Connected Vehicle Pilot Deployment Program Independent Evaluation

Environmental Impact Assessment (EIA)—Tampa (THEA)

www.its.dot.gov/index.htm

Research Report—March 10, 2022
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16. Abstract

In September 2015, the U.S. Department of Transportation Intelligent Transportation Systems Joint Program Office selected three Connected Vehicle Pilot Deployment (CVPD) Program sites: Wyoming, New York City, and Tampa. Each deployment represents different potential settings for connected vehicle (CV) technologies and was comprised of different applications that address vastly different problems. This report provides an independent assessment of the mobility impacts associated with the Tampa Hillsborough Expressway Agency (THEA) CVPD. This evaluation is primarily qualitative in nature and based on data provided by the THEA CVPD Team. The THEA CVPD Team did not provide any evidence that the deployment had any impact on fuel consumption and emissions. Using the change in idle time of CVs reported by the THEA CVPD Team, the Texas A&M Transportation Institute (TTI) showed that total fuel consumption was reduced in the post-deployment period, but this was caused by fewer vehicles entering the study area during the post-deployment period compared to the pre-deployment period. Using the Environmental Protection Agency's Greenhouse Emissions Calculator, TTI estimated a reduction of 240 kilograms of carbon dioxide emissions per year. This reduction was based on the estimated reductions in fuel consumed while idling resulting from the end-of-ramp deceleration warning in Use Case 1.

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Executive Summary

The Tampa Hillsborough Expressway Agency (THEA) Connected Vehicle Pilot Deployment (CVPD) was one of the first connected vehicle (CV) 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 is 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 are meant to mitigate several existing transportation challenges in the downtown area of Tampa, FL.

The THEA CVPD Team originally intended to deploy 13 different CV applications in the deployment; however, due to installation delays and equipment issues, the THEA CVPD Team was unable to deploy all the planned applications during Phase 3. The final list of applications deployed by the THEA CVPD Team included the following:

- Electronic Emergency Brake Light.
- End of Ramp Deceleration Warning.
- Forward Collision Warning.
- Intersection Movement Assist.
- Pedestrian Crossing Warning.
- Vehicle Turning Right in Front of a Transit Vehicle.
- Wrong-Way Entry.

The Texas A&M Transportation Institute (TTI) used the reported pre- and post-deployment idle times to estimate the total fuel consumed by the idling equipped vehicle in each evaluation period. TTI then computed the average total amount of time the equipped vehicle spent idling during a typical peak period by dividing the total amount of observed idle time by the number of peak periods in each evaluation period. The computation showed that, on average, equipped vehicles spent 78.38 minutes idling in the peak period in the pre-deployment period and 55.69 minutes idling per peak period in the post-deployment period.

Using a methodology developed by the Argonne National Laboratory, TTI then estimated the amount of fuel consumed while idling. The computation shows that the total amount of fuel consumed by equipped vehicles idling on the Reversible Expressway Lanes (REL) of the Selmon Expressway in the pre-deployment periods was approximately 0.36 gallons and 0.26 gallons in the post-deployment period. This equates to a reduction in fuel consumption of 0.104 gallons per peak period or approximately 27 gallons per year.

A considerable difference exists between the average number of equipped vehicles observed in a peak period between the pre- and post-deployment periods. In the pre-deployment period, the average daily total of connected vehicles on the REL was computed at 71.3 CVs per peak period, while in the post-deployment period, the average number of observed CVs dropped to approximately 46 vehicles per peak period. The number of equipped vehicles trended down throughout most of the pre-deployment period. TTI concluded that the drop in the number of observed equipped vehicles is the source of the reduction in fuel consumption.

Using the Environmental Protection Agency's Greenhouse Emissions Calculator, TTI estimated a reduction of 240 kilograms of carbon dioxide emissions per year. This reduction was based on the estimated reductions in fuel consumed while idling resulting from the end-of-ramp deceleration warning in Use Case 1.

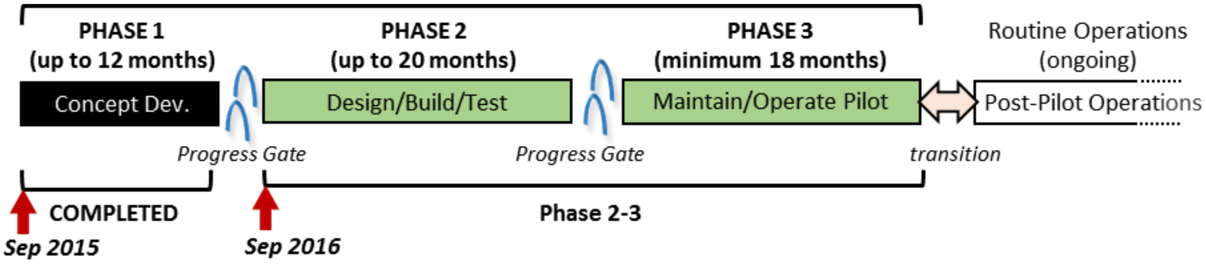
Chapter 1. Introduction

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

The Connected Vehicle Pilot Deployment (CVPD) Program seeks to spur innovation among early adopters of CV application concepts. The pilot deployments are 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. The pilot deployments also provided transferable lessons learned for other prospective deployers across the Nation. The intent of the pilot deployments was to encourage partnerships of multiple stakeholders (e.g., private companies, State and local agencies, transit agencies, CV 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 (i.e., transit, freeway, arterial, parking facilities, and tolled roadways). The sites will demonstrate improved performance in one or more of the following areas: safety, mobility, public agency efficiency, or reduced negative environmental impact. Pilot deployers will identify a set of key quantitative performance measures and implement a system that supports continuous monitoring of observed data capable of quantifying the measures. Pilot deployments are expected to become part of a permanent CV capability that is fully integrated into routine operational practice at the pilot site and create a foundation for expanded and enhanced deployments. The deployers will identify and implement institutional and financial models that will 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. The Intelligent Transportation Systems Joint Program Office 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 addressed 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 deployment under actual traffic conditions. This report focuses on Phase 3 and includes an evaluation of the overall environmental impact assessment associated with the deployment.



Source: Federal Highway Administration, 2015

Figure 1. Flowchart. Three phases of a Connected Vehicle Pilot Deployment

Independent Evaluation

This report provides the results of the independent environmental impact assessment (EIA) associated with the Tampa Hillsborough Expressway Agency (THEA) CVPD. Because of delays in the deployment and because of unforeseen external factors (e.g., the COVID-19 pandemic), the Federal Highway Administration (FHWA) revised the Texas A&M Transportation Institute's (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 National Transportation Center's safety impact assessments.
- Site-generated dashboards and lessons-learned logbooks.
- Outcomes of the CVPD Program Independent Evaluation Stakeholder Acceptance and User Satisfaction surveys and interviews.

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 discusses THEA's goals and objectives associated with the deployment and provides a brief overview of the architecture of 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.
- Chapter 4 provides the results of the EIA for the THEA CVPD.
- Chapter 5 summarizes the findings from the EIA.

Chapter 2. THEA Tampa Connected Vehicle Pilot System Overview

This chapter describes the deployer's goals and objectives for the pilot deployment site. The 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 the performance of the deployment.

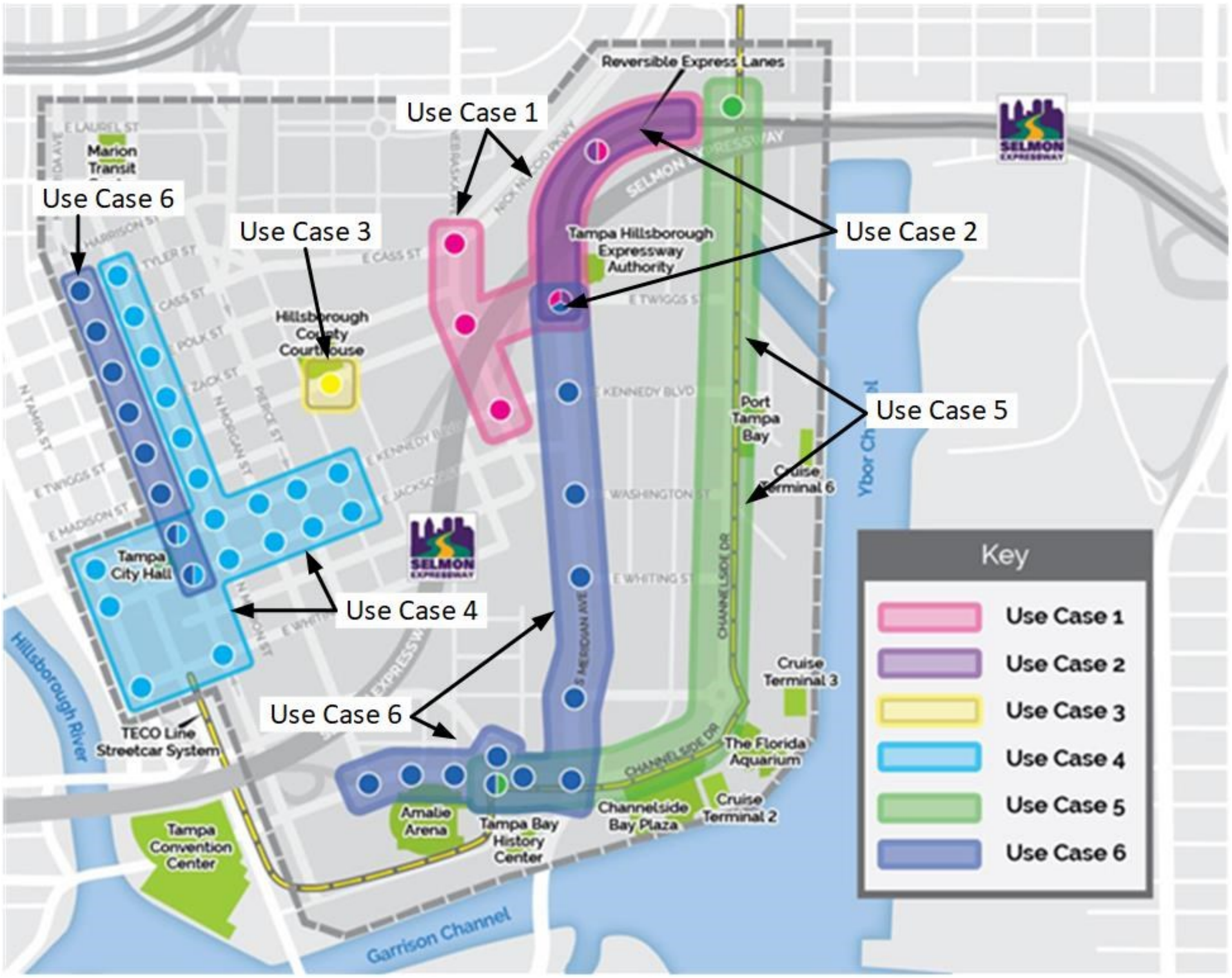
Site Description and Transportation Issues

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.(1) In terms of transportation features of the Tampa downtown area, THEA owns and operates the Reversible Expressway Lanes (REL) on the Selmon Expressway. 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 McDill 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 is 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 is 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 are meant to mitigate several existing transportation challenges in the CBD of Tampa.(1)

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. However, due to implementation delays and equipment issues, the THEA CVPD Team was unable to install the planned applications.



Source: Center for Urban Transportation Research, 2020

Figure 2. Map. THEA CVPD site[(2)]

Table 1. Summary of use cases addressed by the THEA's CVPD(1,2)

Use Case	Condition	Description of Issues to Be Addressed	Applications
1	Rush-hour collision avoidance	As drivers approach the end of the Selmon Expressway REL, they 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 (I-SIG)
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) • I-SIG
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, 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 Streetcar runs north along Channelside Drive from the Amalie Arena area 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 Turing 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 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.	• I-SIG • Intersection Movement Assist (IMA) • FCW

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

The area encapsulated by the THEA CVPD experiences several different mobility and safety issues daily.(1) 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).
- Transit Signal Prioritization (TSP) on the Marion Street Transitway (Use Case 4).
- Vehicle and pedestrian conflicts with the Tampa historic streetcars on Channelside Drive (Use Case 5).
- Traffic flow optimization and signal progression on Meridian Avenue, Nebraska Avenue, Channelside Drive, and Florida Avenue (Use Case 6).

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 2. Summary of devices for deployment(1)

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 app in personal information devices (PIDs)	500+	0***

* THEA determined that the operational reliability of the LiDAR sensors was not adequate to support the PCW application and replaced them with video and thermal imaging sensors.

** Only deployed on a limited number of vehicles as a test.

*** During the deployment, the Pedestrian Crossing (PED-X) portion of the applications was not implemented due to issues associated with the GPS accuracies in the PIDs.

Source: Texas A&M Transportation Institute based on information contained in references 1 and 2, 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.[1]
- Multimodal Intelligent Traffic Signal System (MMITSS) Java Script Object Notation (JSON)–formatted Siemens-MMITSS calculated metrics.[1]
- PED-X–JSON-formatted structure with the element “psm” containing the Pedestrian Safety Message (PSM) that triggered the collision alert as J2735 Message Frame.[1]

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

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).(2) Figure 3 shows the volume of data files transferred to the SDC during the deployment. The OBU files began logging beginning in

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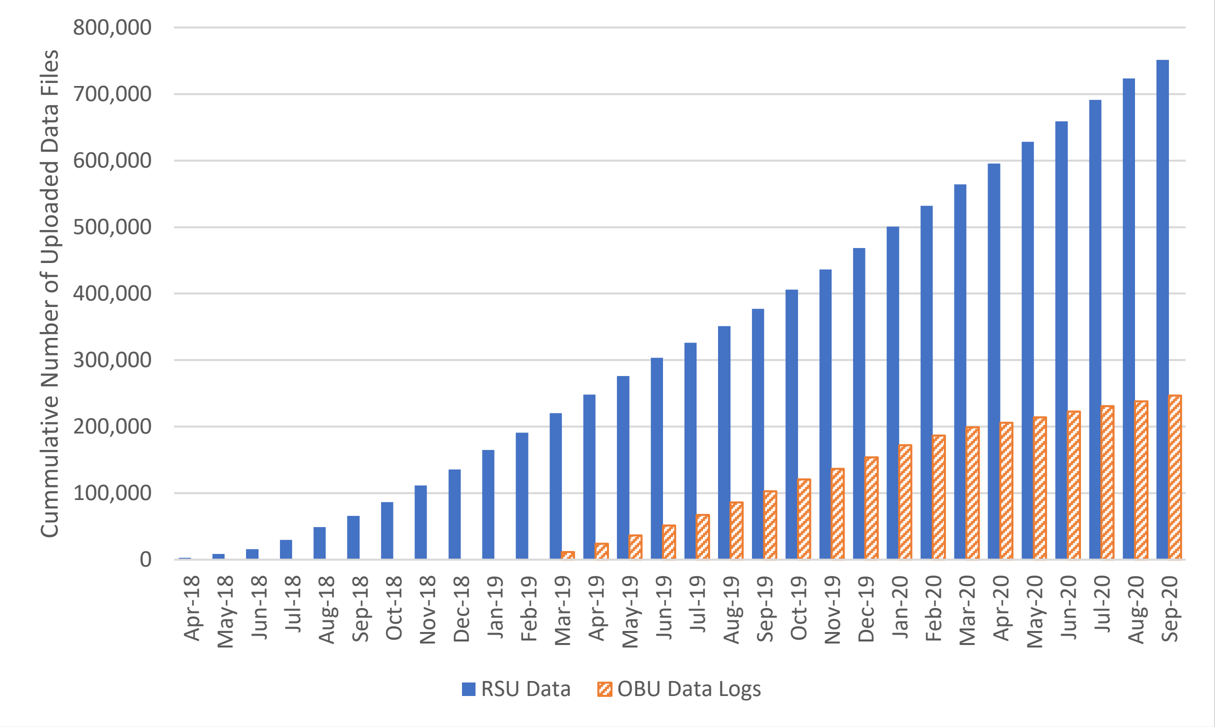
[1] While the RSUs are capable of logging SRMs, SSMs, MMITSS, and PSMs, the applications that generate these data sources were not active during the Phase 3 evaluation.

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.(3)



Source: Center for Urban Transportation Research, 2020

Figure 3. Bar chart. Volume of RSU and OBU data files generated by the THEA CVPD(2)

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. Table 3 shows the list of final applications deployed by the THEA CVPD Team in each Use Case.(2) 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.

The *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation—Tampa (THEA) CV Pilot Phase 3 Evaluation Report* provides a complete description of the applications deployed by THEA.(2) Appendix A provides a summary description of the applications.

Table 3 shows the final applications deployed by the THEA CVPD Team in each Use Case.

Table 3. Applications deployed in each use case in the THEA CVPD(2)

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.

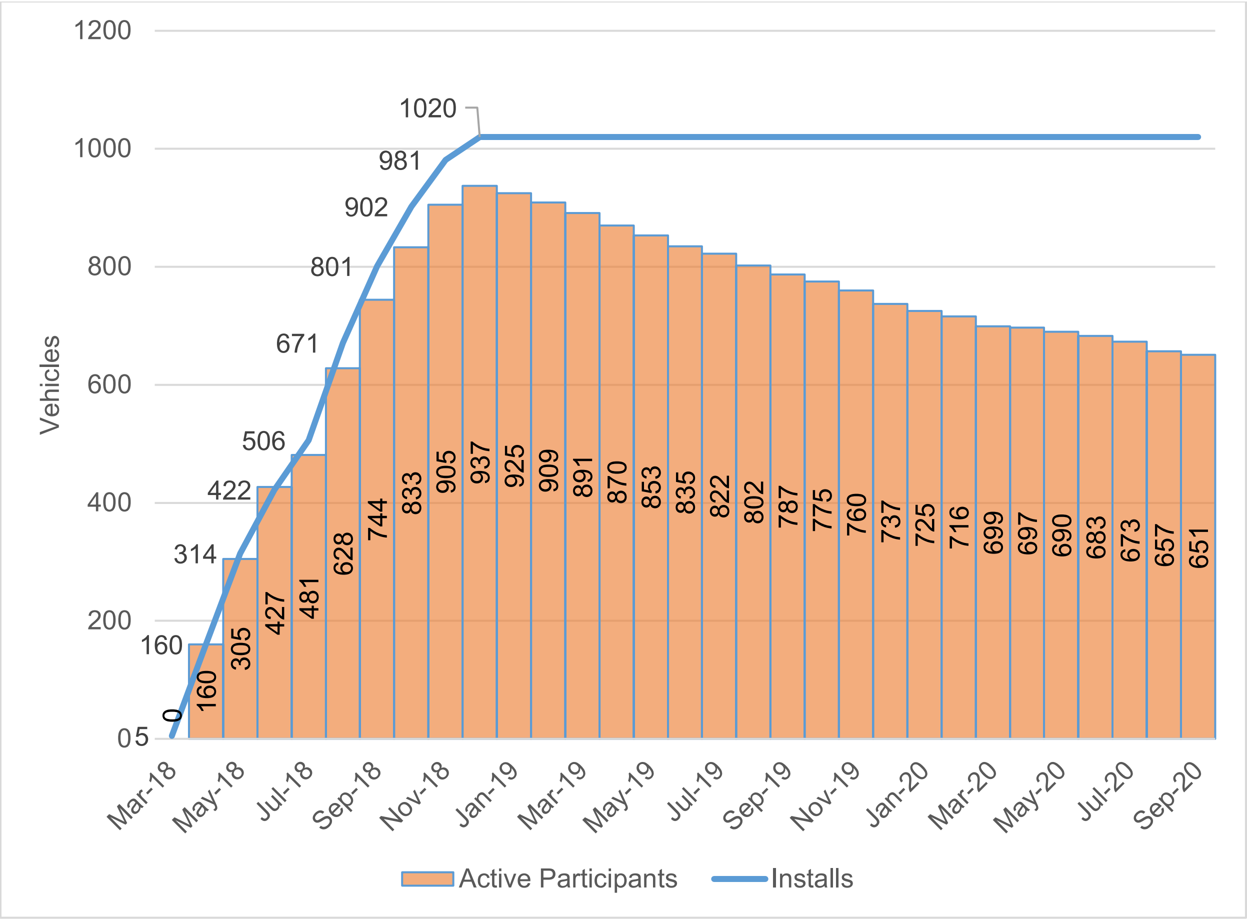
Source: Texas A&M Transportation Institute based on information contained in reference 2, 2022

The applications were developed and deployed by aftermarket vendors using Society of Automotive Engineers International standards and application specifications.(4) 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 warning event records belonging to the same warning event. The OBU creates a set of warning event data records per warning. Each record of the set represents a point in time before, during, and after the warning triggered. A warning event data 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 that result from receiving a PSM populate the "vruPSM" field with PSMs from the vulnerable road user triggering the pedestrian collision warning. 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 Center for Urban Transportation Research (CUTR) server to the SDC, along with a separate data dictionary.(2)

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)

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 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, 2020

Figure 4. Bar chart. Number of OBU installations and monthly active participants(2)

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.(2) 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 generated by the applications.

Other demographic information about the THEA CVPD participants includes the following:(2)

- 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.(2)

Chapter 3. Evaluation Data Sources and Data Availability

The THEA CVPD Team had planned to collect data to allow the assessment of the environmental impacts of the deployment; however, they were not able to provide direct or indirect measures of environmental impact for the following reasons.(2)

- The primary focus of the deployment was on improving safety.
- Several of the mobility applications (e.g., the TSP and I-SIG applications) were not successfully deployed during Phase 3.
- Due to the COVID-19 pandemic, insufficient data existed in the post-deployment period to allow a full assessment of the mobility-oriented applications.

Because of the limitations of the deployment, TTI used THEA's reported mobility benefits to conduct the EIA. According to FHWA's Congestion Mitigation and Air Quality Improvement Program website,(5) transportation improvement projects typically reduce motor vehicle emissions in one of three ways:

- Improving traffic flow, thereby reducing vehicle idling and stop-and-start driving conditions that are associated with higher levels of emissions.
- Encouraging changes in travel behavior that reduce motor vehicle mile traveled (e.g., shifts to ridesharing, transit, bicycling, or walking).
- Using technology to reduce the rates of emissions (e.g., through purchases of cleaner buses or retrofits of diesel vehicles).

Since the deployed applications do not focus on encouraging mode shift behaviors or use technologies that directly reduce emissions, TTI focused on using the results of the mobility analysis to assess the environmental impacts associated with the deployment. Table 4 summarizes the reported mobility benefits. These benefit estimates are based on a limited number of days when the applications were active.

The Argonne National Laboratory developed a method to estimate the amount of fuel consumed while idling. This methodology uses equation 1 for estimating the amount of fuel consumed while idling.(6)

$$\mathrm{FC} = \mathrm{I} * \mathrm{n} * \mathrm{R} \tag{1}$$

where:

FC = total amount of fuel consumed by idling (gallons)
I = average duration spent idling (minutes of idling per vehicle)

N = number of vehicles experiencing idling (vehicles)
R = rate of fuel consumed while idling (gallons per hour of idling)

Table 4. Summary of mobility benefits reported for each use case for the Tampa CVPD

Use Case	Deployed Applications	Reported Mobility Benefits[(2)]
1: Rush-hour collision avoidance	- ERDW - EEBL - FCW	The ERDW contributed to: - 2.1 percent reduction in mean travel times - 1.8 percent reduction in idle time or time spent traveling at less than 1 mph - 1.8 percent reduction in queue length - A travel time index (measured as peak-hour travel time divided by off-peak travel time) reduction from 2.7 to 1.9
2: Wrong-way entry prevention	- WWE	Use Case 2 did not generate quantifiable mobility measures directly attributed to the WWE application deployment
3: Pedestrian conflict	- PCW	THEA did not assess the impact of this application on mobility
4: Transit signal priority	Not deployed	The TSP application underwent a change in operations and therefore has not produced data for performance evaluation as of the date of this report
5: Streetcar Conflicts	- VTRFTV	THEA did not assess the impact of this application on mobility
6: Traffic Progression	Not deployed	Use Case 6 only generated data conducive to establishing a baseline for a mobility assessment. THEA was unable to fully deploy the I-SIG and MMITSS applications during the evaluation period and did not generate the required data to conduct a before-after assessment

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

As part of the mobility assessment, the THEA CVPD Team reported the change in average idle time for equipped vehicles in Use Case 1 during the before and after evaluation periods. The THEA CVPD Team defined idle time as the "time [vehicles] spent traveling at a speed of less than one mile per hour."(2) Table 5 shows the average pre- and post-deployment idle times reported by the THEA CVPD Team associated with the ERDW application in Use Case 1.(2) The table shows that the average observed idle time for each CV was 1.1 minutes in the pre-deployment period and 1.2 minutes in the post-deployment period.

Table 5. Reported idle time by equipped vehicles before and after deploying technologies(2)

Evaluation Period	Number of Vehicles Observed	Mean Observed Idle Time (Minutes per Vehicle)	Maximum Observed Idle Time (Minutes per Vehicle)	Standard Deviation (Minutes per Vehicle)	95th Percentile (Minutes per Vehicle)
Pre-deployment	18,457	1.1	3.5	0.5	2.0
Post-deployment	1,578	1.2	2.6	0.5	2.1

Evaluation Period	Number of Vehicles Observed	Mean Observed Idle Time (Minutes per Vehicle)	Maximum Observed Idle Time (Minutes per Vehicle)	Standard Deviation (Minutes per Vehicle)	95th Percentile (Minutes per Vehicle)
Overall sample	**20,035**	**1.1**	**3.5**	**0.5**	**3.2**

Source: Center for Urban Transportation Research, 2020

CUTR performed an interrupted time-series analysis on idle time and found the following:(2)

- At the beginning of the pre-deployment period, equipped vehicles experienced, on average, 1.2 minutes of idle time.
- Idle time tended to be significantly less on Fridays than other days of the week.
- Days that experienced rain also tended to have higher idle times.
- Days after the onset of COVID-19 experienced less idle times than before COVID-19.
- After accounting for confounding factors, the average idle time in the post-deployment period is under 1 minute.

Chapter 4. Environmental Impact Assessment

As described in the previous chapter, the Argonne National Laboratory developed a method to estimate the amount of fuel consumed when idling. TTI used this method to first estimate the fuel reduction benefits in the THEA CVPD, based on the reduction in idling observed in Use Case 1. TTI then applied a methodology developed by the U.S. Environmental Protection Agency (EPA) to estimate the greenhouse gas equivalencies based on the reduction change in fuel consumption. This chapter summarizes the impacts of the THEA CVPD on fuel consumption and emissions. This analysis is based on the data contained in the *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation—Tampa (THEA) CV Pilot Phase 3 Evaluation Report.*(2)

Fuel Consumption

The Argonne National Laboratory determined fuel consumption rates for different types of idling gasoline- and diesel-powered vehicles. Table 6 shows these fuel consumption rates for different vehicle types.

Table 6. Fuel consumption during idling for different vehicle types(6)

Vehicle Type	Fuel Type	Engine Size (Liter)	Gross Vehicle Weight	Idling Fuel Use (Gal/Hr with No Load)
Compact sedan	Gasoline	2	NA	0.16
Large sedan	Gasoline	4.6	NA	0.39
Compact sedan	Diesel	2	NA	0.17
Medium heavy truck	Gasoline	5–7	19,700–26,000	0.84
Delivery truck	Diesel	NA	19,500	0.84
Tow truck	Diesel	NA	26,000	0.59
Medium heavy truck	Diesel	6–10	23,000–33,000	0.44
Transit bus	Diesel	NA	30,000	0.97
Combination truck	Diesel	NA	32,000	0.49
Bucket truck	Diesel	NA	37,000	0.90
Tractor-semitrailer	Diesel	NA	80,000	0.64

NA = not applicable.

Source: U.S. Department of Energy, 2015

Because TTI does not know the type and mix of equipped vehicles in the deployment, the TTI Evaluation Team used 0.275 gallons/hour as the idle fuel consumption rate, the average of the idle fuel usage rates for the gasoline-powered, compact sedan and gasoline-powered, large sedan. This value represents an ideal fuel consumption rate because the Argonne National Laboratory produced these rates for vehicles with no load (i.e., no use of accessories such as air conditioners, fans, etc.) on the engines. Because Tampa is in a humid subtropical climate, most vehicles are likely to operate with their air conditioning on, thereby producing higher fuel consumption rates than those used in the analysis.

TTI computed the amount of fuel consumed per day by the idling CVs during each evaluation period using equation 1. TTI then calculated the change in daily fuel consumption generated under Use Case 1 using equation 2.

$$\Delta \text{ Fuel Consumption} = \text{Fuel Consumption}_{\text{After}} - \text{Fuel Consumption}_{\text{Before}} \qquad (2)$$

A negative value represents a reduction (or savings) in daily fuel consumption, while a positive value represents an increase in daily fuel consumption between the two evaluation periods.

Using this methodology, TTI used the reported pre- and post-deployment idle times to estimate the total fuel consumed by the idling equipped vehicle in each evaluation period (see table 7). The total number of minutes the CVs spent idling per day can then be computed by multiplying the average idle time per CV reported in table 5 by the average number of CVs observed during the evaluation period (see table 7). The total number of minutes CVs spent idling per day can then be converted into the number of hours the CVs spent idling by dividing by 60 minutes per hour.

Table 7. Average total idle time per peak period by equipped vehicles on the REL

Evaluation Period	Total Number of Observed Vehicles	Average Reported Idle Time (Minutes per Vehicle)	Total Amount of Observed Idle Time (Minutes)	Number of AM Peak Periods in Evaluation Period	Average Total Idle Time per Peak Period (Minutes)
Pre-deployment	18,457	1.1	20,303.7	259	78.38
Post-deployment	1,578	1.2	1,893.6	34	55.69

Source: Texas A&M Transportation Institute, 2022

TTI computed the average total amount of time the equipped vehicle spent idling during a typical peak period by dividing the total amount of observed idle time by the number of peak periods in each evaluation period. The computation showed that, on average, equipped vehicles spent 78.38 minutes idling in the peak period in the pre-deployment period and 55.69 minutes idling per peak period in the post-deployment period.

After converting the average total idle time per peak period from minutes to hours and then multiplying by the average fuel consumption rate for a gasoline-powered engine under no load (as measured by the Argonne Laboratories), the TTI Evaluation Team then computed the total amount of fuel consumed while idling per peak period in both the pre- and post-deployment periods. Table 8 shows the result of this computation. The computation shows that the total amount of fuel consumed by equipped vehicles idling on the REL per peak period in the pre-deployment periods was approximately 0.36 gallons and 0.26 gallons in the post-deployment period. This equates to a reduction in fuel consumption of 0.104 gallons per peak period or approximately 27 gallons per year.

Table 8. Total fuel consumed while idling by CVs on the REL

Evaluation Period	Average Total Idle Time per Peak Period (Minutes)	Average Total Idle Time per Peak Period (Hours)	Fuel Consumption Rate Idling (Gal/Hr)	Total Fuel Consumed While Idling during Peak Period (Gallons)
Pre-deployment	78.38	1.30	0.275	0.359
Post-deployment	55.69	0.92	0.275	0.255

Source: Texas A&M Transportation Institute, 2022

This finding, however, does not intuitively make sense given that the average idle time for equipped vehicles slightly increased between the pre- and post-deployment periods. Table 9 shows that there is a considerable difference between the average number of equipped vehicles observed in a peak period between the pre- and post-deployment periods. In the pre-deployment period, the average daily total of CVs on the REL was computed to 71.3 CVs per peak period, while in the post-deployment period, the average number of observed CVs dropped to approximately 46 vehicles per peak period. Previous graphs and tables have shown that the number of equipped vehicles was trending down throughout most of the pre-deployment period. Also, the post-deployment evaluation period was shortened considerably due to the COVID-19 pandemic. Therefore, the drop in the number of observed equipped vehicles is the source for this reduction in fuel consumption. Without more analysis days in the post-deployment period, TTI cannot conclusively report that the ERDW application resulted in an overall reduction in fuel consumption.

Table 9. Average number of CV observations per peak period

Evaluation Period	Total Number of Observed CV Vehicles per Evaluation Period	Number of AM Peak Periods in Evaluation Period	Average Number of CV Observations per Peak Period
Pre-deployment	18,457	259	71.3
Post-deployment	1,578	34	46.4

Source: Texas A&M Transportation Institute, 2022

Emissions

THEA did not report information that would allow the TTI Evaluation Team to estimate the change in emissions resulting from the THEA CVPD in Tampa.

EPA developed a methodology for estimating greenhouse gas equivalencies for several types of energy consumed.(7) The methodology is based on the information contained in the preamble to the joint EPA/USDOT rulemaking on May 7, 2010, that states the two agencies agreed to use a common conversion factor of 8,887 grams of carbon dioxide (CO_2) emissions per gallon of gasoline consumed.(8) This conversion factor assumes that all the carbon in the gasoline is converted to CO_2.(9) Equation 3 shows how the greenhouse gas equivalents are computed using the conversion factor.

$$\text{Greenhouse Gas Equivalent } (CO_2) = \Delta\text{Fuel Consumption} \times 8.887 \text{ Kg of } CO_2/\text{gallons of gas consumed} \tag{3}$$

TTI applied this conversion factor to the total annual reduction in fuel consumption due to the reduction in idle time (27 gallons per year). Using EPA's Greenhouse Emissions Calculator,(7) this reduction in fuel consumption equates to a reduction of 240 kilograms of CO_2 emissions per year in the Tampa CBD. This reduction is attributed to the ERDW application only. This reduction maybe also be due to the reduction in the number of equipped vehicles during the post-deployment period compared to the pre-deployment period. TTI expects that additional reductions in emissions are likely to occur once more of the mobility-related applications, such as the TSP and I-SIG, become operational in the Tampa CBD.

Chapter 5. Summary of Findings

This chapter summarizes the findings from the mobility, environmental, and public agency EIA.

TTI used the reported pre- and post-deployment idle times to estimate the total fuel consumed by the idling equipped vehicle in each evaluation period. TTI then computed the average total amount of time the equipped vehicle spent idling during a typical peak period by dividing the total amount of observed idle time by the number of peak periods in each evaluation period. The computation showed that, on average, equipped vehicles spent 78.38 minutes idling in the peak period in the pre-deployment period and 55.69 minutes idling per peak period in the post-deployment period.

Using a methodology developed by the Argonne National Laboratory, TTI then estimated the amount of fuel consumed while idling. The computation shows that the total amount of fuel consumed by equipped vehicles idling on the REL in the pre-deployment periods was approximately 0.36 gallons and 0.26 gallons in the post-deployment period. This equates to a reduction in fuel consumption of 0.104 gallons per peak period or approximately 27 gallons per year.

A considerable difference exists between the average number of equipped vehicles observed in a peak period between the pre- and post-deployment periods. In the pre-deployment period, the average daily total of connected vehicles on the REL was computed as 71.3 CVs per peak period, while in the post-deployment period, the average number of observed CVs dropped to approximately 46 vehicles per peak period. Previous graphs and tables have shown that the number of equipped vehicles trended down throughout most of the pre-deployment period. TTI concluded that the drop in the number of observed equipped vehicles is the source for the reduction in fuel consumption.

Using EPA's Greenhouse Emissions Calculator,(7) TTI estimated a reduction of 240 kilograms of CO_2 emissions per year. This reduction was based on the estimated reductions in fuel consumed while idling resulting from the ERDW application in Use Case 1.

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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.(2)

V2V 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.

Electronic Emergency 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 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 plans to deploy 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

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:(2)

- 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.(2)

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 may 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 plans to deploy 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.(2)

THEA was unable to deploy I-SIG due to integration issues between the MMITSS, I-SIG, and the signal controllers.(2) Phase 3 deployment testing also revealed that the MMITSS application was not successful in correctly estimating queue length.(2) THEA plans to explore what would allow the signal controllers to communicate with the I-SIG application without relying on key input measures from the MMITSS as part of its Phase 4 activities.(2)

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.(2)

Appendix B. 2019 and 2020 Observed Federal Holidays

The observed Federal holidays impacting traffic operation in the Tampa CVPD are as follows.

Holiday	2019*	2020**
New Year's Day	Jan. 1 (Tuesday)	Jan. 1 (Wednesday)
Martin Luther King Jr. Day	Jan. 21 (Monday)	Jan. 20 (Monday)
President's Day	Feb. 18 (Monday)	Feb. 17 (Monday)
Memorial Day	May 27 (Monday)	May 25 (Monday)
Independence Day	July 4 (Thursday)	July 3 (Friday) (in lieu)
Labor Day	Sept. 2 (Monday)	Sept. 7 (Monday)
Columbus Day	Oct. 14 (Monday)	Oct. 12 (Monday)
Veterans Day	Nov. 11 (Monday)	Nov. 11 (Wednesday)
Thanksgiving	Nov. 28 (Thursday)	Nov. 26 (Thursday)
Day after Thanksgiving	Nov. 29 (Friday)	Not a Federal holiday
Christmas Eve	Not a Federal holiday	Dec. 24 (Thursday)
Christmas Day	Dec. 25 (Wednesday)	Dec. 25 (Friday)

Sources:
* https://www.officeholidays.com/countries/usa/2019
** https://www.officeholidays.com/countries/usa/2020

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