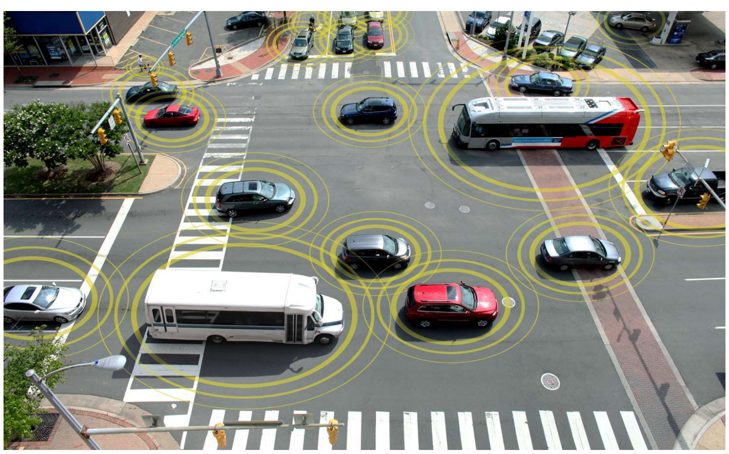
Connected Vehicle Pilot Deployment Program Independent Evaluation

Mobility Impact Assessment—Tampa (THEA)

www.its.dot.gov/index.htm

Research Report—May 11, 2022
FHWA-JPO-22-923



U.S. Department of Transportation

Produced by Texas A&M Transportation Institute
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
Intelligent Transportation Systems (ITS) Joint Program Office

Cover photo courtesy of ITS Joint Program Office Module 13 ePrimer Presentation (Connected Vehicles)

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-22-923		

4. Title and Subtitle	5. Report Date
Connected Vehicle Pilot Deployment Program Independent Evaluation: Mobility Impact Assessment—Tampa (THEA)	May 11, 2022
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
Kevin Balke (TTI) and Chris Simek (TTI)	
9. Performing Organization Name and Address	**10. Work Unit No. (TRAIS)**
Texas A&M Transportation Institute The Texas A&M University System 3135 TAMU College Station, TX 77843-3135	**11. Contract or Grant No.** DTFH6116D00045/0003
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
ITS Joint Program Office 1200 New Jersey Avenue, S.E. Washington, DC 20590	Research Report **14. Sponsoring Agency Code**

15. Supplementary Notes

Work Performed for: Tom Kearney, Federal Highway Administration (FHWA) and Walter During FHWA

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, NY, and Tampa, FL. Each deployment represents different potential settings for connected vehicle 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 assessment shows that there is little evidence to support that the deployment had a significant impact on mobility in the deployment area, primarily because several of the mobility-focused applications were not operational during the post-deployment period. The COVID-19 pandemic also substantially altered travel patterns in the Tampa downtown area and significantly reduced the availability of post-deployment data to complete the evaluation.

17. Keywords	18. Distribution Statement
Connected Vehicle, Connect Vehicle Pilot Deployment, Independent Evaluation, Tampa	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		74	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Acknowledgments

The authors would like to thank the following individuals for their assistance in developing this plan in support of the independent evaluation of the Connected Vehicle Pilot Deployment Program:

- Walter During, Federal Highway Administration (FHWA).
- Tom Kearney, FHWA.
- John Halkias, FHWA.
- Kate Hartman, Intelligent Transportation Systems Joint Program Office (ITS JPO).
- Jonathan Walker, ITS JPO.
- Govindarajan Vadakpat, FHWA.
- Douglas Laird, FHWA.
- James Sturrock, FHWA.
- Volker Fessmann, FHWA.
- Margaret Petrella, Volpe National Transportation Systems Center.
- Najm Wassim, Volpe Center.
- Karl Wunderlich, Noblis.
- Meenakshy Vasudevan, Noblis.
- Sampson Asare, Noblis.
- Kathy Thompson, Noblis.
- Peiwei Wang, Noblis.
- Claire Silverstein, Noblis.

Table of Contents

Executive Summary ..... **vii**

Chapter 1. Introduction **1**

Connected Vehicle Pilot Deployment 1

Independent Evaluation 2

Deployment Goals and Objectives 3

Organization of the Report 3

Chapter 2. THEA Tampa CV Pilot System Overview **7**

Site Description and Transportation Issues 7

Applications 9

Vehicle-to-Vehicle Safety Applications 9

Vehicle-to-Infrastructure Safety Applications 10

V2I Mobility Applications 11

Deployed Equipment 12

Onboard Units 12

Roadside Units 14

Participants 14

Chapter 3. Evaluation Data Sources and Data Availability **19**

Data Generated by Each Use Case 20

Use Case 1: Morning Backups 20

Use Case 2: Wrong-Way Entry 20

Use Case 3: Pedestrian Conflicts 21

Use Case 4: Transit Signal Priority 22

Use Case 5: Streetcar Conflicts 22

Use Case 6: Traffic Progression 22

Crash Experiences and History 25

Confounding Factors 29

Traditional Confounding Factors 29

Participant Participation and Attrition 30

COVID-19 Pandemic 32

Chapter 4. Evaluation Performance Measures **34**

Mobility 34

Participant Surveys 37

Chapter 5. Mobility Impacts **39**

Direct Impacts on Mobility 39

Changes in Travel Times 41
Change in Travel Time Reliability 43
Change in Queue Lengths 43
Change in Idle Time 45
Indirect Impacts on Mobility 46

Chapter 6. User Perceptions of Mobility Impacts 48

Survey Methodology 48
User Survey Results 49
Satisfaction with Aspects of Driving in Downtown Tampa 49
Opinions about CV Technology 49
Concerns and Benefits Relating to CV Technologies 53

Chapter 7. Summary of Findings 56

Primary Impacts on Mobility 56
Secondary Mobility Impacts 57
Participant Perceptions of Mobility Impacts 57
Confounding Factors 58

References 59

Appendix A. 2019 and 2020 Observed Federal Holidays 61

List of Tables

Table 1. Summary of Use Cases Addressed by the THEA CVPD[1,2] 4
Table 2. Applications Deployed in Each Use Case in the THEA CVPD[2] 6
Table 3. Summary of Devices for Deployment 13
Table 4. Number of Potential WWE Warnings and Events Analyzed by the THEA CVPD Team 21
Table 5. Crash Rates Reported by CUTR for Use Case 6[2] 25
Table 6. Number and Percentage of Valid Alerts by V2V Applications[9] 27
Table 7. Number and Percentage of Valid Alerts by V2I Applications[9] 27
Table 8. Number and Percentage of Valid Hazards Associated with V2V Applications[9] 27
Table 9. Number and Percentage of Valid Hazards Associated with V2I Applications[9] 28
Table 10. Number of Observations in Tampa's Post-deployment Period 33
Table 11. Number of Days in Each Tampa CVPD Evaluation Period 33
Table 12. Availability of Mobility-Related Performance Measures Used to Evaluate Use Case Applications in the Tampa CVPD 35
Table 13. Summary of Mobility Benefits Reported for Each Use Case for the Tampa CVPD 40
Table 14. Comparison of Travel Time (Minutes) before and after Deploying CV Technologies 42
Table 15. Statistical Comparison of Reported Average Travel Times 42
Table 16. Comparison of the Reported Travel Time Index before and after Deploying CV Technologies 43
Table 17. Statistical Comparison of Reported Average Travel Time Index 43
Table 18. Comparison of Reported Queue Lengths (Meters) before and after Deploying CV Technologies 45
Table 19. Statistical Comparison of Reported Average Queue Lengths 45
Table 20. Comparison of Reported Idle Time before and after Deploying CV Technologies 46
Table 21. Statistical Comparison of Reported Idle Time 46
Table 22. THEA CVPD User Survey Participation Rates[2] 49
Table 23. Concerns about CV Technologies in the THEA CVPD 54
Table 24. Reported Benefits of CV Technologies by THEA CVPD Participants 55

List of Figures

Figure 1. Flowchart. Three Phases of a Connected Vehicle Pilot Deployment 2
Figure 2. Map. THEA CVPD Site[2] 8
Figure 3. Bar Chart. Number of Participants Assigned by THEA to Treatment and Control Groups, Stratified by Gender 15
Figure 4. Bar Chart. Number of Participants Assigned by THEA to Treatment and Control Groups, Stratified by Age 16
Figure 5. Bar Chart. Number of Participants Assigned by THEA to Treatment and Control Groups, Stratified by Highest Level of Education 17
Figure 6. Bar Chart. Number of Participants Assigned by THEA to Treatment and Control Groups, Stratified by Income 18
Figure 7. Bar Chart. Volume of RSU and OBU Data Files Generated by the THEA CVPD 19
Figure 8. Bar Chart. Dataset Used by CUTR in Mobility Evaluation for Use Case 6 23
Figure 9. Bar Chart. Frequency of FCW, EEBL, and IMA Alerts Generated during the AM Peak in Use Case 6 24
Figure 10. Bar Chart. Frequency of FCW, EEBL, and IMA Alerts Generated during the PM Peak in Use Case 6 24
Figure 11. Bar Chart. Number of OBU Installed during the Lifetime of the THEA CVPD 31
Figure 12. Bar Chart. Mobility Evaluation Analysis Dataset for the THEA CVPD 32
Figure 13. Map. Travel Time Segments for Use Case 1 36
Figure 14. Map. Segmentation of the REL for Measuring Queue Lengths in Use Case 1 37
Figure 15. Chart. Pre- and Post-deployment Travel Times Associated with the ERDW Application in the THEA CVPD 41
Figure 16. Graph. Pre- and Post-deployment Average Daily Queue Lengths on the REL 44
Figure 17. Bar Chart. Satisfaction Levels with Overall Travel Time Driving in Downtown Tampa by Survey Participants 50
Figure 18. Bar Chart. Satisfaction Levels with Overall Driving Experience in Downtown Tampa among Tampa CVPD Survey Respondents 51
Figure 19. Bar Chart. Opinions about Whether CV Technology Will Improve Safety among Tampa CVPD Survey Respondents 52
Figure 20. Bar Chart. Opinions about Whether CV Technology Will Reduce Time Spent in Congested Conditions among Tampa CVPD Survey Respondents 53

Executive Summary

The Tampa Hillsborough Expressway Authority (THEA) Connected Vehicle Pilot Deployment (CVPD) was one of the sites selected by the United States Department of Transportation's Intelligent Transportation Systems Joint Program Office to showcase the value of connected vehicle (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 central business district of Tampa, FL.(1)

The THEA CVPD Team originally intended to deploy 13 different CV applications in the deployment.(2) Despite installation delays, equipment issues, and the worldwide COVID-19 pandemic, the THEA CVPD Team was able to successfully deploy the following applications:

- Electronic Emergency Brake Light (EEBL).
- End of Ramp Deceleration Warning (ERDW).
- Forward Collision Warning (FCW).
- Intersection Movement Assist (IMA).
- Pedestrian Crossing Warning (PCW)
- Vehicle Turning Right in Front of Transit Vehicle (VTRFTV).
- Wrong-Way Entry (WWE).

Unfortunately, the THEA CVPD Team was unable to get two applications—the Transit Signal Priority (TSP) and the Intelligent Signal (I-SIG) applications—fully operational during the Phase 3 deployment period. These applications were anticipated to generate significant mobility-related benefits. THEA is currently working with its stakeholders to get these applications operational during Phase 4 of its deployment.

Using the data available, the independent evaluator's mobility impact assessment used the reported benefits generated by Use Case 1: Morning Backups on the Reversible Express Lane (REL) of the Selmon Expressway. In terms of mobility impacts, the THEA CVPD Team reported the following mobility-related benefits associated with the applications deployed to warning motorists of congestion and queues on the REL:

- Mean travel times on the REL decreased by 2.1 percent during the AM peak.
- Time spent idling (i.e., traveling at speeds less than 1 mph) on the REL during the AM peak reduced by 1.8 percent.
- Maximum queue length on the REL reduced by 1.8 percent.
- The travel time index (measured as peak-hour travel time divided by off-peak travel time) reduced from 2.7 to 1.9.

Based on the data provided by the THEA CVPD Team in its evaluation, the Texas A&M Transportation Institute concluded the following:

- Despite the limited number of applications that might directly have an impact of mobility, the THEA CVPD Team was able to show that deployment was able to generate some mobility benefits. Most of the applications that THEA deployed were focused on improving safety and reducing the potential for collisions between equipped vehicles. The reduced evaluation period also restricted the team's ability to observe more notable mobility improvements.
- The ERDW applications deployed in Use Case 1 resulted in slight increases in average travel times, travel time reliability, and queue lengths. However, this is to be expected because the intent of the application is to slow down drivers approaching the back of the queue. These increases are inconsequential (less than 10 seconds) and imperceivable to most drivers.
- The observed differences in travel time, travel time reliability, and queue lengths in Use Case 1 are most likely due to the significant differences in the sample size of observations between the pre- and post-deployment periods.

The deployment was significantly impacted by several confounding factors. The long delay between when the participants were first recruited and when they first started receiving notifications appears to be a significant factor in participant retention. The high number of false alarms may have also contributed to a lack of continued participation. The COVID-19 pandemic, beginning shortly after the start of the post-deployment periods, also significantly impacted evaluation results. While the evaluation period for some applications was longer, the post-deployment evaluation period for the ERDW application was only 34 days. A longer post-deployment period would likely be needed to better quantify mobility and environmental changes.

Safety improvements were also expected to produce secondary mobility benefits—fewer collisions would mean fewer unplanned capacity reductions, thereby resulting in mobility improvements. Because of limited interaction between vehicles equipped with CV technologies, both the THEA and the Volpe crash analyses were able to conclusively report that the safety application did indeed result in reductions in crash frequencies or crash potential. THEA's analysis showed that the percentage of rear-end crashes remained similar in the before and after periods, and that sideswipe crashes increased by 20 percent. THEA's analysis shows however that the rates of conflicts per vehicle, normalized over time, showed a decrease for the FCW (from 4.6 to 4.2) and the EEBL (from 2.2 to 1.7) applications, and an increase in the IMA (from 0.1 to 0.5) application. Many of the safety applications experienced high false alarm rates and required extensive calibration, which may have prevented these applications from reaching their full crash reduction potential. Technology limitations and a limited number of interactions between equipped vehicles were also cited as reasons why safety benefits did not fully materialize. Furthermore, because crashes are rare events, the evaluation period was not long enough to determine the extent to which the applications may have produced safety benefits.

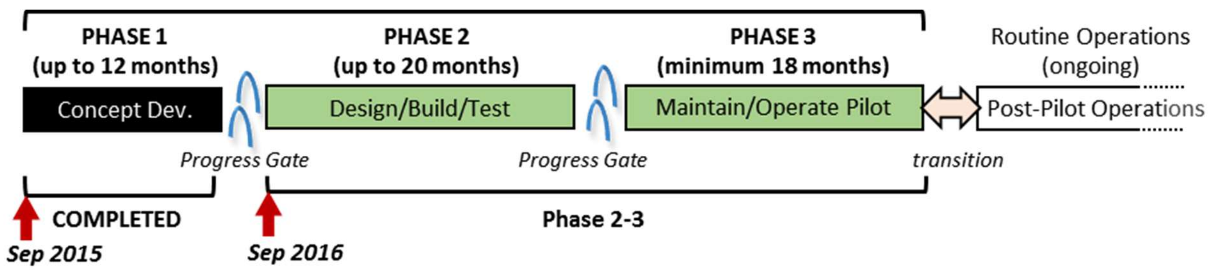
Chapter 1. Introduction

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. 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 deployments. In Phase 3, each site was responsible for managing and operating its deployments under actual traffic conditions. This report focuses on Phase 3 and includes an evaluation of the overall mobility benefits associated with the deployment.



Source: Federal Highway Administration

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

Independent Evaluation

ITS JPO selected the Texas A&M Transportation Institute (TTI) CVPD Evaluation Team to be the independent evaluator (IE) for the mobility, environmental, and public agency efficiency (MEP) 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.

This report provides an independent assessment of the mobility impacts associated with the Tampa Hillsborough Expressway Authority (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 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 Systems 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 task.

Deployment Goals and Objectives

THEA 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 its 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 its planned applications. Table 2 shows the final applications deployed by the THEA CVPD Team in each of the Use Cases.

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 its 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. Specifically, this chapter describes the data generated by the THEA CVPD Team to evaluate each Use Case. The chapter also describes some of the major confounding factors impacting the deployment.
- Chapter 4 provides an overview of the approach the TTI team used to assess the mobility impacts of the deployment.
- Chapter 5 reports the results of the assessment of the impacts of the deployment on mobility in the deployment area. This chapter includes results of the analysis of direct measures of mobility collected by the deployment team, as well as indirect improvement associated with reported safety benefits. This chapter also summarizes simulation-generated mobility performance measures.
- Chapter 6 summarizes the results of the User Acceptance survey conducted by the THEA CVPD.
- Chapter 7 summarizes the findings for the mobility impact assessment (MIA) performed by the IE.

Table 1. Summary of Use Cases Addressed by the THEA CVPD[1,2]

Use Case	Condition	Description of Issues to Be Addressed	Applications
1	Morning Backup	As drivers approach the end of the Selmon Expressway Reversible Express Lanes (REL), they enter a curve where the speed limit reduces from 70 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 Avenue 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, 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 Streetcar runs along Channelside Drive from the Amalie Arena area, 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 Turing Right in Front of 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.	• EEBL • FCW • Intersection Movement Assist (IMA) • I-SIG

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

Table 2. 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
Electronic Emergency Brake Light	Deployed	NA	NA	NA	NA	Deployed
End of Ramp Deceleration Warning	Deployed	NA	NA	NA	NA	NA
Forward Collision Warning	Deployed	NA	NA	NA	NA	Deployed
Intersection Movement Assist	NA	NA	NA	NA	NA	Deployed
Pedestrian Crossing Warning	NA	NA	Deployed	NA	NA	NA
Vehicle Turning Right in Front of a Transit Vehicle	NA	NA	NA	NA	Deployed	NA
Wrong-Way Entry	NA	Deployed	NA	NA	NA	NA
Transit Signal Priority	NA	NA	NA	Planned but not deployed	NA	NA
Intelligent Traffic Signals	Planned but not deployed	NA	NA	NA	NA	Planned but not deployed

NA = not applicable.

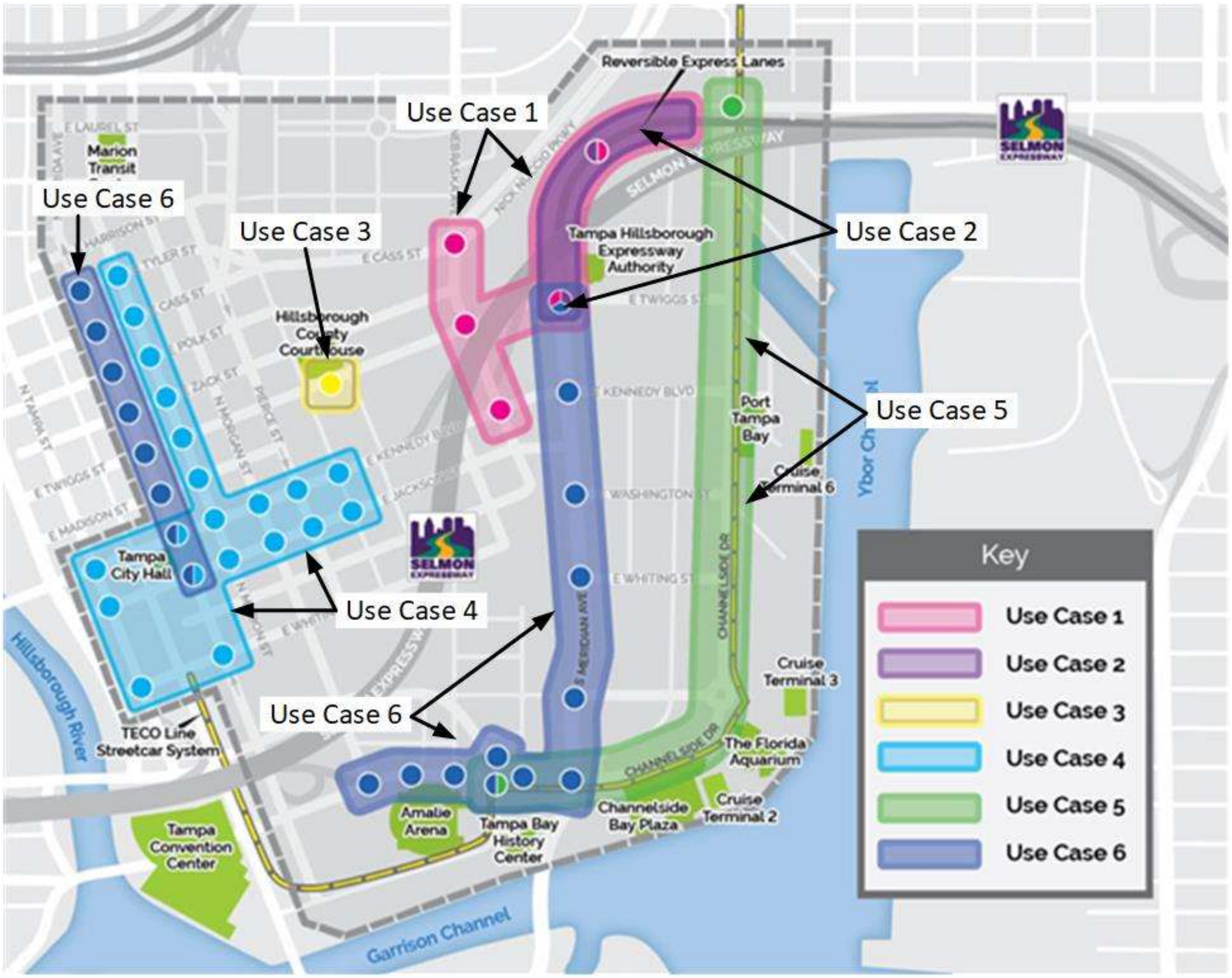
Source: Texas A&M Transportation Institute based on information contained in Reference 2

Chapter 2. THEA Tampa CV 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 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 Selmon Expressway 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 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.



Source: Center for Urban Transportation Research

Figure 2. Map. THEA CVPD Site(2)

The area encapsulated by the THEA CVPD experiences several different mobility and safety issues daily.(1) For example, in the morning commute, the endpoint of the REL toll lanes is 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 is deploying 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 Case 5).
- Traffic flow optimization and signal progression on Meridian Avenue, Nebraska Avenue, Channelside Drive, and Florida Avenue (Use Case 6).

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 2 shows the list of final applications deployed by the THEA CVPD Team in each of the Use Cases.(2) As part of the 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 Phase 2, System Design Document—Tampa (THEA)* document provides a detailed description of the planned CV applications.(4) 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)

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 basic safety messages (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 the driver of an impending rear-end collision with another vehicle ahead 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 advises the driver to take specific actions to avoid or mitigate rear-end vehicle collisions in the forward path of travel. THEA expected the FCW application, like the EEBL, 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 the IMA. If the 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 inform 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 roadside unit (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 from 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 dedicated short-range communication (DSRC). Any vehicle equipped with an onboard unit (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 will receive a warning of the approaching wrong-way driver. The TMC will broadcast 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 light detection and ranging (LiDAR) sensors installed at the crosswalk located pedestrians in the area, translated the information to pedestrian safety messages (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 the Phase 4 activities.[(2)]

V2I Mobility Applications

V2I mobility applications communicate operational data between vehicles and infrastructure. The 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, THEA intended the I-SIG application in Use Case 6 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 Multimodal Intelligent Traffic Signal System (MMITSS) application. 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 intended 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 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.(5) THEA plans to explore what would allow the signal controllers to communicate with I-SIG without relying on key input measures from MMITSS as part of the 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 Marion Street (Use Case 4), 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 that 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)

Deployed Equipment

Table 3 summarizes the number and type of devices that the THEA CVPD Team originally planned to deploy and those that were deployed.

Onboard Units

Certified technicians and student trainees at Hillsborough Community College installed the OBU on participant vehicles. Between March and December 2018, installation teams equipped 1,020 private vehicles with aftermarket OBUs.(2)

Table 3. Summary of Devices for Deployment

Device Category	Devices	Planned Number to Be Deployed	Actual Number Deployed
Infrastructure	RSUs at intersections	40	49
Infrastructure	LiDAR-equipped pedestrian detection systems	2	2*
Vehicle	Light vehicles equipped with OBUs	1,600	1,021
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.
** Deployed on a limited number of buses for test purposes only. Not permanently deployed.
** During the deployment, the 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

All vehicles equipped with OBUs recorded received and transmitted data from interaction with nearby vehicles and 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).

The THEA CVPD uploaded all the raw data into USDOT's Secure Data Commons (SDC).(7)

The applications were developed and deployed by aftermarket vendors using Society of Automotive Engineers International standards and application specifications.(6) Driver warning event records are created whenever one of the applications triggers a warning. The OBU creates a unique warning ID used to identify data from multiple warning event records belonging to the same warning event. The OBU creates a set of warning event records per warning. Each record of the set represents a point in time before, during, and after the warning triggered. A warning event record always contains the host vehicle's BSM at a given point in time within "hvBSM." Warnings that result from receiving a remote vehicle's basic safety message 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)

Roadside Units

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

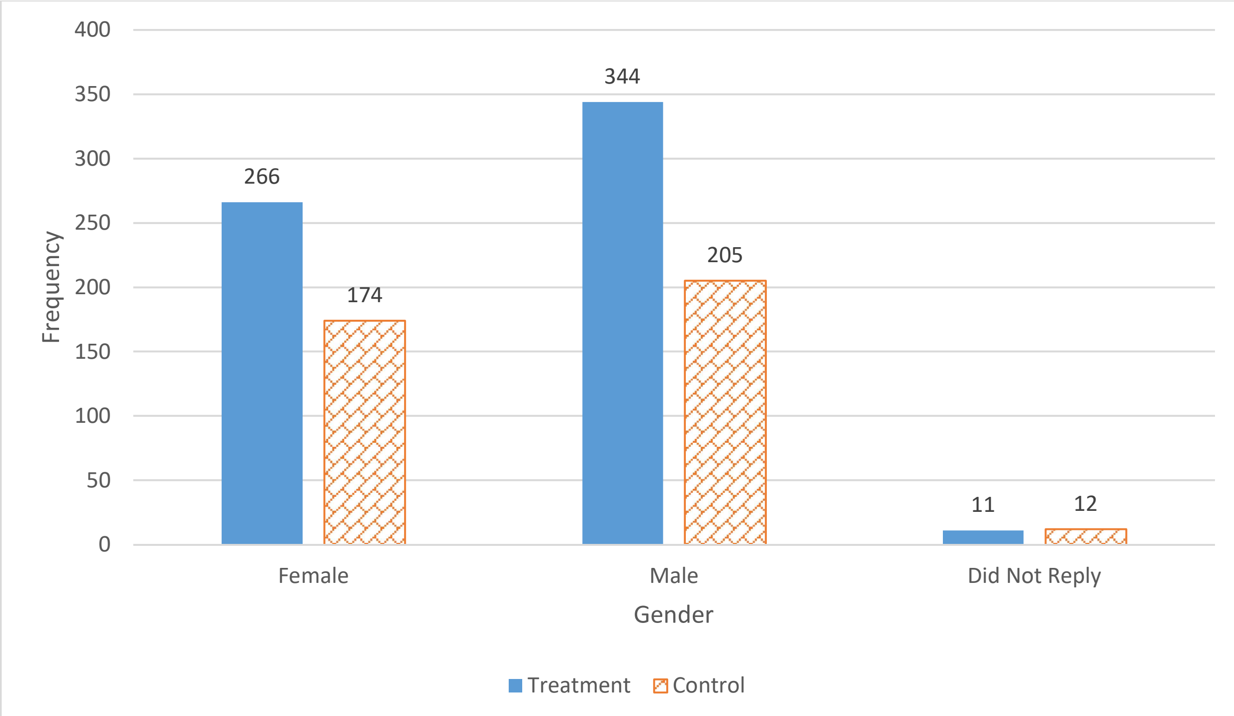
- BSMs from the participant and public transit vehicles (up to 10 Hz), also called “sniffed” BSMs or BSMs collected by a vehicle operating in range of an RSU.
- Signal Phase and Timing (SPaT) message from RSUs (10 Hz).
- Map Data Message from RSUs (1 Hz).
- Traveler Information Message from RSUs at 1 Hz.

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

Participants

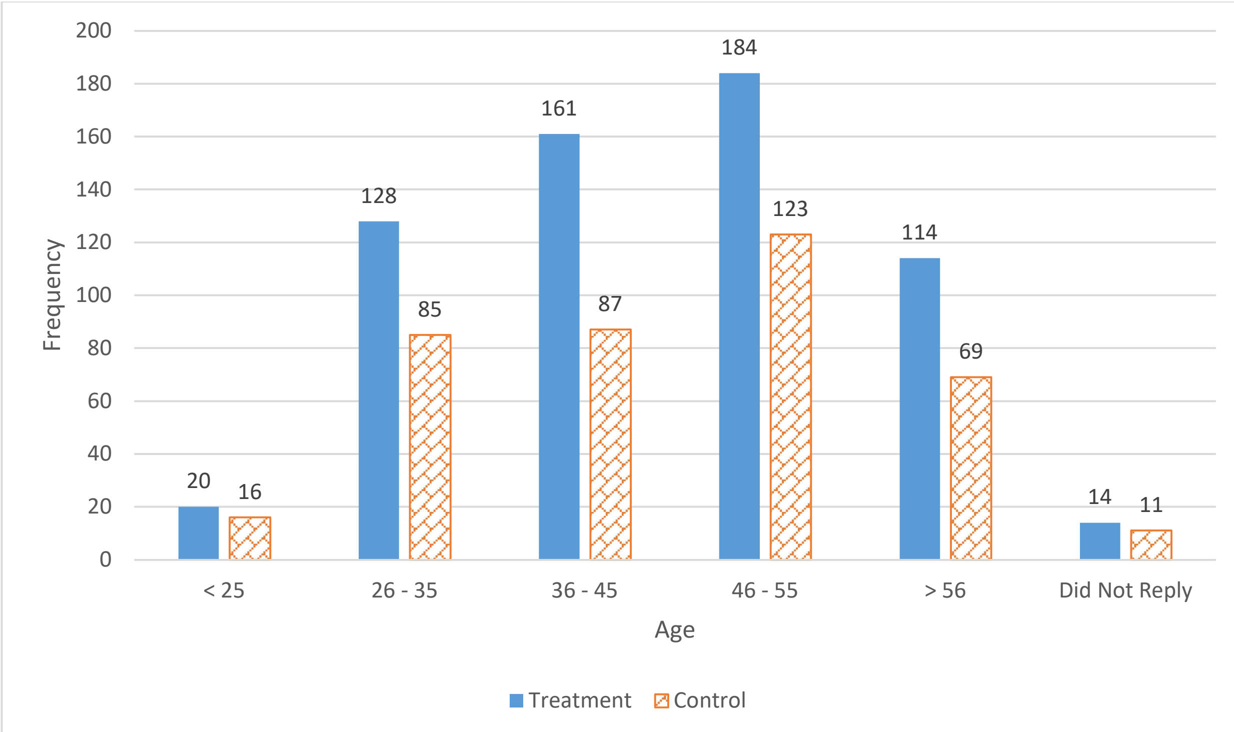
Participants in the CVPD study included drivers, pedestrians, and bus/streetcar drivers. Beginning in early 2018, the THEA CVPD Team recruited and trained the participants from the pool of existing THEA customers. As an incentive for participating in the project, THEA provided a discount on tolls.(2)

For evaluation purposes, the THEA CVPD Team assigned each participant to either a treatment or control group using a randomized two-to-one matching (two treatments to one control) stratified by gender, age, income, and education.(2) Figure 3 shows the distribution of the study participants by gender. Similarly, Figure 4 shows the age distribution of the participants in each study group (treatment and control). Figure 5 shows the highest level of education of the study participants, while Figure 6 shows the breakdown of the study participant group by income level. The THEA CVPD Team used Pearson’s and likelihood-ratio chi-square statistics to verify that the participants within the treatment and control groups agreed with the experimental plan. Reference 2 provides more information on the study participants.



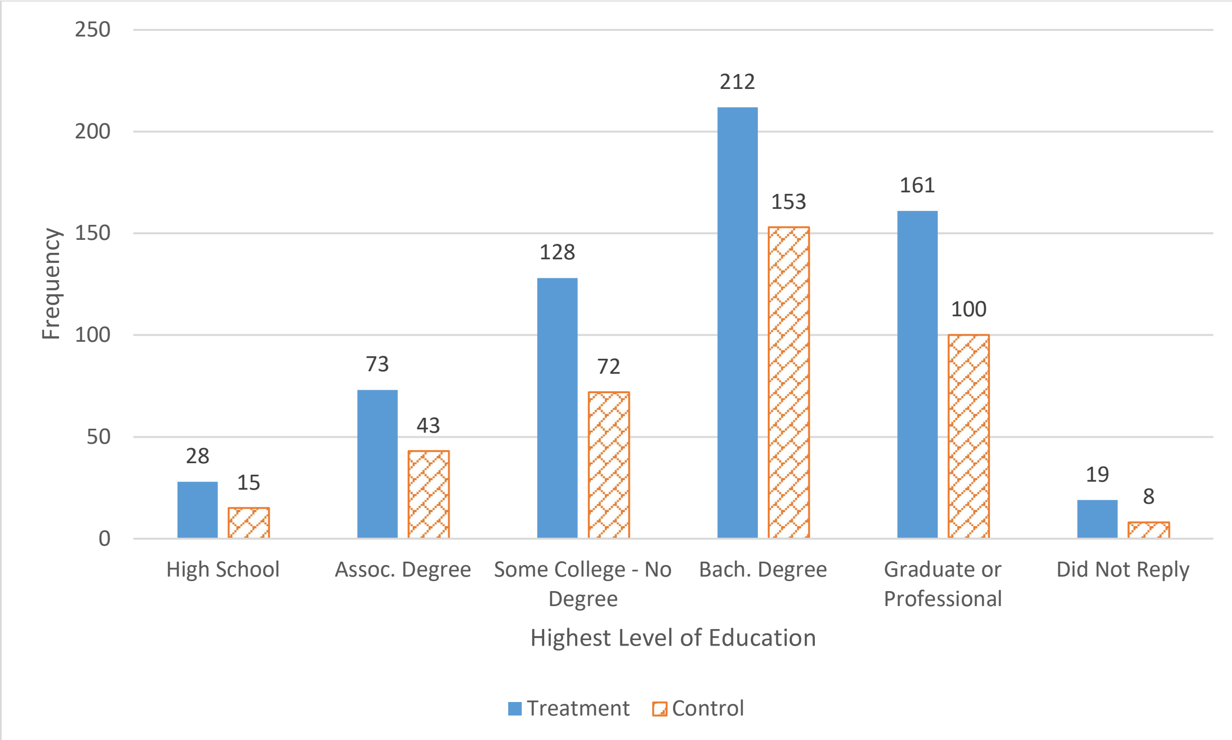
Source: Texas A&M Transportation Institute based on data contained in Reference 2

Figure 3. Bar Chart. Number of Participants Assigned by THEA to Treatment and Control Groups, Stratified by Gender



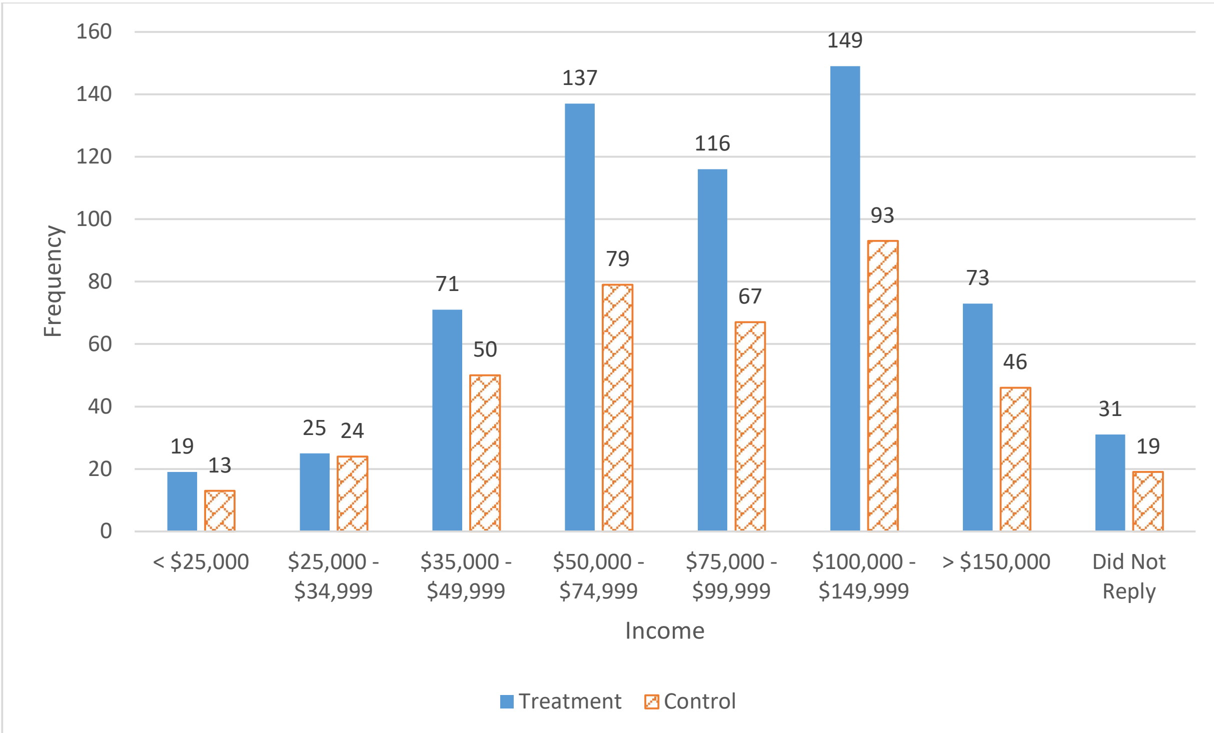
Source: Texas A&M Transportation Institute based on data contained in Reference 2

Figure 4. Bar Chart. Number of Participants Assigned by THEA to Treatment and Control Groups, Stratified by Age



Source: Texas A&M Transportation Institute based on data contained in Reference 2

Figure 5. Bar Chart. Number of Participants Assigned by THEA to Treatment and Control Groups, Stratified by Highest Level of Education



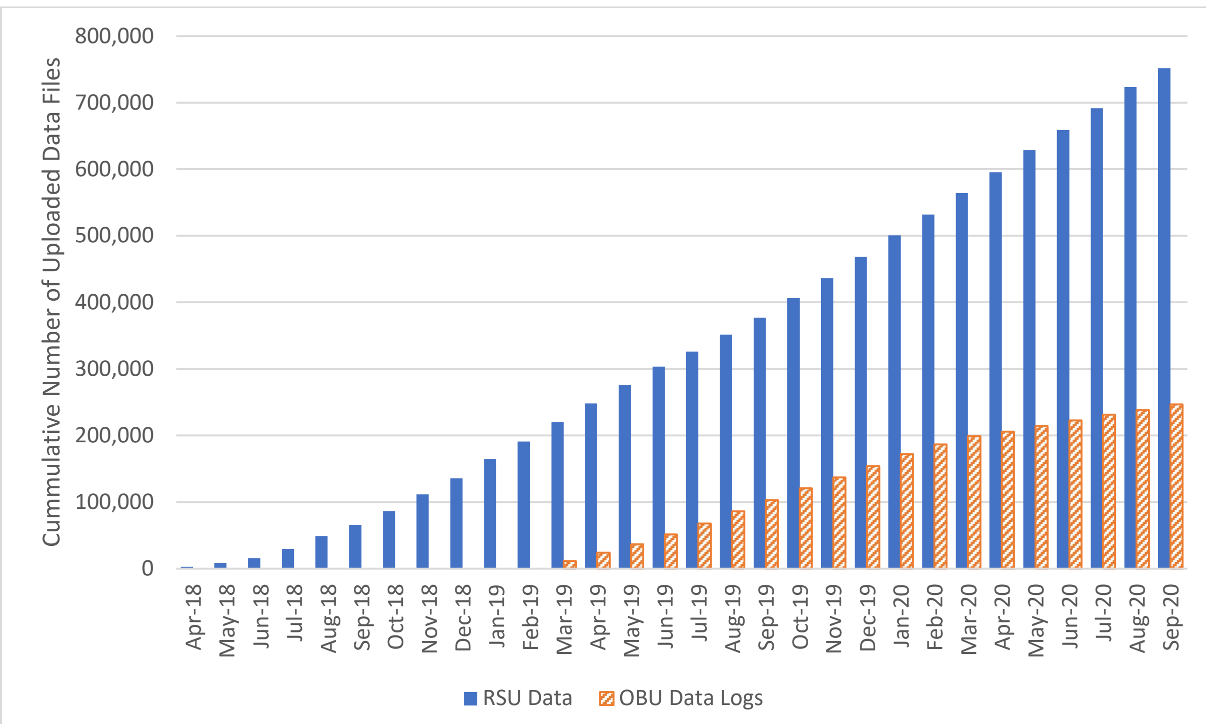
Source: Texas A&M Transportation Institute based on data contained in Reference 2

Figure 6. Bar Chart. Number of Participants Assigned by THEA to Treatment and Control Groups, Stratified by Income

Chapter 3. Evaluation Data Sources and Data Availability

Because of technical challenges associated with newly implemented devices and delays due to confounding factors, FHWA revised the scope of the independent evaluation to be based on published data provided by each CVPD site. For the THEA CVPD, the primary source of evaluation data was the *Tampa (THEA) CV Pilot Phase 3 Evaluation Report.*(2) This chapter summarizes the sources and availability of evaluation data as reported by the THEA CVPD Team.

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 SDC.(2) Figure 7 shows the volume of data files transferred to the SDC during the deployment. The OBU files began logging in March 2019 (at the beginning of the pre-deployment period), whereas the RSU data were available at the beginning of Phase 2 (August 2018).



Source: Texas A&M Transportation Institute based on data provided in Reference 2

Figure 7. Bar Chart. Volume of RSU and OBU Data Files Generated by the THEA CVPD

Data Generated by Each Use Case

THEA structured its analysis around its Use Cases. Each Use Case represented an operational issue or situation THEA was looking to improve using CV technology. Not all Use Cases are germane to TTI's MEP. The following summarizes the data used by the THEA CVPD Team to evaluate the applications associated with each Use Case.

Use Case 1: Morning Backups

The applications deployed in Use Case 1 focus on improving mobility and safety of participants using the REL during their morning commute, between 6:00 a.m. and 10:59 a.m. on weekdays. During the morning rush hour, the REL operates in the westbound direction from Brandon toward downtown Tampa. Travel times and travel time reliability data were computed using the first and last BSM as each vehicle traveled through the REL study area. Idle time was estimated by measuring the cumulative time vehicles spent traveling at a speed of less than 1 mph. Queue lengths were determined by dividing the REL into 49 consecutive polygons and determining the highest ordered congested segment over a 10-minute interval. THEA defined the segment as being congested if the estimated speed on the segment was less than or equal to 7 mph.[2]

For this Use Case, THEA defined the before period beginning February 4, 2019 (Monday), and ending January 31, 2020 (Friday). The after period began February 3, 2020 (Monday), and ended March 20, 2020 (Friday). On March 20, 2020, THEA set the REL to operate in the eastbound direction on a 24-hour basis (leaving downtown Tampa toward Brandon) in response to the COVID-19 pandemic. The dataset consists of 29.8 million RSU BSMs collected from 587 unique participant vehicles traveling through the study impact area (excluding national holidays when the REL operates eastbound on a 24-hour basis).

Use Case 2: Wrong-Way Entry

According to THEA's *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation Support Plan, Phase 2 Update—Tampa,*[8] the WWE application warns drivers entering the REL the wrong way. The REL is a three-lane bidirectional expressway that provides a direct connection between Brandon and downtown Tampa, allowing for express travel of people in cars and buses. The schedule for the REL permits travel into downtown Tampa (westbound) in the morning between 6:00 a.m. and 10:00 a.m., split operation midday between 10:00 a.m. and 1:00 p.m., and travel toward Brandon (eastbound) in the afternoon/evening between 3:00 p.m. and 6:00 a.m.

The WWE application has multiple warning levels that are all recorded with the same warning type (WWE) in the OBU data logs:[2]

- DOT NOT ENTER warning if determined that the vehicle is advancing to enter the REL going the wrong way.
- WRONG-WAY warning if determined that the same vehicle has continued up the REL the wrong way.
- NO TRAVEL LANE warning if the vehicle enters the outbound or inbound closed section of the REL.
- WRONG-WAY VEHICLE warning to the legal inbound driver after the wrong-way violation occurs. This feature produces a different warning titled "WRONG WAY DRIVER" and is not part of this assessment.

THEA's analysis refers to the first three types of WWE warnings.(2) These warnings are not identified separately in the warning data but are all recorded with a generic WWE warning type. To determine the first warning, or pre-warning, THEA uses OBU data to analyze trajectory, speed, and allowed movements of vehicles on the Selmon Expressway's morning and afternoon/evening REL operations. THEA's analysis of these applications used data collected from participant vehicles between March 1, 2019, and March 20, 2020. On March 20, 2020, THEA set the REL to operate in the eastbound direction on a 24-hour basis (leaving downtown Tampa toward Brandon) in response to the COVID-19 pandemic. THEA's evaluation focused on weekday travel and the following time periods: 6:00 a.m. to 10:00 a.m. (AM movements) and 3:00 p.m. to 12:00 a.m. (PM movements). THEA excluded the weekday time between 10:00 a.m. and 3:00 p.m. because of the REL's split operation during those hours. Finally, the dataset excludes national holidays since the REL operates eastbound on a 24-hour basis during those days.

Table 4 shows the total number of WWE warnings and unique WWE events identified by the THEA CVPD Team during the period of March 1, 2019, through March 20, 2020. Unique events are identified by grouping the WWE warnings issued by the host vehicle within 1 minute of each other. These warnings and events form the basis of THEA's evaluation of the impacts of the WWE warnings.(2)

Table 4. Number of Potential WWE Warnings and Events Analyzed by the THEA CVPD Team

REL Operation	Total WWE Warnings	Unique WWE Events
REL westbound AM (6:00 to 9:59 a.m.)	906	687
REL eastbound PM (3:00 to 11:59 p.m.)	5,070	4,137
Total	**5,976**	**4,824**

Source: Center for Urban Transportation Research(2)

Because the WWE application is primarily a safety evaluation, the THEA CVPD Team did not include analyzing the impact of this application on mobility.(2)

Use Case 3: Pedestrian Conflicts

THEA designed Use Case 3 to assess the benefits of deploying a PCW application to improve pedestrian safety at a midblock crosswalk on East Twiggs Street at the Hillsborough County Courthouse. THEA designed the application to warn drivers of the presence of pedestrians located within the crosswalk. The data used in the assessment of these applications were as follows:(2)

- Warning event data collected and stored in the OBU data logs.
- BSM data collected and stored in the OBU data logs.
- PSM data generated by the RSU using pedestrian identification algorithms.

The THEA CVPD Team used data collected for two periods to assess the effectiveness of the PCW application. The first analysis period ran from March 1, 2019, to August 5, 2019, where the system used data from LiDAR sensors to detect pedestrians in the crosswalk. In October 2019, THEA replaced the LiDAR sensors with thermal-imaging sensors. Because of issues associated with the sensor technology, THEA installed a new, thermal-based system, which became operational in October 2020. Because of the COVID-19 pandemic, THEA was unable to collect any pedestrian crossing working data from participant vehicles but instead used test vehicles to collect operational data between June 1, 2020, and August 31, 2020.(2)

Between March 1 and October 31, 2019, the PCW application issued only 27 warnings to participants. Of these, the THEA CVPD Team classified only four of them (14.8 percent) to be true positive alarms and the remaining balance (23 or 85.2 percent) as false alerts. However, using test vehicles, the THEA CVPD Team triggered 87 PCWs with the thermal sensors. The THEA CVPD Team judged 16 of these alerts (18.4 percent) to be true alerts and 63 of these alerts (72.4 percent) to be false alerts.(2)

Because the PCW application is primarily a safety evaluation, the THEA CVPD Team did not include analyzing the impact of this application on mobility.(2)

Use Case 4: Transit Signal Priority

The THEA CVPD Team initially expected TSP to be one of the applications to impact mobility and public agency efficiency in the deployment area. TSP is an application that provides preferential treatment to transit vehicles at signalized intersections. Past implementations have shown that TSP can not only reduce travel times in a corridor, but also help transit agencies maintain schedule reliability and reduce transit delays.

Originally, THEA planned to deploy the TSP application to service two express routes (24LX and 25LX) that use the Selmon Expressway to connect the east and west sides of the metropolitan areas via stops in the downtown area during the morning and evening peak.(2)

The TSP applications underwent significant changes during the Phase 3 implementation. As a result of these changes, the THEA CVPD Team was unable to collect any performance data to use for assessing improvements in on-time performance or improved travel reliability. THEA is currently conducting evaluations of this application as part of its Phase 4 activities.

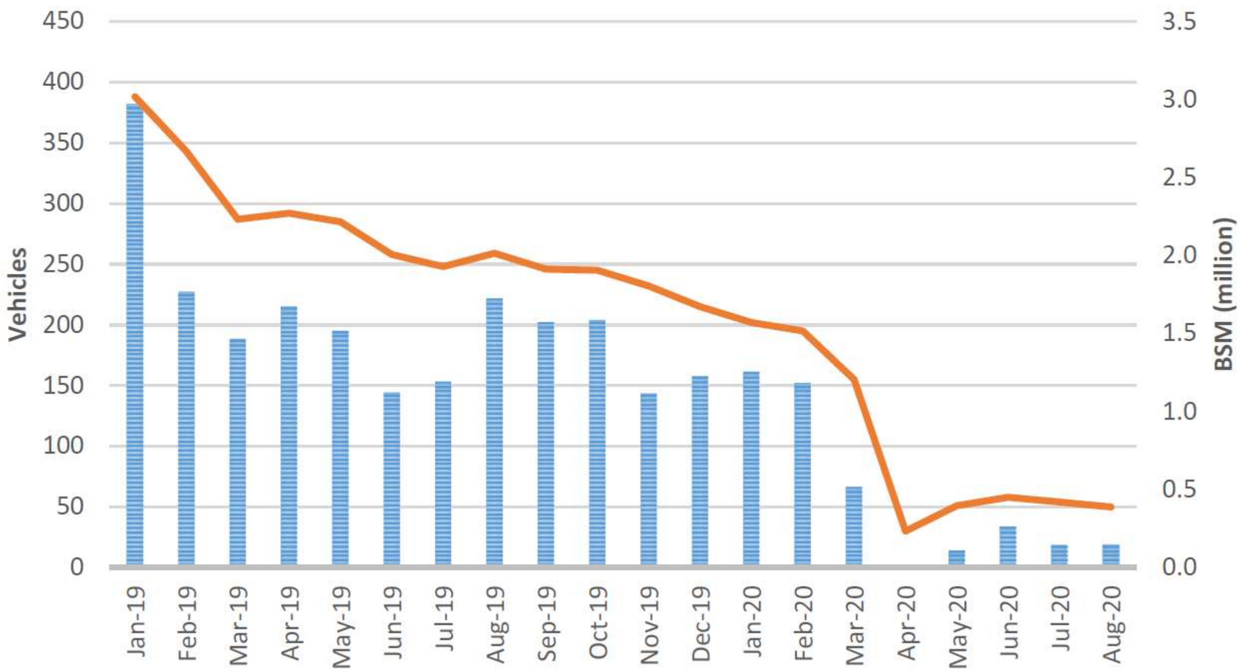
Use Case 5: Streetcar Conflicts

The VTRFTV application provides warnings to drivers of participant vehicles and streetcar operators of imminent collisions when the vehicle makes a right turn in front of the streetcar. During the evaluation period, 61 VTRFTV warnings were produced between 13 unique participant vehicles and seven unique streetcars. Of these 61 warnings, visual inspections classified 52 of these warnings (85.2 percent) as false alarms and nine (14.8 percent) as true warnings. Because VTRFTV can trigger multiple warnings per conflict if the warning conditions persist, only five of these true positives were deemed to be unique conflict events.(2)

Because VTRFTV is primarily a safety application, TTI did not include this application in its MEP evaluation.

Use Case 6: Traffic Progression

In Use Case 6, THEA planned to use the I-SIG mobility application as well as the IMA, FCW, and EEBL applications to reduce congestion and improve mobility along Meridian and Florida Avenues in the downtown deployment area. THEA planned to use travel time, travel time reliability, delay, and arrival on green as the primary measures of mobility. However, THEA was unable to complete the I-SIG deployment during the evaluation period; therefore, no post-deployment data were available for this Use Case. The pre-deployment dataset consists of travel time at the vehicle level computed by the first and last BSM for each vehicle traveling on Meridian Avenue during the morning and afternoon peak periods. The analysis uses data collected from participant vehicles between May 1, 2018, and August 31, 2020. This Use Case considers travel occurring on weekdays (Monday–Friday) between 6:00 a.m. and 9:59 a.m. for morning peak hours and between 3:00 p.m. and 6:59 p.m. for afternoon peak hours. During the period of February 2019 through August 2020, 22.6 million BSMs were collected from 719 unique participant vehicles.(2) Figure 8 shows the monthly distribution of vehicles and BSMs that produced the dataset.

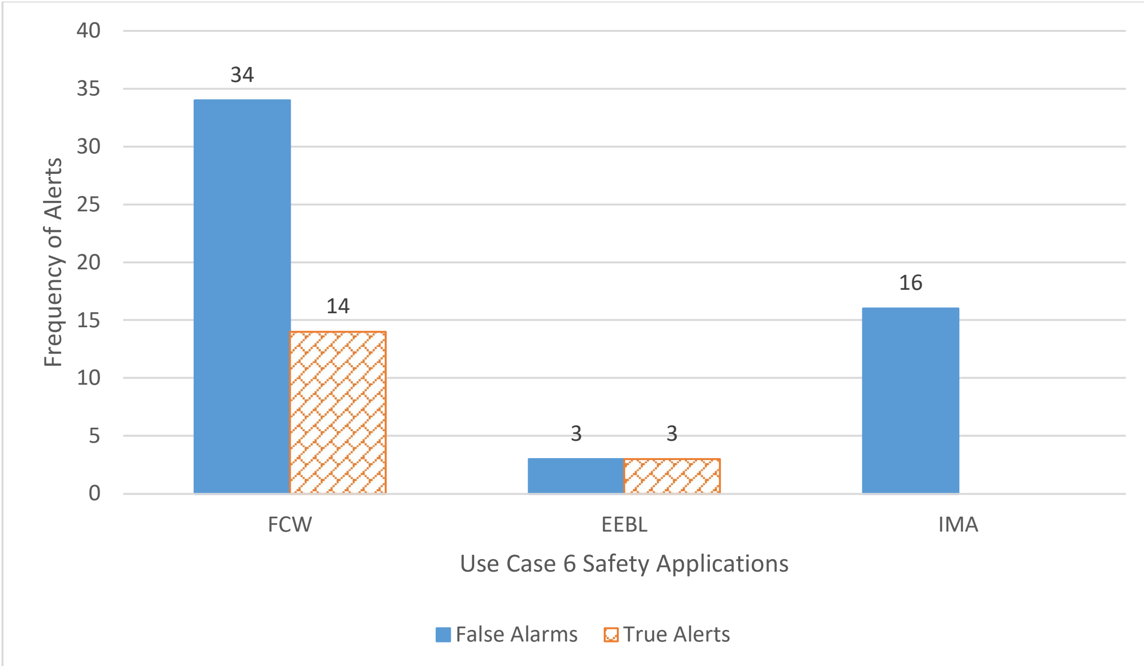


Source: Center for Urban Transportation Research(2)

Figure 8. Bar Chart. Dataset Used by CUTR in Mobility Evaluation for Use Case 6

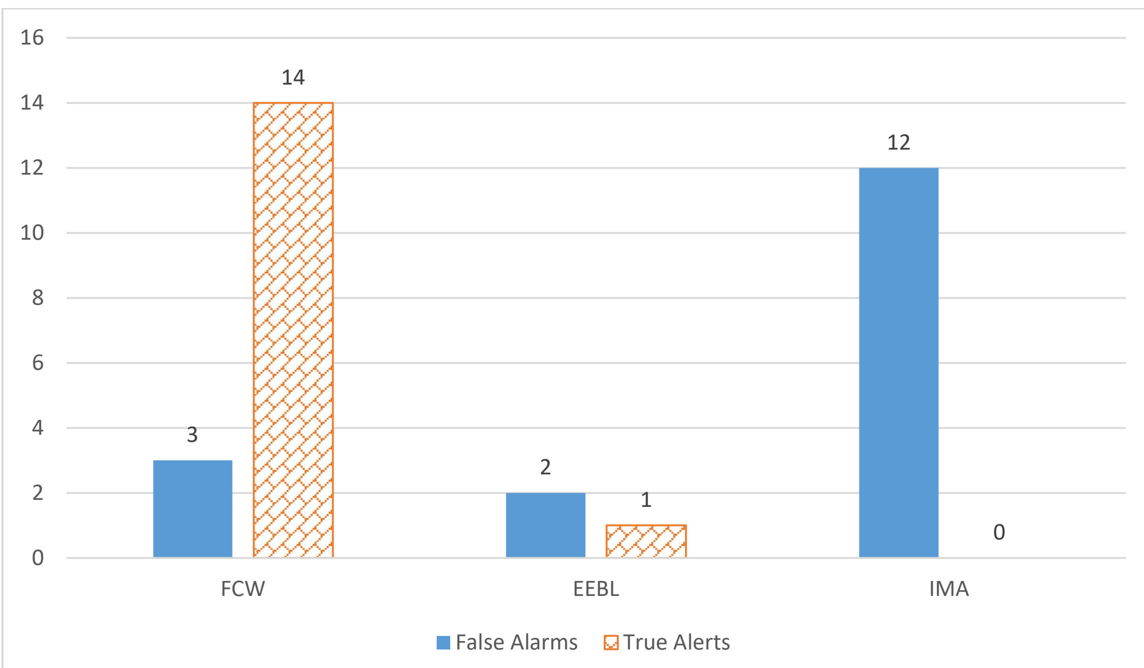
While the focus of Use Case 6 is on the deployment of the I-SIG application to improve traffic progression, inherent safety and mobility benefits are associated with the deployment of V2V safety applications.(2) Figure 9 and Figure 10 show the number of alerts (true alerts and false positives) produced by the FCW, EEBL, and IMA warnings issued to participants while driving on Meridian Avenue during the AM and PM peak period, respectively.[1] Although the three safety applications generated 26 warnings classified as true positive, only eight were shown to drivers due to the evaluation's experimental design.(2)

[1] The THEA CVPD Team only included data from Median Avenue in the dataset because participant vehicles did not generate V2V warnings while traveling on Florida Avenue.



Source: Texas A&M Transportation Institute based on data contained in Reference 2

Figure 9. Bar Chart. Frequency of FCW, EEBL, and IMA Alerts Generated during the AM Peak in Use Case 6



Source: Texas A&M Transportation Institute based on data contained in Reference 2

Figure 10. Bar Chart. Frequency of FCW, EEBL, and IMA Alerts Generated during the PM Peak in Use Case 6

Crash Experiences and History

While not used in this analysis, the THEA CVPD Team monitored the crash experience in the corridor. CUTR used the Signal Four Analytics portal to obtain both long- and short-form police-reported crashes. In Florida, law enforcement personnel must complete a long-form report when a motor vehicle crash meets one of the following criteria:(2)

- The crash results in the death of, personal injury to, or any indication of complaints of pain or discomfort by any of the parties or passengers involved.
- The crash involves a “leaving the scene of crash with an attended vehicle” or “driving under the influence” violation.
- The crash renders a vehicle inoperable to the degree that it requires a wrecker to remove it from the scene.
- The crash involves a commercial motor vehicle.

For crashes not satisfying the above conditions, law enforcement personnel may complete (but are not required to complete) a short-form report or may provide drivers with an exchange-of-information form. CUTR cites that short-form crashes are underreported since not all minor crashes require a law enforcement report.(2)

CUTR obtained crash reports for two periods:

- The pre-deployment period from February 2014 to February 2019 (5 years before the analysis period).
- The post-deployment period from March 2019 to August 2020.

Only crash reports from 6:00–9:59 a.m. and from 3:00–6:59 p.m. on Meridian Avenue on weekdays were included in the dataset.

Table 5 shows the number of reported crashes and calculated crashes per month. CUTR did not calculate traditional crashes per vehicle miles traveled (VMT) because VMT data for 2020 were not available at the time the analysis was performed.(2) Of the 40 reported crashes in the pre-deployment period, CUTR classified 37 as being potentially avoidable crashes using V2V applications. Of the 16 crashes occurring in the post-deployment period reported, CUTR classified 14 as potentially avoidable using CV technologies.

Table 5. Crash Rates Reported by CUTR for Use Case 6(2)

Period	Dates	No. of Months	No. of Avoidable Crashes	Crash Rate (Crashes per Month)
Pre-deployment	2/2014–2/2019	61	37	0.60
Post-deployment	3/2019–8/2020	18	14	0.78

Source: Center for Urban Transportation Research

It is unknown whether any of these crashes involved vehicles participating in the deployment.

The Volpe National Transportation Systems Center also assessed the safety impacts of four V2V and three V2I safety applications deployed as part the THEA CVPD.[9] Volpe's assessment used naturalistic driving data collected at the vehicle level from the deployed vehicles, with the driver display turned on or off during a limited time or throughout the deployment period. Volpe use a multiple-step process to analyze vehicle logs to evaluate the crash avoidance effectiveness of the applications. In the first step, Volpe determined the validity of the alerts in terms of their accurate applicability to the target driving conflict scenario. This step excluded invalid (false positive) events from the alert analysis. Volpe reviewed the remaining alerts to determine if they were issued during hazardous driving scenarios. Volpe then compared the responses of vehicles in silent mode to those operating in the active mode to those alerts issued under true hazard conditions. Alerts in silent mode were matched with alerts in active mode that had similar initial kinematic conditions (speed, time to collision, brake status, and acceleration of host and remote vehicles) at the time of alert onset. Finally, statistical analyses were performed to reveal any statistically significant differences in driver response that existed between the silent and active alerts triggered by the CVPD safety applications.

Volpe examined data from 806 passenger vehicles and 17 transit vehicles from March 31, 2019, to June 30, 2020.[9] Volpe found that 503 equipped vehicles (61 percent of the total deployment fleet) did not receive any alerts during the deployment. Volpe was unable to determine if these vehicles did not receive any alerts because they were part of the experimental control group (a group whose devices operated in a silent mode) or just did not meet the conditions that would trigger an alert because this information is not contained in the BSM. The remaining 320 equipped vehicles received 8,073 total alerts from the seven safety applications combined. Six percent of these alerts were V2V alerts (FCW, EEBL, IMA, and VTRFTV), while 94 percent of the alerts were from the V2I applications (PCW, ERDW, and WWE). Volpe reported that the WWE application alone produced 6,297 (78 percent) of all alert messages (both V2V and V2I).

In assessing the validity of the alerts for each application, Volpe found the following for the V2V applications:[9]

- Thirty-three percent of FCW events with corresponding BSM data were found to be valid alerts where the remote vehicle (RV) was in the path of the host vehicle (HV).
- Ninety-four percent of the EEBL alerts were determined to be valid events with the RV ahead of the HV in the same or adjacent lanes.
- Twenty-one percent of the IMA alerts were determined to be valid events with the RV approaching the same intersection as the HV with an intersecting path.
- Twenty percent of VTRFTV alert events were determined to be valid events with the HV and RV on intersecting paths.

For the V2I applications, Volpe found the following:[9]

- Five PCW alert events, or 56 percent of all PCW alerts, were determined to be valid events with pedestrians crossing or about to cross the equipped crosswalk.
- About half of the ERDW alert events were considered valid, where the HV was traveling above the advisory speed on the exit ramp of the REL.
- WWE alert validity was assessed using four programmatic filters that examined HV location, heading, and movement during a WWE alert event, as well as manual examination of alerts that were still

deemed potentially valid after the filtering steps. The programmatic filters removed 94 percent of the WWE alerts that had available BSM data, leaving 359 alerts to be examined manually.

Table 6 and Table 7 show the number and percentage of valid alerts of the V2V and V2I applications, respectively.

Table 6. Number and Percentage of Valid Alerts by V2V Applications[(9)]

V2V Applications	Total Number of Alerts	Valid Alerts	Valid Alerts (%)	Invalid Alerts (%)
FCW	259	85	33	67
EEBL	16	15	94	6
IMA	133	28	21	79
VTRFTV	45	9	20	80
Total	**453**	**137**	**30**	**70**

Source: Volpe National Transportation Systems Center

Table 7. Number and Percentage of Valid Alerts by V2I Applications[(9)]

V2V Applications	Total Number of Alerts	Valid Alerts	Valid Alerts (%)	Invalid Alerts (%)
PCW	9	5	56	44
ERDW	1,232	628	51	49
WWE	5,614	359	6	94
Total	**6,855**	**992**	**14**	**86**

Source: Volpe National Transportation Systems Center

Volpe then went through a process to determine if the alert occurred during a hazardous vehicle scenario.[(9)] For the V2V applications, this process involved examining the vehicle logs associated with each event to determine if an alert occurred in a condition where the participant would have potentially benefited from the alert. Table 8 and Table 9 show the number and percentage of alerts issued during hazardous conditions potentially benefiting drivers for each V2V and V2I applications, respectively.

Table 8. Number and Percentage of Valid Hazards Associated with V2V Applications[(9)]

V2I Applications	Number of Valid Alerts	Number of Valid Hazards	Valid Hazards (%)	Invalid Hazards (%)
FCW	85	78	92	8
EEBL	15	13	87	13
IMA	28	28	100	0
VTRFTV	9	9	100	0
Total	**137**	**128**	**93**	**7**

Source: Volpe National Transportation Systems Center

Table 9. Number and Percentage of Valid Hazards Associated with V2I Applications[9]

V2I Applications	Number of Valid Alerts	Number of Valid Hazards	Valid Hazards (%)	Invalid Hazards (%)
PCW	5	1	20	80
ERDW	628	584	93	7
WWE	359	0	0	100
Total	**992**	**585**	**59**	**41**

Source: Volpe National Transportation Systems Center

Based on this analysis, Volpe found the following:[9]

- Seventy-eight FCW alerts, or 92 percent of the valid FCW alerts, were found to be useful FCW alerts received during a hazardous driving scenario.
- Thirteen EEBL alerts, or 87 percent of the valid EEBL alerts, were deemed to be useful alerts triggered in potentially hazardous driving scenarios.
- Twenty-eight valid IMA alerts were considered useful alerts triggered in potentially hazardous driving scenarios.
- The nine VTRFTV alert events that were considered valid were examined and assessed differently for participant light vehicles and trolleys.
- Only one of the five valid PCW alerts were deemed potentially hazardous with the pedestrian crossing the sidewalk as the HV accelerated toward the crosswalk.
- All 628 of these valid alerts were deemed to be useful alerts in a potentially hazardous driving scenario. ERDW alerts were often received consecutively by the same drivers as they traveled along the exit ramp. Thus, Volpe did not analyze these successive alerts separately. Considering consecutive ERDW alerts as one and removing events without human-machine interface information, Volpe retained 584 unique ERDW alerts as valid and useful alerts.
- GPS inaccuracies during vehicle maneuvers at the WWE intersection caused the likelihood of a WWE alert to increase substantially; 288 WWE alert events had HV GPS offsets when entering the REL outbound, and 56 WWE alert events had heading inaccuracies.

Volpe then separated the alerts based on whether the vehicles were operating in the silent or active mode.[9] Alerts in the silent mode were matched to alerts in the active mode based on the initial kinematic conditions (speed, time to collision, brake status, and acceleration of HVs and RVs) at the onset of the alert. Volpe then planned to estimate the crash avoidance effectiveness (EA) for each of the safety application if a statistical analysis showed a significant difference in some measures of HV driver response operating in the active mode compared to the silent mode.[9] The EA is estimated from vehicle/application performance data collected during the CVPD using Equation 1.

$$E_A = 1 - Driving\ Conflict\ Exposure\ Ratio\ \times\ Crash\ Prevention\ Ratio\ (1)$$

The driving conflict exposure ratio measures the ability of a safety application to reduce the encounter rate of HVs to driving conflicts when receiving active alerts, in comparison to HVs without active alerts (i.e., silent alerts).[10] The crash prevention ratio measures the ability of a safety application to reduce the likelihood of a crash when HVs in active alert mode encounter a driving conflict, in comparison to HVs in silent alert mode. Equation 1 can be expressed as Equation 2 to account for the silent alert mode (i.e., without application assistance) and active alert condition (i.e., with application assistance).

$$E_A = 1 - \frac{EM_{with}}{EM_{with}} \times \frac{CP_{with}}{CP_{without}} \quad (2)$$

Where:

EM_{with} = Exposure measures to a driving conflict corresponding to a target scenario for vehicles in the active alert mode.
$EM_{without}$ = Exposure measures to a driving conflict corresponding to a target scenario for vehicles in the silent alert mode.
CP_{with} = Crash probability when exposed to a driving conflict corresponding to a target scenario for vehicles in the active alert mode.
$CP_{without}$ = Crash probability when exposed to a driving conflict corresponding to a target scenario for vehicles in the silent alert mode.

Only the FCW and ERDW applications had enough matched events to allow a statistical comparison of driver responses.(9) Unfortunately, Volpe was unable to estimate the crash avoidance effectiveness of the EEBL, IMA, VTRFTV, PCW, and WWE due to insufficient valid alerts in the silent and active alert groups.

For the events involving an FCW, Volpe examined numerous driver response performance indicators, including brake response time, mean deceleration, peak deceleration, brake onset time to collision, and brake onset time headway. Volpe was unable to confirm any statistical difference in any of these measures between the matched silent and active alerts. Because no statistical difference existed between any of the driver response parameters, the crash prevention ratio becomes one, indicating that the application had no effect on driver conflict resolution.(9)

For the ERDW application, Volpe identified 232 silent and 352 active ERDW alerts.(9) The active and silent alerts were matched based on initial kinematic conditions. After comparing the matched silent and active alerts, Volpe was unable to determine any statistically different in driver responses at alert onset. Because there was no statistical difference in driver responses, the crash prevention ratio is one, implying that the application had no impact on driving conflict resolution.(9)

Confounding Factors

Several confounding factors influenced the type and quality of data available to the IE. These confounding factors ranged from traditional confounding factors that impact long-term evaluations (e.g., weather, special events, political, economic, etc.) to unique worldwide events (e.g., the COVID-19 pandemic). The following sections highlight factors reported by the THEA CVPD Team as potentially impacting the evaluation data. Two of the most notable factors are the attrition rate of the participants and the COVID-19 pandemic.

Traditional Confounding Factors

The THEA CVPD Team lists weather and special events as being two factors that have the potential to confound the performance data in the study area.(2) Because Tampa lies in a subtropical range, rain is the primary weather event that can impact traffic behavior and performance, with midafternoon showers and thunderstorms occurring daily during the summer months. These rain events may last anywhere from a few moments to several hours or even for an entire day. During the summer, average monthly rainfall increases to about 7.5 inches from the winter average of 2.5 inches. Localized weather conditions can have spatially heterogeneous effects on travel behavior.[2]

To control for weather-related factors at the aggregate level, THEA included a daily weather log recording temperature, observed precipitation, and other weather-related occurrences. Weather data were provided by a third-party weather information service provider. Weather data were collected at 10-minute intervals describing humidity, visibility, and other conditions.[2]

The THEA CVPD Team also identified special events as another traditional factor that could confound the study results. Downtown Tampa includes several events that have the potential to attract residents and visitors to the study area. Examples of potential special events include sporting events in the Amalie Arena, downtown festivals at Curtis Hixon Waterfront Park, cruise ship activity in the Ybor Channel, etc. The research team collected from the City of Tampa TMC information about road closures and events that were regularly scheduled inside the CBD.[2]

While the Tampa CVPD Team may have collected information about these events, it is unclear from the evaluation report how these data were used in the analysis process.

Participant Participation and Attrition

THEA began installing the OBU beginning in March 2018. Figure 11 shows the number of installations per month over the course of the installation window (March 2018 to February 2019).

Over time, some participants dropped out for assorted reasons, including trading in their vehicles, changing their commute patterns (creating incompatibility with the participation incentive scheme), and relocating out of state.[2] Some applications (e.g., ERDW) did not achieve full operational maturity until extremely late in the evaluation period.[2] Limited alert notifications and high false alarm rates may have also contributed to some participants leaving the study before the end of the evaluation period.

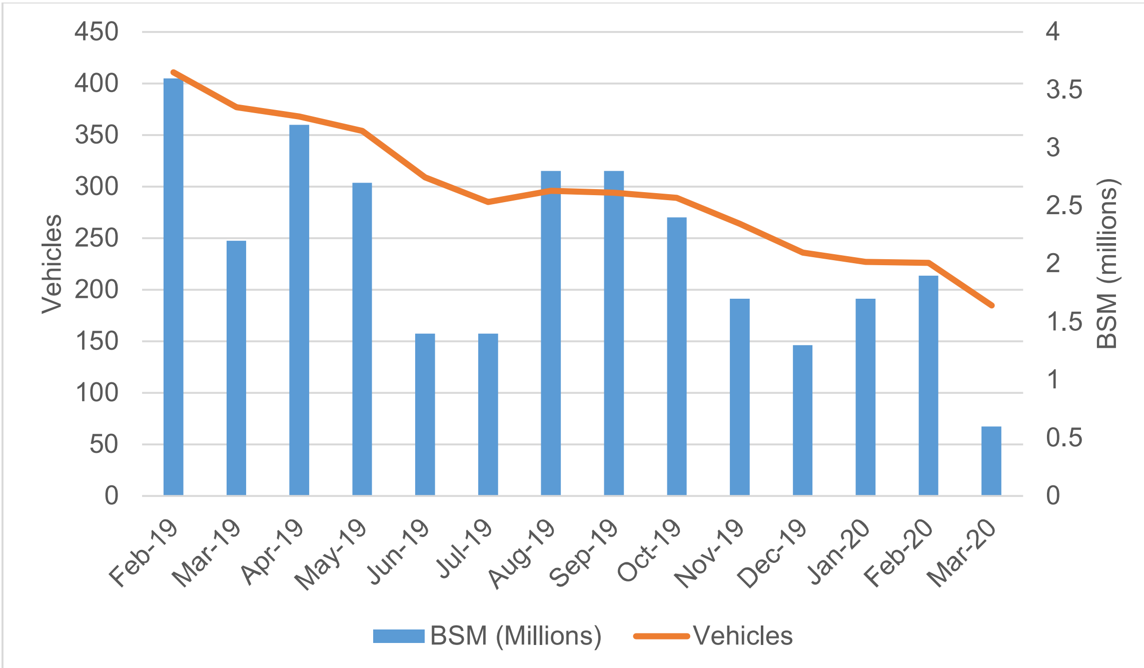
At the beginning of the pre-deployment evaluation period (February 2019), the THEA CVPD Team reported 909 active participants. At the end of the post-deployment evaluation period (March 2020), the number of active participants had declined to 699. As of September 30, 2020, there were 651 active participants.[2]

Source: Center for Urban Transportation Research[8]

Figure 11. Bar Chart. Number of OBU Installed during the Lifetime of the THEA CVPD

To encourage participation in the study, THEA offered a discount on tolls to the initial participants. The results of the participant survey showed that a sizeable share of the study participants selected to enroll due to the toll discount.[2] However, as the toll incentive program approached its end, the number of participants dropping from the study also increased. While the Performance Measurement and Evaluation Support Plan (PMESP) called for a participant refreshment strategy, the THEA CVPD funding constraints limited the replacement of the participant pool.[2]

Figure 12 shows the monthly distribution of the data sample over the deployment evaluation periods.[2] The figure shows a downward trend in both the total number of vehicles reporting each month as well as the reported number of BSMs logged by the Tampa systems. The figure shows a 45 percent reduction in the total number of vehicles detected and a 47 percent reduction in the number of reported BSMs from the beginning of the evaluation period through February 2020.



Source: Center for Urban Transportation Research[2]

Figure 12. Bar Chart. Mobility Evaluation Analysis Dataset for the THEA CVPD

COVID-19 Pandemic

Finally, the COVID-19 pandemic had a significant impact on the availability of performance assessment data. Originally, the Tampa "after" evaluation period was planned to run from June 1, 2019, through May 31, 2020; however, delays in getting the applications operational delayed the actual beginning of the post-deployment periods to February 3, 2020.

On March 1, 2020, Florida officially reported its first two COVID-19 cases, one in Manatee County and the other in Hillsborough County. In response, Governor Ron DeSantis declared a public health emergency, and on April 1, 2020, Governor DeSantis issued a statewide stay-at-home order. Furthermore, on March 20, 2020, THEA set the operational direction of the REL to eastbound on a 24-hour basis (leaving downtown Tampa toward Brandon) in response to the growing COVID-19 pandemic. Demand for the REL declined substantially (as shown by the sharp drop in the number of observed vehicles and BSMs recorded for March 2020 in Figure 12). As a result, one should consider any post-deployment evaluation data after March 20, 2020 (Friday), confounded by impacts of COVID-19.

Table 10 further illustrates the limitations of the dataset used in the post-deployment analysis period. With the post-deployment period ending on March 20, the post-deployment evaluation period included a total of 29 weekday AM periods (excluding President's Day on February 17, 2020, and the Tampa Hillsborough County School's spring break from March 16 through March 20, 2020). This table shows that, on average, between 12 and 19 vehicles per day provided data used in the Use Case 1 mobility analysis. It is unknown how many of these vehicles were operating in the silent group (not receiving alerts) versus operating in the treatment group (receiving alerts).

Table 10. Number of Observations in Tampa's Post-deployment Period

Factor	February 2020	March 2020	Total
Total number of reported vehicles per month	226	185	411
Number of workdays per month	19	10	29
Average number of vehicles per day	11.9	18.5	14.2

Source: Texas A&M Transportation Institute

Table 11 shows the number of days in both the "before" and "after" evaluation periods. The total number of minutes CVs spent idling per day can then be computed by multiplying the average idle time per CV (the value reported by the Tampa CVPD Team in its evaluation) by the average number of CVs observed during the evaluation period. 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 11. Number of Days in Each Tampa CVPD Evaluation Period

Factor	Before	After
Evaluation period	Feb. 4, 2019, to Jan. 31, 2020	Feb. 3, 2020, to March 20, 2020
Number of workdays (Monday–Friday)	270	35
Number of Federal holidays*	11	1
Total number of days in evaluation period	259	34

* See Appendix A for 2019 and 2020 Federal holiday dates.

Source: Texas A&M Transportation Institute

Chapter 4. Evaluation Performance Measures

Table 12 shows the performance measures the THEA CVPD Team used in assessing the impact of its deployment on mobility, safety, environment, and public agency efficiency. THEA tied its planned performance measures directly to target values identified in the Phase 2 concept of operations.(1) However, the THEA CVPD Team did not use all performance measures because of issues associated with their deployment.(2) According to the *Tampa (THEA) CV Pilot Phase 3 Evaluation Report*, not all the planned mobility data were available for use in the evaluation for the following reasons:(2)

- The MMITSS application did not successfully produce vehicle delay measures.
- Percent arrival on green was not collected during the pre-deployment period.
- The TSP application was not successfully deployed during Phase 3.
- Equipped buses were not always running on the selected routes where TSP would have been deployed.

Mobility

The following sections describe how the THEA CVPD Team generated the performance measures used to assess the impact of the deployment on mobility.

Tampa's Use Case 6 Traffic Progression focused on improving traffic congestion and delays during morning peak-hour periods on Meridian Avenue. Because of issues associate with deploying the I-SIG application in Use Case 6, the THEA CVPD Evaluation Team used data collected from participant vehicles traveling on Florida Avenue between May 1, 2018, and August 31, 2020,(2) to provide pre-deployment data for a future evaluation of the I-SIG application (in Phase 4). TTI did not include this Use Case as part of the mobility analysis.

Table 12. Availability of Mobility-Related Performance Measures Used to Evaluate Use Case Applications in the Tampa CVPD

Performance Measures	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
Travel time	Available	Not Available	Not Available	Not Available	Not Available	Available
Travel time reliability	Available	Not Available	Not Available	Not Available	Not Available	Available
Queue length	Available	Not Available	Not Available	Not Available	Not Available	Not Available
Vehicle delay	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
Percent arrival on green	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
Bus travel time	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
Bus route travel-time reliability	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
Percent arrival on schedule	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
Excess time spent in idle	Available	Not Available	Not Available	Not Available	Not Available	Not Available

Source: Center for Urban Transportation Research[(2)]

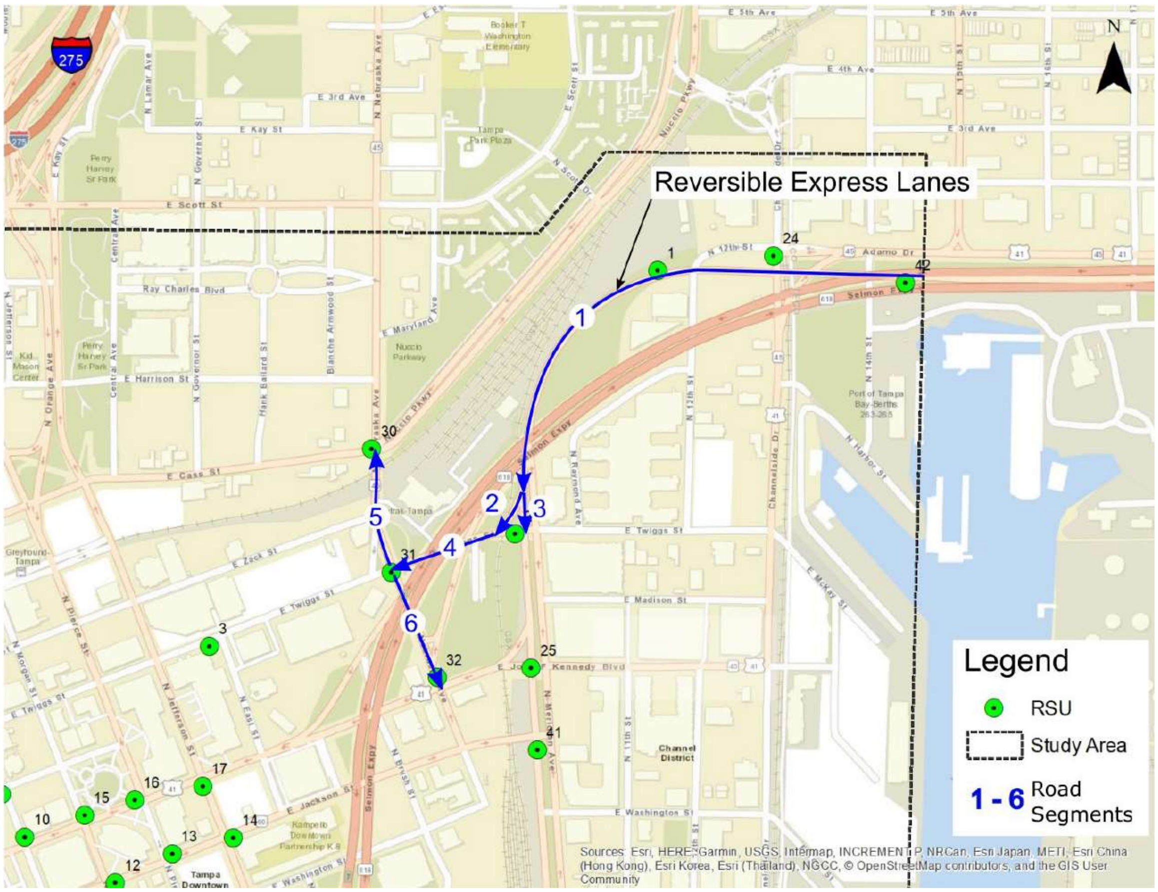
Travel Time and Travel Time Reliability

The THEA CVPD Evaluation Team used the BSMs collected from the RSUs to compute travel time and travel time reliability mobility measures. For Use Case 1, the THEA CVPD Evaluation Team computed travel times based on BSMs for equipped vehicle traveling over the following segments:[(2)]

- Segment 1: REL (beginning of the study area) to the beginning of the REL right-turn lane at East Twiggs Street/Meridian Avenue.
- Segment 2: Beginning of the REL right-turn lane (end of Segment 1) to the end of the right-turn lane.
- Segment 3: Beginning of the REL right-turn lane (end of Segment 1) to the center of the intersection of East Twiggs Street/Meridian Avenue.
- Segment 4: End of the right-turn lane (end of Segment 2) to the center of the intersection of East Twiggs Street/Nebraska Avenue.
- Segment 5: Center of the intersection of East Twiggs Street/Meridian Avenue (end of Segment 4) to the center of the intersection of Nebraska Avenue/Cass Street.

- Segment 6: Center of the intersection of East Twiggs Street/Meridian Avenue (end of Segment 4) to the center of the intersection of Nebraska Avenue/Kennedy Boulevard.

The THEA CVPD Team provided travel times only for vehicles traveling in the westbound direction during the morning period (when the REL was in operation). Figure 13 shows the origin-destination pair that the THEA CVPD Team used to generate vehicle travel times. The reported travel times are for Segment 1 only. From these measures, the THEA CVPD Team aggregated travel time measures in 5-minute intervals and then computed the average travel time and 95th percentile travel time for each 5-minute interval.

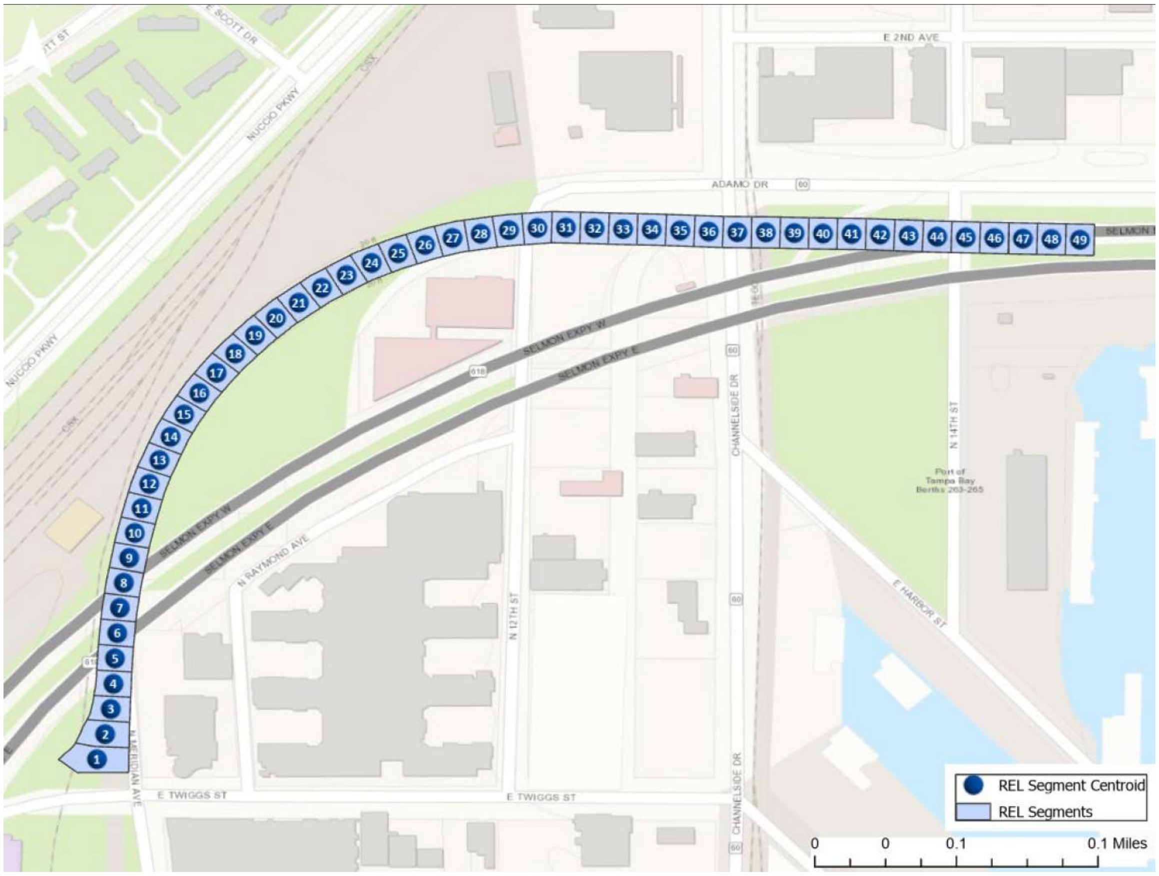


Source: Center of Urban Transportation Research[8]

Figure 13. Map. Travel Time Segments for Use Case 1

Queue Length

The THEA CVPD Team also includes queue length on the REL as a measure of mobility. To measure queue length, the THEA CVPD Team divided the REL into 49 polygons having centroids equally spaced at 16 m, with Segment 1 being the closest to the East Twiggs Street/Meridian Avenue intersection and Segment 49 being the closest to the REL posted 40-mph sign (see Figure 14). The THEA Team then computed mean speed using polynomial local smoothing regression. If the estimated speed was less than or equal to 7 mph, the THEA CVPD Team defined the polygon as congested. THEA then determined the highest ordered segment classified as congested over a 10-minute interval. THEA then computed the queue length by multiplying the segment number by 16 m. THEA estimated the queue length for the morning peak hours (7:00 a.m.–9:00 a.m.) only.[2]



Source: Center of Urban Transportation Research[2]

Figure 14. Map. Segmentation of the REL for Measuring Queue Lengths in Use Case 1

Idle Time

Using the vehicle speed reported in the BSM data, the THEA CVPD Team also estimated the amount of time vehicles spent idling in congestion on the REL. For this analysis, the Tampa CVPD Team defined idle time as the amount of time that an equipped vehicle spent traveling at a speed of less than 1 mph. Idle time was reported for equipped vehicles located on the REL only and does not include the idle time of non-equipped vehicles. CUTR reported idle times for both the pre- and post-deployment periods.

Participant Surveys

In addition to direct measures of mobility, TTI proposed examining participant survey data to determine if drivers' perceptions of congestion and mobility improved as a result of the deployment. The THEA CVPD Team administered a series of surveys to collect driver perception and user satisfaction data associated with the deployment. The THEA CVPD Team first surveyed users at their initial installation appointment. At this initial survey, the THEA CVPD Team collected information on participants' travel preferences in the study area, their level of knowledge about CV technologies, and their reasons/motivations for participating in the pilot deployment.

The THEA CVPD Team administered two separate surveys during the post-deployment periods. These surveys focused on participants' experiences with the applications (i.e., how the applications impacted travel decisions) and, for those receiving alerts and warnings through the human-machine interface, their perceptions and responses to the warning.

Chapter 6 summarizes how participant attitudes and perceptions changed as a result of the deployment.

Chapter 5. Mobility Impacts

This chapter describes TTI's assessment of the mobility impacts associated with the THEA CVPD. This assessment is based on the observed data provided by the THEA CVPD Team. TTI's assessment was limited to building upon the results provided by THEA's assessment and does not include a detailed assessment of raw performance data collected by the THEA CVPD Team.

Table 13 summarizes the mobility benefits associated with each Use Case as reported by the THEA CVPD Team in the *Tampa (THEA) CV Pilot Phase 3 Evaluation Report*.(2) The THEA CVPD Team only reported direct mobility benefits associated with the ERDW application in Use Case 1: Morning Backup for inbound traffic traveling on the REL during the morning hours of operation. THEA was only able to get the ERDW application fully operational during Phase 3 of the deployment. While some of the safety applications like EEBL, FCE, and IMA may have provided secondary mobility benefits through the reduction of certain types of collisions, neither the THEA CVPD Team nor the Volpe Safety Analysis Team reported that there was sufficient evidence to support that these applications reduced crash frequencies or severities.(2,9)

Direct Impacts on Mobility

The THEA CVPD Team based its MIA on the reported mobility benefits from the applications deployed as part of Use Case 1: Morning Backups. The THEA CVPD Team used the following performance measures in the analyses:(2)

- Travel time (average travel time at 5-minute intervals).
- Travel time reliability (95th percentile travel times).
- Idle time (time spent traveling at speeds less than 1 mph).
- Queue length (maximum queue length in meters hourly).

Table 13. Summary of Mobility Benefits Reported for Each Use Case for the Tampa CVPD

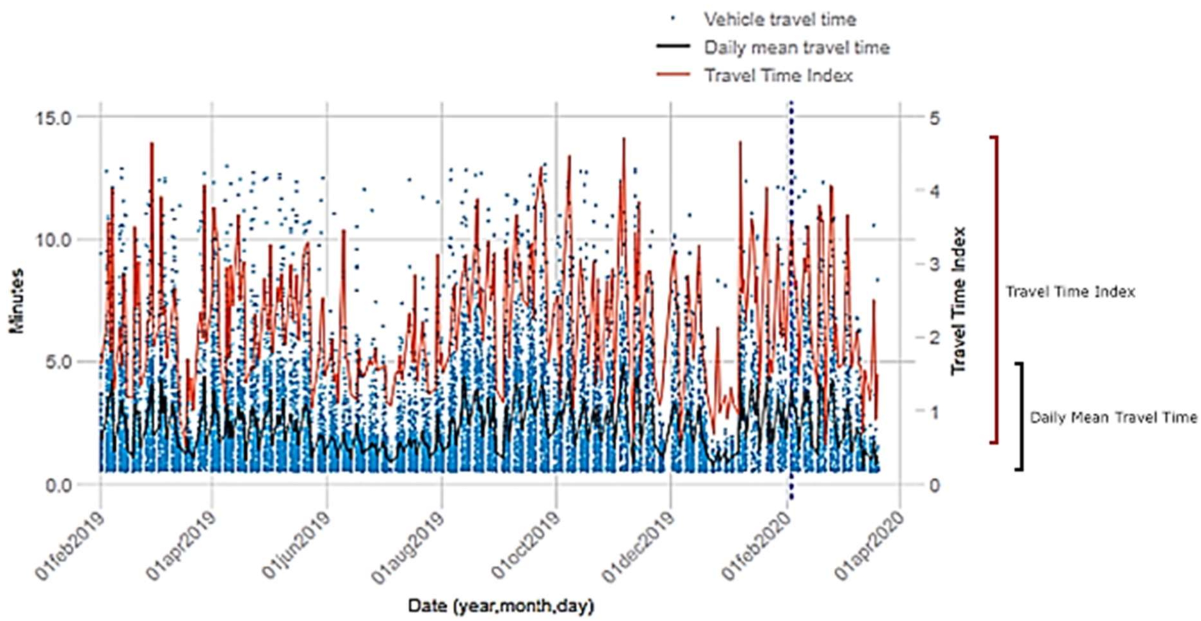
Use Cases	Deployed Applications	Reported Mobility Benefits[2]
Use Case 1: Morning Backup	• ERDW • EEBL • FCW	The ERDW contributed to: • 2.1 percent reduction in mean travel times • 1.8 percent reduction in idle time or time spent traveling at less than 1 mph • 1.8 percent reduction in queue length • A travel time index (measured as peak-hour travel time divided by off-peak travel time) reduction from 2.7 to 1.9)
Use Case 2: Wrong-Way Entry	• WWE	Use Case 2 did not generate quantifiable mobility measures directly attributed to the WWE application deployment
Use Case 3: Pedestrian Conflict	• PCW	THEA did not consider analyzing the impact on mobility
Use Case 4: Transit Signal Priority	None	The TSP application underwent a change in operations and therefore has not produced data for performance evaluation as of the date of this report
Use Case 5: Streetcar Conflicts	• VTRFTV	THEA did not consider mobility assessment for Use Case 5
Use Case 6: Traffic Progression	None	Use Case 6 only generated data conducive to setting up the baseline; the I-SIG and MMITSS architectures were not deployed and did not generate the required data to conduct a before-after assessment

Source: Center for Urban Transportation Research[2]

Changes in Travel Times

In the *Tampa (THEA) CV Pilot Phase 3 Evaluation Report,*[2] the THEA CVPD Team conducted a before and after comparison of average travel times on the REL. Figure 15 shows the pre- and post-deployment travel times associated with the ERDW application. This figure shows both the average daily travel time and reported travel time index as well as the travel times of each observed CV traveling on the REL to downtown. The following lists several observations related to travel times and travel time reliability from this figure:

- Travel times in the corridor appear in "bins" separated by the empty spaces. The empty spaces correspond to weekends when the REL was not in operation.
- There appears to be a dip in the average daily travel times beginning around the last week in May and ending in the first week of August 2019. This corresponds to when the Hillsborough County public schools were out for the summer holiday.
- There also appears to be a drop in average daily travel times during the last two weeks of December 2019, corresponding to the Christmas and New Year holiday.
- There also appears to be a slight dip in average travel time in the third week in March 2019. This dip is due to the spring break holiday.
- Beginning in the second and third week of March 2020, average travel times decline. This decline in travel time is most likely associated with the onset of the COVID-19 pandemic.



Source: Center of Urban Transportation Research[2]

Figure 15. Chart. Pre- and Post-deployment Travel Times Associated with the ERDW Application in the THEA CVPD

The THEA CVPD Team performed an interrupted time series analysis of the travel time data. This analysis used regression analysis to estimate the impacts of the deployment (specifically the ERDW application) on before and after travel times. The coefficient of correlation (R value) for this analysis was 0.177. From this analysis, the THEA CVPD Team reported the following findings:[2]

- At the beginning of the analysis period of February 2019, the estimated mean travel time (10-minute frequency) through the Use Case 1 study impact area was about 2.7 minutes.
- After the deployment of the ERDW application in March 2020, the average travel time was about 2.1 minutes.
- The presence of rain increased travel time by about a minute.
- The onset of the pandemic caused a decrease in travel time as indicated by the negative sign of the estimated parameter. This is substantiated by the observed reduction in the number of participant vehicles beginning on March 13, 2020.

Based on statistical modeling, the THEA CVPD Team reported a 2.1 percent reduction in mean travel times because of the ERDW application.[2] TTI was unable to confirm this reported reduction because this analysis was not reported in the *Tampa (THEA) CV Pilot Phase 3 Evaluation Report.*[2]

Table 14 shows the peak-hour travel times of vehicles using the REL during the peak hour over the entire evaluation period, as reported by the THEA CVPD Team.[2] This table shows a nominal increase (0.2 minutes) in average travel time between the before and after evaluation periods. Table 15 shows a statistical comparison of these two mean travel times using a Welch t-test. This test shows the difference between the before and after average travel times to be statistically significant (at a 95 percent confidence level). However, a 0.2-minute (12-second) difference in travel time is imperceivable to most drivers.

Table 14. Comparison of Travel Time (Minutes) before and after Deploying CV Technologies

ERDW Deployment	Sample Size	Average	Maximum	Standard Deviation	95th Percentile
Pre-deployment	17,613	2.5	13.0	2.1	6.7
Post-deployment	1,484	2.7	12.5	2.2	7.0
Overall	**19,097**	**2.5**	**13.0**	**2.1**	**6.8**

Source: Center for Urban Transportation Research[2]

Table 15. Statistical Comparison of Reported Average Travel Times

Performance Measure	Degrees of Freedom	Welch T-Statistic	P-Value	Effect
Average travel time	1,718.5885	–3.3749	0.00075	Small (0.095)

Source: Texas A&M Transportation Institute

Change in Travel Time Reliability

The THEA CVPD Team reported an improvement in the travel time index for the segment of the REL impacted by the ERDW application from 2.7 to 1.9. [2] TTI was unable to independently validate this reported improvement as the details of the approach applied by the THEA CVPD Team were not included in their final report. As a result, TTI was unable to reproduce the improvement estimated through the THEA CVPD Team's analysis.

Table 16 compares the average reported travel time index before and after the deployment, as reported by the THEA CVPD Team.[2] Table 17 shows a statistical comparison of the reported travel time indices. The results of this statistical comparison show that the difference in the average travel time indices is not big enough to be statistically significant; therefore, the before and after travel time indices are equal (at a 95 percent confidence level).

Table 16. Comparison of the Reported Travel Time Index before and after Deploying CV Technologies

Evaluation Period	Sample Size	Average	Maximum	Standard Deviation	95th Percentile
Pre-deployment	17,600	2.4	17.8	2.0	6.3
Post-deployment	1,484	2.5	14.9	2.0	6.5
Overall	**19,084**	**2.4**	**17.8**	**2.0**	**6.3**

Source: Center for Urban Transportation Research[2]

Table 17. Statistical Comparison of Reported Average Travel Time Index

Performance Measure	Degrees of Freedom	Welch T-Statistic	P-Value	Effect
Travel time index	1,742.5872	–1.8497	0.0645	Small (0.050)

Source: Texas A&M Transportation Institute

Change in Queue Lengths

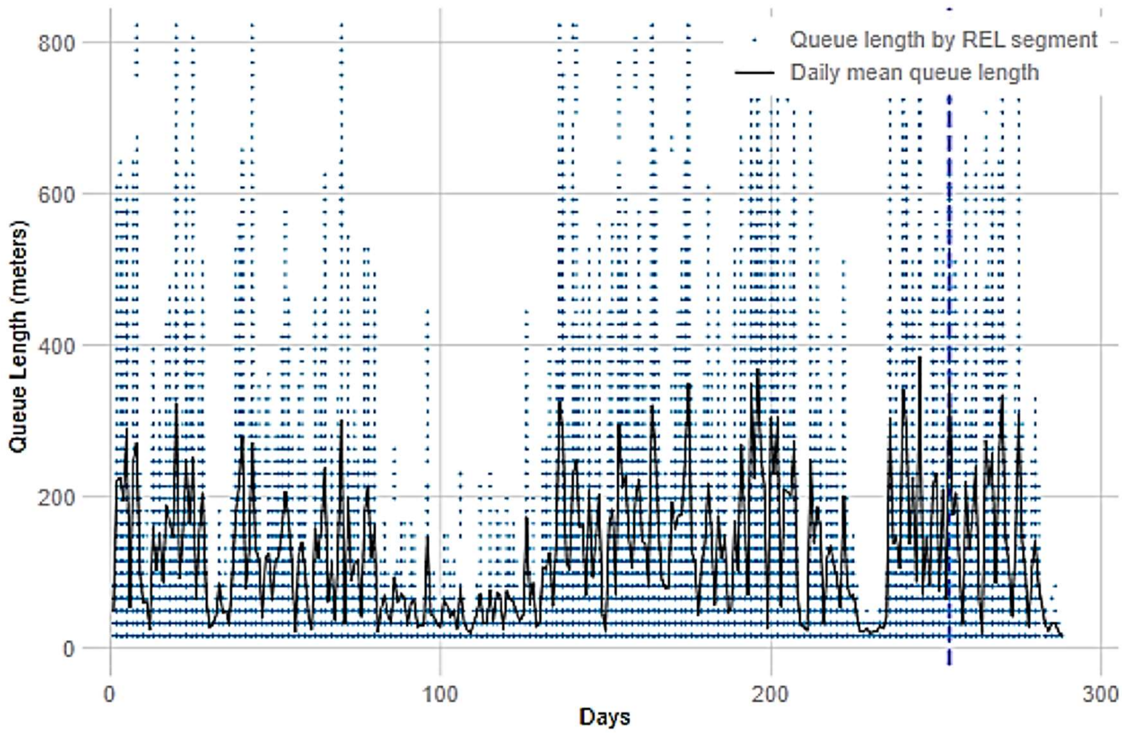
Figure 16 reports the queue length estimation over the analysis period. Each point on the graph represents a queue length estimate using the approach described in Chapter 4. The solid line represents the average daily queue length observed. The vertical dash line indicates the start of the ERDW deployment (February 3, 2020).

CUTR conducted an interrupted time series analysis of the queue length data and reported the following:[2]

- At the beginning of the pre-deployment period, the maximum queue length (measured for the East Twiggs Street/Meridian Avenue intersection) was estimated to be 178.7 meters.
- Maximum average queue lengths trended upward over the duration of the pre-deployment period.

- Maximum average queue lengths were significantly impacted by weather (in particular, rain).
- When controlling confounding factors such as rain, day of the week, and the onset of the COVID-19 pandemic, average maximum queue lengths tended to be lower in the post-deployment period. (This finding was based on a limited number of days in the post-deployment period).

The THEA CVPD Team reported a 1.8 percent reduction in average queue length because of the ERDW application;[2] however, TTI was unable to confirm this reported reduction because this analysis was not reported in the *Tampa (THEA) CV Pilot Phase 3 Evaluation Report.*[2]



Source: Center for Urban Transportation Research[2]

Figure 16. Graph. Pre- and Post-deployment Average Daily Queue Lengths on the REL

Table 18 compares the average queue lengths before and after the deployment, as reported by the THEA CVPD Team.[2] Table 19 shows the results of using a Welch T-test for unequal sample sizes. The results of the T-test show that the difference between the average queue lengths before and after the deployment is large enough to be statistically significant at a 95 percent confidence level.

Table 18. Comparison of Reported Queue Lengths (Meters) before and after Deploying CV Technologies

Evaluation Period	Sample Size	Average	Minimum	Maximum	Standard Deviation
Pre-deployment	1,347	189.8	16.5	823	184.8
Post-deployment	172	223.5	16.5	823	207.9
Overall	**1,519**	**193.6**	**16.5**	**823**	**187.8**

Source: Center for Urban Transportation Research[2]

Table 19. Statistical Comparison of Reported Average Queue Lengths

Performance Measure	Degrees of Freedom	Welch t-Statistic	p-value	Effect
Average queue length	206.98	–2.0261	0.00404	Small (0.18)

Source: Texas Transportation Institute

Increases in queue lengths may not necessarily imply that the deployment had a negative impact. Therefore, increases in queue length may mean that CV-equipped vehicles were slowing down further upstream of the back of the queue, limiting the need for a faster deceleration (or hard stop) at the back of the queue.

Change in Idle Time

The THEA CVPD Team also 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]

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 was under 1 minute.

The THEA CVPD Team report a 1.8 percent reduction in idle time because of the ERDW application;[2] however, TTI was unable to confirm this reported reduction because this analysis was not reported in the *Tampa (THEA) CV Pilot Phase 3 Evaluation Report.*[2]

Table 20 shows the before and after idle time reported by the THEA CVPD Team. Table 21 shows the results of the statistical comparison of the difference in the mean idle time before and after the deployment. Table 21 shows that although the change is small, the difference between before and after average idle time is big enough to be statistically significant (at a 95 percent confidence level).

Table 20. Comparison of Reported Idle Time before and after Deploying CV Technologies

Evaluation Period	Sample Size	Average	Maximum	Standard Deviation	95th Percentile
Pre-deployment	18,457	1.1	3.5	0.5	2.0
Post-deployment	1,578	1.2	2.6	0.5	2.1
Overall	**20,035**	**1.1**	**3.2**	**0.5**	**3.2**

Source: Center for Urban Transportation Research[2]

Table 21. Statistical Comparison of Reported Idle Time

Performance Measure	Degrees of Freedom	Welch T-Statistic	P-Value	Effect
Idle time	1857.0218	–7.626	$3.85e^{-14}$	Small (0.20)

Source: Texas A&M Transportation Institute

Indirect Impacts on Mobility

Intuitively, fewer collisions mean less congestion. Therefore, if a CVPD was successful in reducing the number of collisions (or the potential for collisions), one could infer that overall mobility would be improved.

As part of its evaluation, THEA reported the following regarding crash reductions associated with deploying the FCW and EEBL applications in Use Case 6:[2]

- The percentage of rear-end crashes remained similar in the before and after periods, and sideswipe crashes increased by 20 percent.
- The rates of conflicts per vehicle, normalized over time, showed a decrease for FCW (from 4.6 to 4.2) and for EEBL (from 2.2 to 1.7), and showed an increase in IMA (from 0.1 to 0.5).
- The IMA application seems to have not worked as planned for this Use Case. This was because the warnings issued were either too far or in non-conflicting situations. The current settings of the IMA application might produce better results in non-urban environments, suggesting the need for further fine-tuning of the application to make it more suitable to congested roads within the CBD.

Volpe also conducted a safety impact assessment of the THEA CVPD.[9] Volpe analyzed each safety application (FCW, EEBL, IMA, VTRFTV, ERDW, PCW, and WWE) separately by comparing driver responses between vehicles operating in the active mode and vehicles operating in the silent mode under similar initial kinematic conditions. Key findings from this analysis were as follows:

- There was no statistically significant difference in any driver responses (brake response time, mean deceleration, peak deceleration, break onset to collision, and brake onset time headway) to FCW and ERDW alerts.
- Due to the small sample sizes and insufficient data availability for this alert, the Volpe Team was not able to estimate driver response metrics or crash prevention ratios for EEBL, IMA, VTRFTV, and PCW alerts.
- There was no evidence of drivers altering vehicle maneuver or travel path after WWE alerts in any of the 359 WWE alert events.

- A small percentage (39 percent) of the deployment fleet received any alerts during the evaluation period.

As a result of this analysis, the Volpe Team concluded that there was an insufficient number of valid alert events to observe any statistically significant differences in crash avoidance effectiveness or changes in driver performance due to CV technology. As a result, the safety analysis does not provide any valuable insight that can be used in the MIA.

Chapter 6. User Perceptions of Mobility Impacts

This chapter summarizes the results of THEA's user survey as it relates to the mobility evaluation. THEA's *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation Support Plan, Phase 2 Update—Tampa*[8] or TTI's *Connected Vehicle Pilot Deployment Program Independent Evaluation: Stakeholder Acceptance and User Satisfaction Evaluation—Tampa (THEA)*[11] reports provide a complete analysis of the results of the THEA's user survey.

Survey Methodology

In coordination with USDOT Independent Evaluators, CUTR designed a series of surveys to be administered throughout the deployment. CUTR administered the first survey at the installation facility when the participants brought their vehicles in to have the equipment installed. The survey was administered online and covered attitudes and perceptions about CV technology, driving experiences in downtown Tampa, previous experience with CV applications, and general travel behavior. The number of respondents in the initial survey (1,058) was more than the number of OBUs installed because it was administered at the installation site. Some participants left the study after taking the survey because they either elected not to have the equipment installed in their vehicle or were excluded from participation because their vehicle did not meet the minimum study requirements. The initial participant survey collected information on the participants' travel, their perceived knowledge of CVs, and their reason for participating in the study.[2]

Invitations to participate in the second and third surveys were sent via email to participants. The THEA CVPD Team provided participants with a link to access the online survey questionnaire via email. For purposes of discussing results, TTI refers to these two post-deployment surveys as the After-Immediate survey, initiated in December 2019, and the After-Final survey, initiated in summer 2020. According to CUTR, the administration of these two surveys took a few months each. The post-deployment surveys were meant to capture vehicle participants' experience with the CV apps, their satisfaction with participating in the pilot, and other related information. The same questions were asked in the two post-deployment surveys.

Participation rates in the three surveys varied and were calculated based on the number of active participants at the time of survey administration (see Table 22).

Table 22. THEA CVPD User Survey Participation Rates[2]

Survey Type	Approximate Dates	Active Participants	Respondents	Rate
Initial—at installation	March–Oct. 2018	1,058	1,058	100%
After-Immediate	Dec. 2019	736	389	53%
After-Final	Summer 2020	650	384	60%

Source: Center for Urban Transportation Research

User Survey Results

The following is a summary of TTI's findings from the user survey data collected by the THEA CVPD Team.[11]

Satisfaction with Aspects of Driving in Downtown Tampa

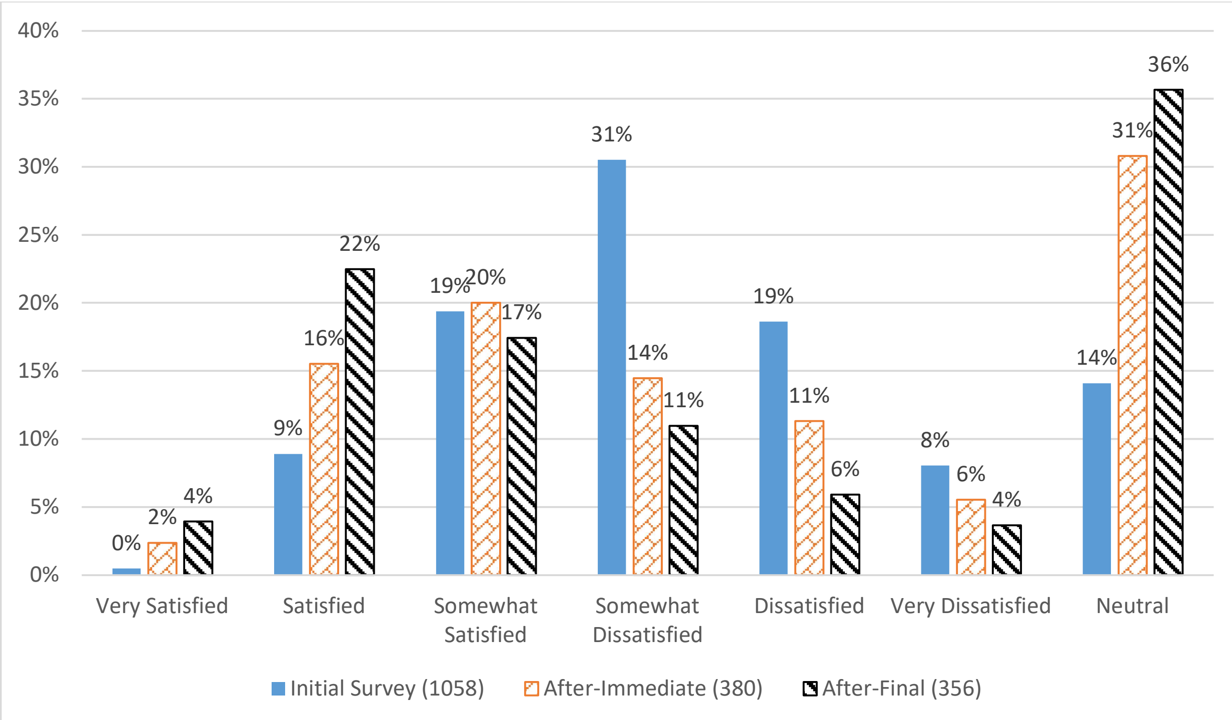
Respondents in the post-deployment surveys indicated being satisfied or very satisfied with overall travel time driving in downtown Tampa to a significantly greater degree than respondents in the initial survey (see Figure 17). Eighteen percent of After-Immediate survey respondents and 26 percent of After-Final survey respondents were satisfied or very satisfied, compared to 9 percent of those in the initial survey. Levels of dissatisfaction were also higher among initial survey respondents, while significant proportions of the post-deployment survey respondents were neutral (neither satisfied nor dissatisfied).

The final After survey was conducted during the summer of 2020 when the COVID-19 pandemic was still very active and the number of VMT was still substantially down. Increases in the percentage of respondents reporting being satisfied or very satisfied during this period may have been impacted by the COVID-19 restriction still in place in the Tampa area.

Like satisfaction levels noted previously, respondents in the post-deployment surveys indicated being satisfied or very satisfied with the overall driving experience in downtown Tampa to a greater degree than those in the initial survey (see Figure 18). Levels of dissatisfaction were also higher among initial survey respondents, while significant proportions of the post-deployment survey respondents were neutral (neither satisfied nor dissatisfied).

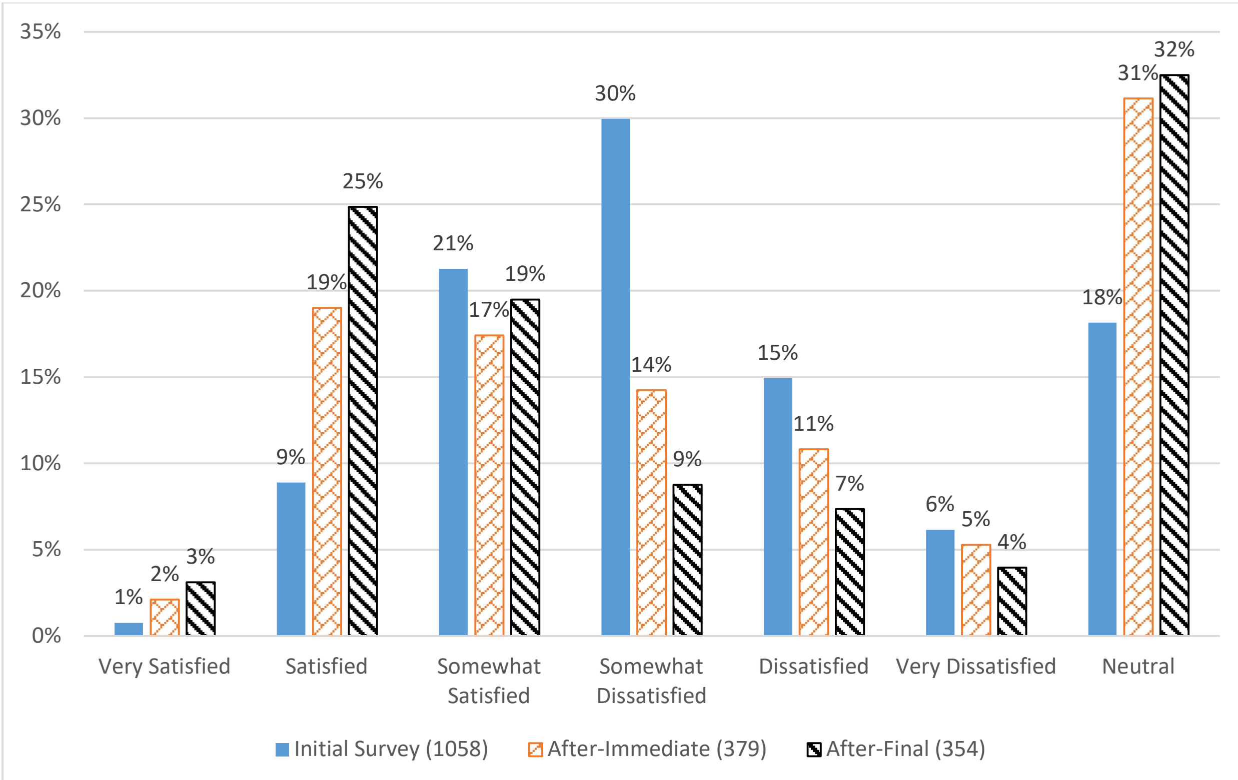
Opinions about CV Technology

Prior to using the CV technology, participants in the initial survey had extremely positive perceptions of its utility; those that might have experienced the technology had fewer positive perceptions. Almost three-fourths (74 percent) of initial survey respondents agreed or strongly agreed that CV technologies would improve their safety, compared to only 16 percent in the After-Immediate and 23 percent in the After-Final surveys (see Figure 19). Regarding the opinions of initial survey respondents, while they thought CVs could improve safety, a minority (34 percent) were extremely or very concerned about roadway safety when driving in downtown Tampa. Most (38 percent) were moderately concerned, and 28 percent were slightly or not concerned at all.



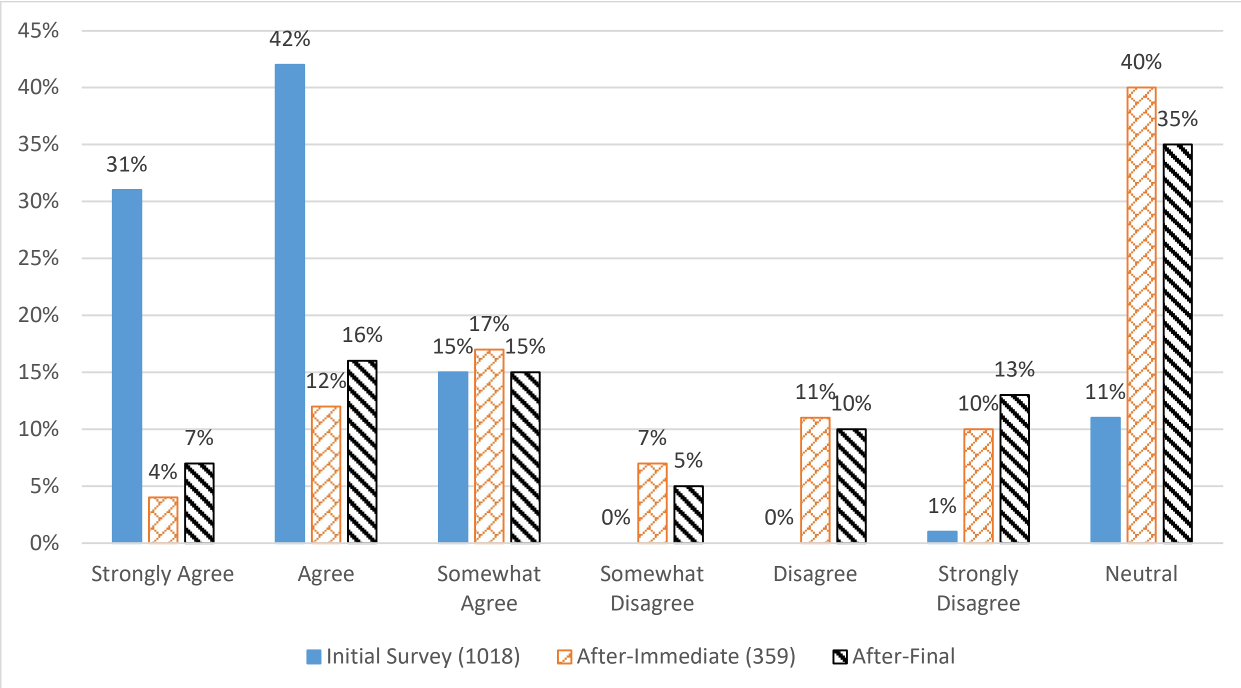
Source: Texas A&M Transportation Institute

Figure 17. Bar Chart. Satisfaction Levels with Overall Travel Time Driving in Downtown Tampa by Survey Participants



Source: Texas A&M Transportation Institute

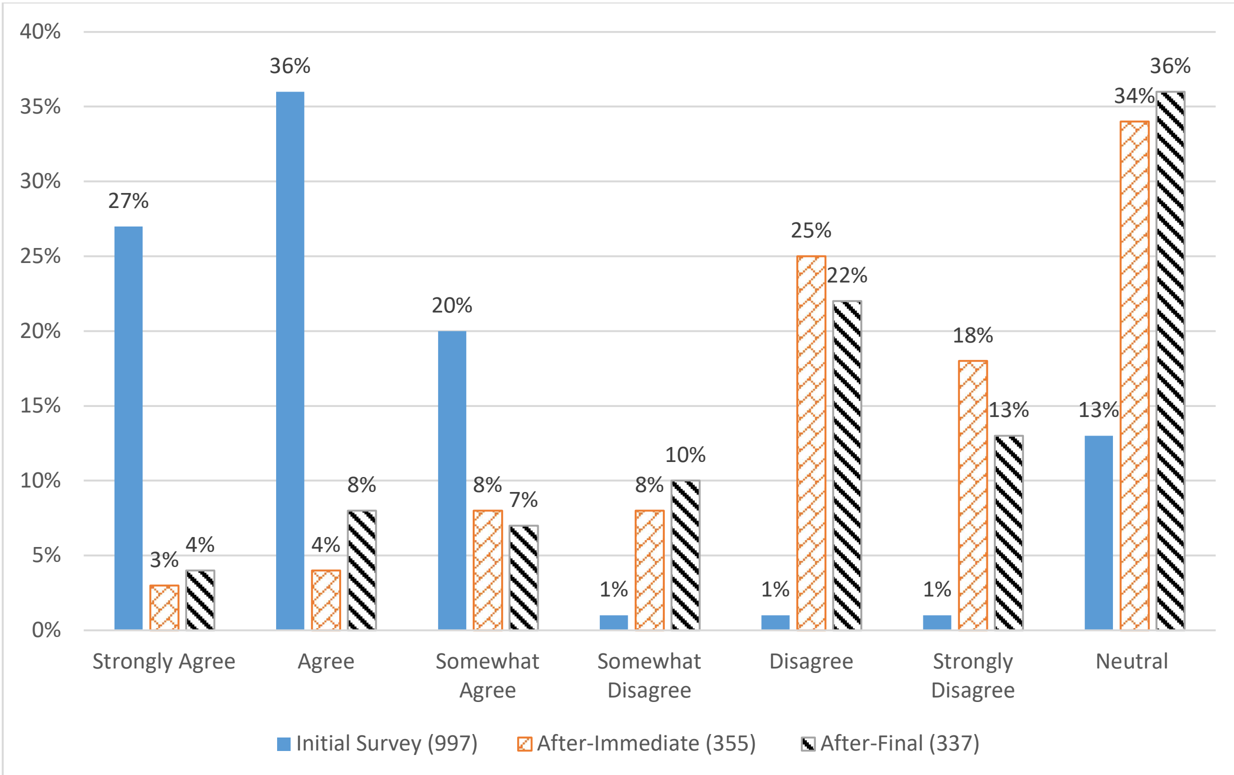
Figure 18. Bar Chart. Satisfaction Levels with Overall Driving Experience in Downtown Tampa among Tampa CVPD Survey Respondents



Source: Texas A&M Transportation Institute

Figure 19. Bar Chart. Opinions about Whether CV Technology Will Improve Safety among Tampa CVPD Survey Respondents

Most initial survey respondents (63 percent) agreed or strongly agreed that CV technologies would reduce time spent in congested conditions compared to respondents in the post-deployment surveys. Only 7 percent in the After-Immediate survey and 12 percent in the After-Final survey thought that CV technologies had reduced their time spent in congested conditions (see Figure 20).



Source: Texas A&M Transportation Institute

Figure 20. Bar Chart. Opinions about Whether CV Technology Will Reduce Time Spent in Congested Conditions among Tampa CVPD Survey Respondents

Concerns and Benefits Relating to CV Technologies

The percent of persons concerned about privacy at OBU installation was about the same in the final survey (46 percent compared to 44 percent in the pre-deployment period); however, privacy concerns were eclipsed by other concerns among After-Final survey respondents such as false alarms (58 percent), cost (53 percent), and trust in the technology (48 percent) (see Table 23). It is significant that the concern about “too many warnings” increased from 5 percent in the initial survey to 23 percent in the final survey.

Table 23. Concerns about CV Technologies in the THEA CVPD

Concern	Initial Survey (N=1058)	After-Immediate (N=399)	After-Final (N=384)
Privacy	46%	32%	44%
False alarms	45%	42%	58%
Trust in technology	30%	40%	48%
Cost	16%	24%	53%
Safety	8%	11%	9%
Too many warnings	5%	12%	23%
No concerns	18%	16%	19%
Do not know enough about CV technology	11%	10%	14%

Source: Texas A&M Transportation Institute

In terms of perceived benefits, the participants believed that applications would result in fewer crashes and increased roadway safety (see Table 24). This opinion was especially true among participants in the final survey. There was a more positive perception that CV technology would result in less stressful driving among respondents to the initial survey than among those who were surveyed post-deployment. A significant percentage of respondents in the final survey identified lower car insurance rates as a benefit when compared with respondents in the prior two surveys. The same percentage of respondents indicated that the applications deployed by THEA would lessen traffic congestion, increase fuel efficiency, and lower vehicle emissions. Also, the percentage of people who responded that they did not know enough about CV technology to identify benefits increased from 8 percent in the initial survey to 26 percent in the final survey. While the reason for this increase in percentage is not known, the actual number of respondents citing a lack of knowledge about CV technologies remained relatively constant from the initial survey to the final after survey. These could include individuals who participated in control group and never received alert messages. It may also include individuals who were in the treatment group but did not experience conditions that would trigger an alert.

Table 24. Reported Benefits of CV Technologies by THEA CVPD Participants

Benefits	Initial Survey (N=1058)	After-Immediate (N=399)	After-Final (N=384)
Fewer traffic crashes and increased roadway safety	67%	52%	80%
Less traffic congestion	55%	32%	49%
Less stressful driving experience	55%	31%	44%
Lower car insurance rates	34%	33%	46%
Increased fuel efficiency	29%	18%	24%
Lower vehicle emissions	21%	11%	18%
Do not know enough about CV technologies	8%	18%	26%
No benefits	N/A	15%	19%

Source: Texas A&M Transportation Institute

Chapter 7. Summary of Findings

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. The THEA CVPD Team originally intended to deploy 13 different CV applications in the deployment.(2) However, despite installation delays, equipment issues, and the worldwide COVID-19 pandemic, the THEA CVPD Team was able to successfully deploy the following applications:

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

This chapter provides a summary of the findings from the IE's MIA.

Primary Impacts on Mobility

Using the data available, the IE's MIA used the reported benefits generated by Use Case 1: Morning Backups on the REL of the Selmon Expressway. In terms of mobility impacts, the THEA CVPD Team reported the following mobility-related benefits associated with one application (ERDW) in Use Case 1:

- Mean travel times on the REL decreased by 2.1 percent.
- There was a 1.8 percent reduction in idle time or time spent traveling at less than 1 mph reported on the REL.
- Maximum queue length on the REL reduced by 1.8 percent
- The travel time index (measured as peak-hour travel time divided by off-peak travel time) reduced from 2.7 to 1.9.

TTI was unable to corroborate these findings by the THEA CVPD Team based on the data available. Instead, based on the data provided by the THEA CVPD in its evaluation, TTI found the following:

- The THEA CVPD deployed only a limited number of applications that might directly have an impact on mobility. Most of the applications that THEA deployed were focused on improving safety and reducing the potential for collisions between equipped vehicles. The reduced evaluation period also restricted the team's ability to observe more notable mobility improvements.
- The ERDW application deployed in Use Case 1 resulted in slight increases in average travel times, travel time reliability, and queue lengths. However, this is to be expected because the intent of the

application is to slow drivers down approaching the back of the queue. These increases are inconsequential (less than 10 seconds) and imperceivable to most drivers.

- The observed differences in travel time, travel time reliability, and queue lengths in Use Case 1 are most likely due to the significant differences in the sample size of observations between the pre- and post-deployment periods.

It is worth reiterating that most of the applications that were implemented in the deployment focused on reducing crashes and conflicts between equipped vehicles. The THEA CVPD Team was not able to get the TSP and the I-SIG applications operational during Phase 3 of the deployment. As a result, two of the applications most likely to produce mobility benefits were included in the Phase 3 MIA. As part of the Phase 4 activities, THEA is working with its vendors to ensure that these applications become operational and can be evaluated.

Secondary Mobility Impacts

While improving safety might also generate secondary mobility benefits, both the THEA crash analysis and the Volpe analysis did not provide enough evidence to conclude that the safety application did indeed result in reductions in crash frequencies or crash potential. THEA's analysis showed that the percentage of rear-end crashes remained similar in the before and after periods, and that sideswipe crashes increased by 20 percent. THEA's analysis shows however that the rates of conflicts per vehicle, normalized over time, showed a decrease for FCW (from 4.6 to 4.2) and EEBL (from 2.2 to 1.7), and an increase in IMA (from 0.1 to 0.5); however, there is no evidence to support that these reductions in conflicts translate to a reduction in crashes. The Volpe team reported it was unable to observe any evidence to support that the applications reduced crash frequencies or severities based on limitations contained in the data. Many of the safety applications experienced high false alarm rates and required extensive calibration, which may have reduced their potential to prevent collisions. Furthermore, because crashes are rare events, the evaluation period was not long enough to determine the extent to which the applications may have produced safety benefits.

Participant Perceptions of Mobility Impacts

Respondents in the post-deployment surveys indicated being satisfied or very satisfied with overall travel time driving in downtown Tampa to a significantly greater degree than respondents in the initial survey. Eighteen percent of After-Immediate survey respondents and 26 percent of After-Final survey respondents were satisfied or very satisfied, compared to 9 percent of those in the initial survey. Levels of dissatisfaction were also higher among initial survey respondents, while significant proportions of the post-deployment survey respondents were neutral (neither satisfied nor dissatisfied).

The percentage of respondents indicating that the applications deployed by THEA would lessen traffic congestion, increase fuel efficiency, and lower vehicle emissions remained approximately the same throughout the study.

The final After survey was conducted during the summer of 2020 when the COVID-19 pandemic was still very active and the number of VMT was still substantially down. Increases in the percentage of respondents reporting being satisfied or very satisfied during this period may have been impacted by the COVID-19 restriction still in place in the Tampa area.

In terms of perceived benefits, the participants believed that applications would result in fewer crashes and increased roadway safety. This opinion was especially true among participants in the final survey. There was a more positive perception that CV technology would result in less stressful driving among respondents to the initial survey than among those who were surveyed post-deployment. A significant percentage of respondents in the final survey identified lower car insurance rates as a benefit when compared with respondents in the prior two surveys.

Confounding Factors

The deployment was significantly impacted by several confounding factors. Participant retention was an issue in the deployment. The long delay between when the participants were first recruited and when they first started receiving notifications was a significant factor in retaining participants. The high number of false alarms may have also contributed to a lack of continued participation. The COVID-19 pandemic beginning shortly after the start of the post-deployment period also significantly impacted evaluation results. While the evaluation period for some applications was longer, the post-deployment evaluation period for Use Case 1 was only 34 days. A longer post-deployment period is needed to better quantify mobility changes.

A considerable lag existed between when the equipment was first installed in some participants' vehicles and when alert messages were first broadcast to the drivers. This lag may have contributed to participant retention issues. Also, some applications were prone to generate a high number of false alarms. High false alarm rates may have caused the system to lose credibility for some participants.

The THEA CVPD Team was unable to get two applications—the TSP and the I-SIG applications—fully operational during the Phase 3 deployment period. These applications were anticipated to generate significant mobility-related benefits. THEA is currently working with its stakeholders to get these applications operational during Phase 4 of the deployment.

References

1. U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office. *Connected Vehicle Pilot Deployment Program Phase 1, Concept of Operations (ConOps)—Tampa (THEA)*. Report No. FHWA-JPO-16-311. Washington, DC, February 2016.
2. Concas, S., A. Kourtellis, M. Kamrani, and O. Dokur. *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation—Tampa (THEA) CV Pilot Phase 3 Evaluation Report*. FHWA-JPO-20-829. U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, Washington, DC, March 2021. Available at https://rosap.ntl.bts.gov/view/dot/55818. Accessed August 28, 2021.
3. Tampa Hillsborough Expressway Authority. *Connected Vehicle Pilot Deployment Program Phase 2: System Architecture Document—Tampa (THEA).* FHWA-JPO-17-459. U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, Washington, DC, November 2018. Available at https://rosap.ntl.bts.gov/view/dot/42557. Accessed December 27, 2021.
4. Johnson, S., S. Novosad, D. Miller. W. Buckell, D. McNamara, and R. Ignatowicz. *Connected Vehicle Pilot Deployment Program Phase 2, System Design Document—Tampa (THEA).* FHWA-JPO-17-460. U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, Washington, DC, October 2017. Available at https://rosap.ntl.bts.gov/view/dot/50746. Accessed December 27, 2021.
5. Siemens Mobility, Inc. *UC1 Morning Backup Operational Plan: Improved Queue Length Measurement Operation Description.* 2020.
6. Society of Automotive Engineers International. *J2945: On-Board System Requirements for V2V Safety Communications.* 2016.
7. U.S. Department of Transportation. Secure Data Commons. Available at https://www.transportation.gov/data/secure. Accessed January 13, 2022.
8. Concas, S., A. Kourtellis, and S. Rich. *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation Support Plan, Phase 2 Update—Tampa*. FHWA–JPO-20-314. U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, Washington, DC, July 2019. Available at https://rosap.ntl.bts.gov/view/dot/31732. Accessed December 28, 2021.
9. Lam, A., W. Chupp, A. Chouinard, and W. Najm. *Safety Impact Assessment of THEA Connected Vehicle Pilot Safety Applications.* U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, Washington, DC, September 2021, unpublished.
10. McMillan, N., A. Christiaen, and G. Stark. Estimating Safety Benefits for the IVI Generation of Field Operational Tests. Society of Automotive Engineers International Truck and Bus Meeting and Exposition, Chicago, IL, 2001.

11. Zmud, J., M. Petrella, B. Kuhn, and K. Balke. *Connected Vehicle Pilot Deployment Program Independent Evaluation: Stakeholder Acceptance and User Satisfaction Evaluation—Tampa (THEA)*. FWHA-JPO-22-922. U.S. Department of Transportation, Federal Highway Administration, Washington, DC, February 2022, unpublished.

Appendix A. 2019 and 2020 Observed Federal Holidays

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)

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

Source: Texas A&M Transportation Institute

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487

www.its.dot.gov

FHWA-JPO-22-923

U.S. Department of Transportation