Arena to the Selmon Expressway, runs parallel to vehicle lanes with a common approach to traffic control signals. The signal will be red for all vehicle phases during the streetcar crossing. However, right turn on red is typically a legal move, which may cause a motorist—unaware of the streetcar's presence—to turn right into the streetcar's path.

Vehicle-to-Infrastructure Safety Applications

Vehicle-to-infrastructure (V2I) safety applications wirelessly exchange critical safety and operational data between vehicles and roadway infrastructure to help avoid motor vehicle crashes. V2I safety applications will complement V2V safety applications, enabling vehicles to have enhanced awareness and informing vehicle operators through advisories and warnings of hazards and situations they cannot see. The THEA CVPD team deployed three V2I safety applications. These applications are described briefly as follows.

End of Ramp Deceleration Warning

The ERDW application provides speed advice, based on the longest queue length of any lane, to drivers who are approaching or are in the curve leading to the REL exit. An ERDW RSU application calculates the queue length of each lane, determines the longest queue, and determines the safe stopping distance to the end of this queue to the physical curve speed limit sign. Using a lookup, the recommended speed advice is determined based on the calculated distance. This recommended speed advice is sent to a second RSU located near the physical speed limit sign. The RSU broadcasts speed advice using DSRC. Any vehicle equipped with an OBU within range of this RSU receives the recommended speed advice and calculates the specific speed advice for the vehicle based on the vehicle type. A warning including the speed advice is displayed to the driver.

Wrong-Way Entry Warning

The intent of the WWE application was to warn drivers of wrong-way entries onto the REL. Wrong-way entries are detected by sensors at the RSU. When a wrong-way entry is detected, the RSU sends a traveler information message alert to law enforcement and the traffic management center (TMC). When a wrong-way driver of a CV is identified, the wrong-way driver receives an immediate warning from the RSU that detected the wrong-way entry. Other CVs traveling the correct way on the REL receive a warning of the approaching wrong-way driver. The TMC broadcasts a wrong-way driver alert using the variable message signs to warn all other drivers on the REL.

Pedestrian Collision Warning

THEA developed the PCW application to warn drivers when a pedestrian was using a crosswalk in the projected path of the CV. The application was installed at a midblock crosswalk on East Twiggs Street at the Hillsborough County Courthouse. Initially, two LiDAR sensors installed at the crosswalk located pedestrians in the area, translated the information to PSMs, and then broadcast them over DSRC to the OBUs. OBU-equipped vehicles using the PCW application warned drivers who were on a collision course with a pedestrian in the crosswalk.

The THEA CVPD team replaced the LiDAR sensors with thermal imaging sensors for the following reasons: (3)

- The LiDAR system did not track pedestrians until they were located halfway through the crosswalk area.
- The LiDAR sensors could not track pedestrians using the same identification number as they moved through the crosswalk area.

The THEA CVPD team installed new sensors in May 2020 and subsequently tested the performance of the application using test vehicles in June, July, and August 2020. On August 5, 2020, the system began full operation and deployed to participants. Due to the COVID-19 pandemic that began in March 2020 and its impact on the participants' travel in the area, THEA did not record any PCW warning data from participant vehicles during the post-deployment period. The new system became officially operational on August 5, 2020, outside the official post-deployment evaluation period. The THEA CVPD team anticipates completing the evaluation of this application as part of its phase 4 activities. (3)

Vehicle-to-Infrastructure Mobility Applications

V2I mobility applications communicate operational data between vehicles and infrastructure. These applications are intended primarily to increase mobility and enable additional safety, mobility, and environmental benefits. Applications use real-time data to increase safety and operational efficiency while minimizing the impact on the environment and enabling travelers to make better-informed travel decisions. The THEA CVPD team deployed two V2I mobility applications. These applications are described briefly as follows.

Intelligent Traffic Signal System

According to the original THEA CVPD functional architecture, the intent of the I-SIG application for Use Case 6 was to improve traffic signal control operation and maximize flows in real time. The application was to use vehicle location and movement information from CVs and infrastructure measurement from non-equipped vehicles (e.g., standard detection devices) to feed the MMITSS application. The MMITSS uses estimated queue length and other performance measures to adjust signal timing for an intersection or group of intersections to improve traffic flow and allow platoon flow through the intersection. THEA's intent was to use the MMITSS application as an overarching traffic signal system optimization application, capable of accommodating other mobility applications—such as TSP, freight signal priority, emergency vehicle preemption, and pedestrian mobility—to maximize overall arterial network performance. (3)

THEA was unable to deploy I-SIG due to integration issues between the MMITSS, I-SIG, and the signal controllers. (3) Phase 3 deployment testing also revealed that the MMITSS application was not successful in correctly estimating queue length. THEA plans to explore what would allow the signal controllers to communicate with I-SIG without relying on key input measures from the MMITSS as part of its Phase 4 activities. (3)

Transit Signal Priority

The TSP application uses transit V2I communications to allow a transit vehicle to request a priority at one or a series of intersections based on several factors. The proposed application allows transit vehicles to request priority of roadside equipment via an onboard device. The application provides feedback to the transit driver indicating whether the signal priority has been granted. This application can contribute to improved transit vehicle operating performance by reducing the time spent stopped at a red light. This application will be used by HART buses in the Marion Street use case, a primary route where buses and traffic signals communicate. Once TSP is implemented, if a bus is behind schedule, the traffic signal system will give the bus priority (assuming no other higher priorities, e.g., a preemption request or an ongoing pedestrian phase, are active at the intersection) to flush the queue, shortening the wait time of the bus at the intersection.

This application was not fully operational during the phase 3 evaluation period. The THEA CVPD team plans to complete the deployment and evaluation of this application as part of the phase 4 activities. (3)

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