Connected Vehicle Pilot Deployment Program Phase 1, Application Deployment – Tampa (THEA)

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Final Report — September 20, 2016 FHWA-JPO-16-316

U.S. Department of Transportation

Produced by Tampa Hillsborough Expressway Authority
Connected Vehicle Pilot Deployment Program Phase 1
U.S. Department of Transportation, ITS-JPO

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-16-316		

4. Title and Subtitle Connected Vehicle Pilot Deployment Program Phase 1, Application Deployment Plan – Tampa (THEA)	**5. Report Date** September 2016 **6. Performing Organization Code**
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9. Performing Organization Name And Address Tampa Hillsborough Expressway Authority 1104 East Twiggs Street, Suite 300 Tampa, Florida 33602	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH6115R00003
12. Sponsoring Agency Name and Address U.S. Department of Transportation ITS Joint Program Office 1200 New Jersey Avenue, SE Washington, DC 20590	**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code**

15. Supplementary Notes

16. Abstract

The Tampa Hillsborough Expressway Authority (THEA) Connected Vehicle (CV) Pilot Deployment Program is intended to develop a suite of applications that utilize vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication technology to reduce traffic congestion, improve safety, and decrease emissions. These CV applications support a flexible range of services from advisories, roadside alerts, transit mobility enhancements, and pedestrian safety. The pilot is conducted in three phases. Phase 1 includes the planning for the CV pilot including the concept of operations development. Phase 2 is the design, development, and testing phase. Phase 3 includes a real-world demonstration of the applications developed as part of this pilot.

This document represents the Application Deployment Plan. It provides an overview of the applications planned for deployment in Tampa as part of the THEA Pilot, along with the following details about each application: description of the application and its components; the corresponding intellectual property rights; the application safety plan; testing and verification requirements; and cost and schedule for application deployment. The document provides overall plan information, including: cross-cutting development efforts, Security Credential Management System (SCMS), software development process, plan for uploading relevant materials to the OSADP and the RDE, and a depiction of overall cost and schedule.

17. Key Words	18. Distribution Statement
Applications, Connected Vehicles, Hardware, Input, Interface, Mobility, Output, Performance, Pilot, Safety, Software, Testing, Verification	No restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	105	

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

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Executive Summary

The Tampa Hillsborough Expressway Authority (THEA) Connected Vehicle (CV) Pilot Deployment aims to create a connected urban environment to measure the effect and impact of CVs in Tampa's vibrant downtown. The proposed pilot project offers several CV applications that can be deployed in Tampa's Central Business District (CBD) and environs to create a more connected downtown. This environment has a rich variety of traffic, mobility, and safety situations that are amenable to vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) solutions. "Everything" includes all communications media (e.g., smartphones). The deployment area is in busy downtown Tampa and offers a tolled expressway with street-level interface, bus and trolley service, high pedestrian/bicycle densities, special event trip generators, and high dynamic traffic demand over the course of a typical day. These diverse environments are in one concentrated deployment area, which collectively encompasses many traffic situations that allow for CV application deployment and performance testing.

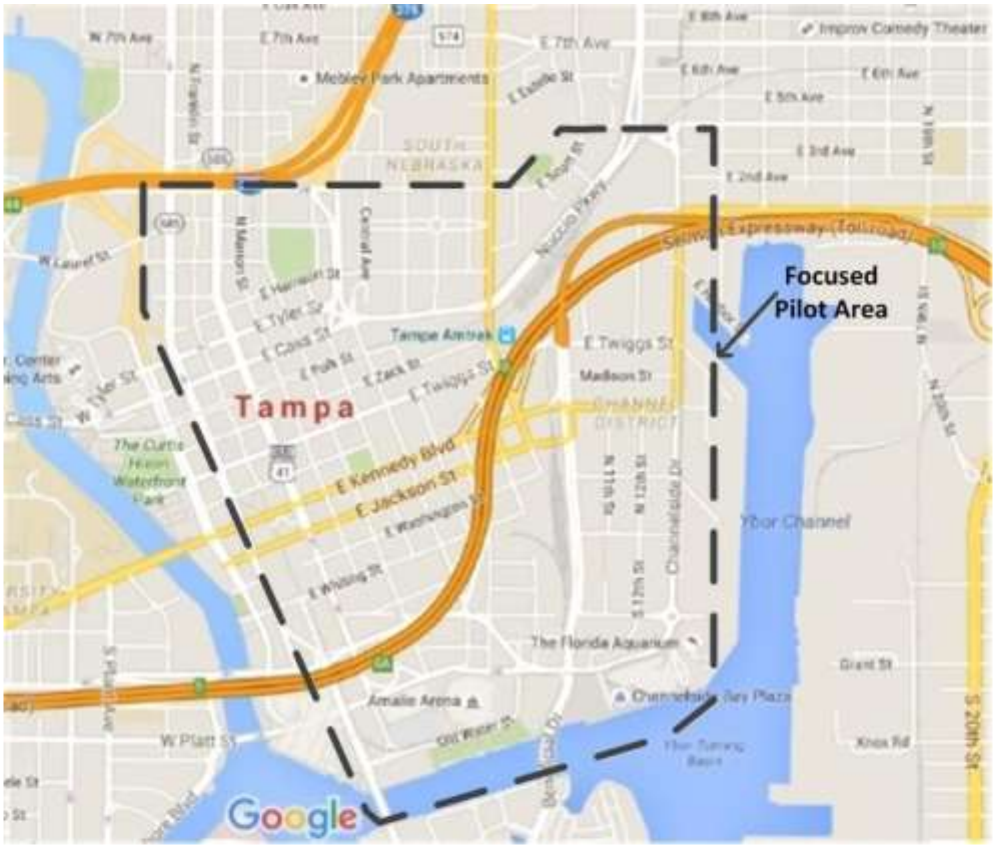
These CV applications support a flexible range of services from advisories, roadside alerts, transit mobility enhancements, and pedestrian safety. The pilot will be conducted in three phases. Phase 1 includes planning for the CV pilot and developing the concept of operations. Phase 2 is the design, development, and testing phase. Phase 3 includes a real-world demonstration of the applications that were developed as part of this pilot.

The following Application Deployment Plan provides an overview of the applications planned for deployment in Tampa as part of the THEA pilot, along with the following details about each application: description of the application and its components; the corresponding intellectual property rights; the application safety plan; testing and verification requirements; and the cost and schedule for application deployment. This document also provides overall plan information including: cross-cutting development efforts, Security Credential Management System (SCMS), software development process, plan for uploading relevant materials to the Open Source Application Development Portal (OSADP) and the Research Data Exchange (RDE), and a depiction of overall cost and schedule.

Pilot Geographical Area

Downtown Tampa is bordered by Ybor Channel (Cruise Ship and Commercial Port Channel) to the east, Garrison Channel (local waterway) to the south, Florida Avenue to the west, and Scott Street to the north. A virtually flat topography near sea level helps to simplify the evaluation of traffic flow parameters. **Error! eference source not found.** shows the focused pilot area.

Figure 0-1. Focused Pilot Area

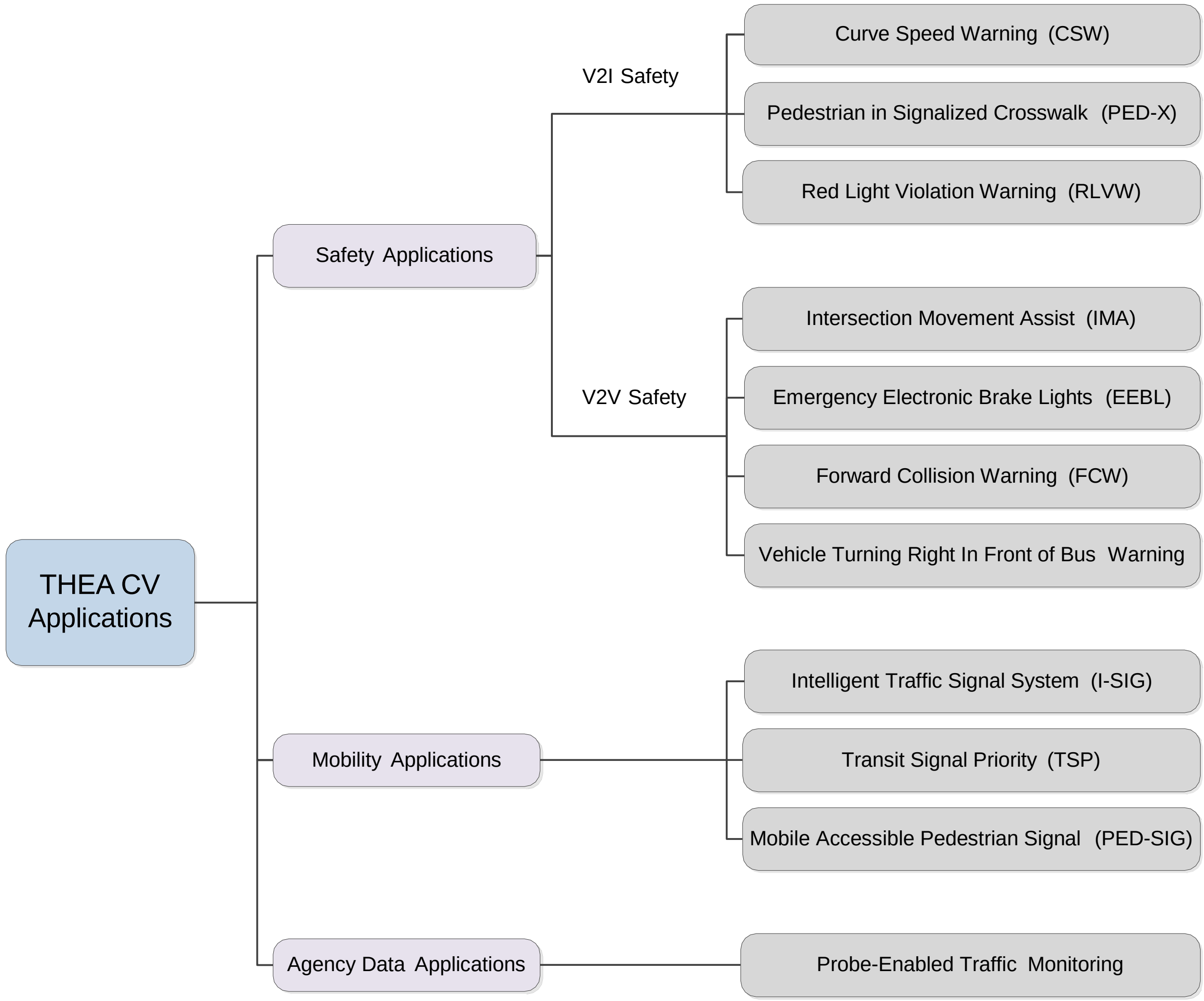


Source: Googlemaps.com, HNTB

Applications Deployed

THEA intends to deploy 11 different CV applications in the Tampa pilot region that fall under the four categories of V2I enabled safety applications, V2V enabled safety applications, mobility applications, and agency data applications. Figure 0-2 depicts the categorization of the eleven THEA CV pilot applications.

Figure 0-2: THEA CV Pilot Applications



Source: THEA, HNTB, Siemens

V2I Safety – 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 a 360-degree awareness and inform vehicle operators through advisories and warnings of hazards and situations they cannot see. The THEA CV pilot team plans to deploy three V2I safety applications:

- Curve Speed Warning (CSW)
- Pedestrian in Signalized Crosswalk (PED-X)
- Red Light Violation Warning (RLVW).

V2V Safety – V2V safety applications wirelessly exchange data among vehicles traveling in the same vicinity to offer significant safety improvements. Each equipped vehicle on the roadway – including automobiles, trucks, transit vehicles, and motorcycles – will be able to communicate with other vehicles. This rich set of data and communications will support a suite of active safety applications and systems. Vehicles will communicate with one another broadcasting basic safety messages (BSMs) that will inform vehicle operators of hazards and situations they cannot see. These applications will only function when the involved vehicles are both equipped with V2V devices. The THEA CV pilot team plans to deploy four V2V safety applications:

- Emergency Electronic Brake Lights (EEBL)
- Forward Collision Warning (FCW)
- Intersection Movement Assist (IMA)
- Vehicle Turning Right in Front of a Transit Vehicle (VTRFTV).

V2I Mobility – V2I mobility applications communicate operational data between vehicles and infrastructure, 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 CV pilot team plans to deploy three V2I mobility applications:

- Intelligent Traffic Signal Systems (I-SIG)
- Transit Signal Priority (TSP)
- Mobile Accessible Pedestrian Signal (PED-SIG).

Agency Data Application – THEA will use data (e.g., basic BSMs) generated by CVs to optimize signal timing based on real-time traffic conditions. The pilot team plans to deploy one agency data application:

- Probe Data Enabled Traffic Monitoring (PDETM).

Maturity Level of Applications

Table 0-1 summarizes the maturity level of applications. Maturity for the selected applications is categorized into the following levels:

1. Simulated Deployment – These applications have been conceptualized along with algorithms under U.S. Department of Transportation (USDOT) projects and were developed and tested under simulated conditions.
2. Proof-of-Concept Deployment – These applications have been developed as prototypes for demonstration purposes only.
3. Testbed Deployment – These applications are mature enough to have conducted real-world testbed deployment at least at a minor facility level.

Table 0-1: Application Maturity Level

No.	Application	Maturity Level
V2I Safety Applications		
1	Curve Speed Warning	Testbed Deployment
2	Pedestrian in Signalized Crosswalk	Testbed Deployment
3	Red Light Violation Warning	Testbed Deployment
V2V Safety Applications		
4	Intersection Movement Assist	Testbed Deployment
5	Emergency Electronic Brake Lights	Testbed Deployment
6	Forward Collision Warning	Testbed Deployment
7	Vehicle Turning Right in Front of a Transit Vehicle	Proof-of-Concept Deployment
V2I Mobility Applications		
8	Intelligent Traffic Signal Systems	Testbed Deployment
9	Transit Signal Priority	Simulated Deployment
10	Mobile Accessible Pedestrian Signal	Simulated Deployment
Agency Data Applications		
11	Probe Data Enabled Traffic Monitoring	Testbed Deployment

Source: THEA, HNTB, Siemens

Required Development Work

The required development work and the required testing process is estimated per FHWA's Systems Engineering Guidance in FHWA-HOP-07-069. Here, estimated "development" effort includes level testing. For example, fully developed applications reused here include level testing as part of the estimated development effort. Table 0-2 summarizes the development work that is required for each of the different applications prior to deployment according to the following hierarchy:

1. Minimal development is required for applications that are mature enough for testbed deployment and the code is available on OSADP or other open source portals. The only development required for these applications pertain to the changes in software and hardware systems used in the Tampa region.
2. Moderate development is required for applications that are mature enough for a proof-of-concept or simulation deployment. These applications would require a major overhaul of some algorithm modules due to how it will be deployed in the Tampa pilot.
3. Significant development is required for applications that are available as algorithms, but not as a usable open-source code. Such applications may require some simulation-based testing prior to deployment to assess the impacts, threats, and vulnerabilities.

Table 0-2: Required Development to Deploy Application

No.	Application	Required Development	Source of Base Application
V2V Safety Applications			
1	Curve Speed Warning	Minimal	Crash Avoidance Metrics Partnership (CAMP)
2	Pedestrian in Signalized Crosswalk	Moderate	CAMP IMA application or TRP Pedestrian crosswalk application
3	Red Light Violation Warning	Minimal	CAMP or Siemens RLVW application
V2I Safety Applications			
4	Intersection Movement Assist	Moderate	CAMP application
5	Emergency Electronic Brake Lights	Minimal	CAMP application
6	Forward Collision Warning	Minimal	CAMP application
7	Vehicle Turning Right in Front of a Transit Vehicle	Moderate	TRP application from Safety Pilot
V2I Mobility Applications			
8	Intelligent Traffic Signal Systems	Moderate	OSADP
9	Transit Signal Priority	Moderate	OSADP
10	Mobile Accessible Pedestrian Signal	Moderate	OSADP
Agency Data Applications			
11	Probe Data Enabled Traffic Monitoring	Moderate	Siemens or European source

Source: THEA, HNTB, Siemens

Cost and Schedule

During the grant proposal phase, the THEA CV pilot team used the USDOT's CO-PILOT tool to estimate Phase 2 and 3 costs for the chosen applications. CO-PILOT is a high-level tool that supports stakeholders considering CV pilot deployments. This tool estimates costs for 56 applications in the V2I safety, V2V safety, agency data, environment, road weather, mobility, and smart roadside application groups. These estimates are intended for high-level, preliminary planning purposes and outputs are intended to support long-range budget planning. They do not replace detailed cost structures that will be developed during Phase 2 (design/build/test), or Phase 3 (maintain and operate). The table below reflects the original costs generated from CO-Pilot:

Application	Cost
Software Development & Testing: PED-SIG	250,000.00
Software Development & Testing: VTRFBW	100,000.00
Software Development & Testing: TSP	100,000.00
Software Development & Testing: RLVW	400,000.00
Software Development & Testing: Q-WARN	250,000.00
Software Development & Testing: PSCWT	400,000.00
Software Development & Testing: IMA	250,000.00
Software Development & Testing: I-SIG	250,000.00
Software Development & Testing: FCW	250,000.00
Software Development & Testing: EEBL	250,000.00
Software Development & Testing: CSW	250,000.00

Source: THEA, HNTB, Siemens, CO-PILOT

The THEA Team will be meeting during the first week of June to produce a second high-level budget for Phase 2 based on the concept development through that time. This budget will be more granular than the initial grant application version, containing estimates of total on-board units (OBUs) and roadside units (RSUs). However, it will still be a high-level budget in need of additional review toward end of Phase 1. The Phase 2 schedule is projected to begin in September of 2016 and run for up to 20 months. Phase 3 will run for up to 18 months. The cost breakdown for Phase 2 and Phase 3 can be found in the Comprehensive Deployment Plan Section 6 Cost Summary.

1 Introduction

The THEA CV pilot *(hereafter referenced as 'the pilot')* is funded by a federal grant that was awarded in September 2015 by the USDOT's Intelligent Transportation Systems Joint Program Office (ITS JPO). The pilot is one of three sites selected from more than 40 applicants. These pilot sites continue the USDOT's efforts to generate a body of research data from tested utilization of CV applications to address real world issues impacting safety, mobility, environment, and agency efficiency. Phase 1 of the pilot began in mid-September 2015 and will run for one year. It aims to meet the purposes set forth in the USDOT's Broad Agency Announcement, to advance and enable safe, interoperable, networked wireless communications among vehicles, infrastructure, and travelers' personal communications devices and to make surface transportation safer, smarter, and greener. Tampa's CBD is an example site that aims to demonstrate the ways that CV technology can improve an urban environment. THEA is deploying site-tailored collections of applications that address specific local needs while laying a foundation for additional local/regional deployment, and providing transferable lessons for other prospective deployers across the nation.

The THEA CV pilot deployment aims to create a connected urban environment to measure the effect and impact of CVs in Tampa's vibrant downtown. The proposed pilot project offers several CV applications that can be deployed in Tampa's CBD and environs. This environment has a rich variety of traffic, mobility, and safety situations that are amenable to V2V, V2I, and V2X solutions. The deployment area is within a busy downtown that collectively encompasses many traffic situations that allow for CV application deployment and performance testing.

These CV applications support a flexible range of services from advisories, roadside alerts, transit mobility enhancements, and pedestrian safety. The pilot will be conducted in three phases. Phase 1 includes planning for the CV pilot and developing the concept of operations. Phase 2 is the design, build, and testing phase. Phase 3 includes a real-world application demonstration.

1.1 Purpose

This document represents the Application Deployment Plan. It provides an overview of the applications planned for deployment in Tampa as part of the THEA pilot, along with the following details about each application: description of the application and its components, the corresponding intellectual property rights, the application safety plan, testing and verification requirements, and the cost and schedule for application deployment. The document further provides overall plan information including: cross-cutting development efforts, SCMS, software development process, plan for uploading relevant materials to the OSADP and the RDE, and a depiction of overall cost and schedule.

This document will be used to describe what additional functionality and/or performance elements will be required to further develop, tailor, and integrate applications for pilot deployment use. It will also identify which, if any, of the expected open source software and other supporting contributions expected from the system design and development process are intended for posting to the OSADP.

1.2 Document Layout

The report is organized into the following sections:

Section 1 – Introduction

Section 2 – Overview of Applications
Briefly describes the applications that are part of this pilot deployment.

Section 3 through Section 13 – Details of the Applications Chosen
These sections go into the details for each specific application that THEA is planning to deploy. For each application, the subsections capture details that include a description of the application, the maturity level and development work needed to make the application deployment ready, and testing and verification requirements. The sections are as follows:

- Section 3 – Curve Speed Warning
- Section 4 – Pedestrian and Signalized Crosswalk
- Section 5 – Red Light Violation Warning
- Section 6 – Intersection Movement Assist
- Section 7 – Emergency Electronic Brake Lights
- Section 8 – Forward Collision Warning
- Section 9 – Vehicles Turning in Front of a Bus
- Section 10 – Intelligent Traffic Signal Systems
- Section 11 – Transit Signal Priority
- Section 12 – Mobile Accessible Pedestrian Signal
- Section 13 – Probe Data Enabled Traffic Monitoring.

Section 14 – Overall Plan Information
This section gives details for the applications as a group, including the required use of the SCMS, the overall software development process, uploading to the OSADP and RDE, and an overall cost estimation discussion and schedule for Phases 2 and 3 of application development and deployment.

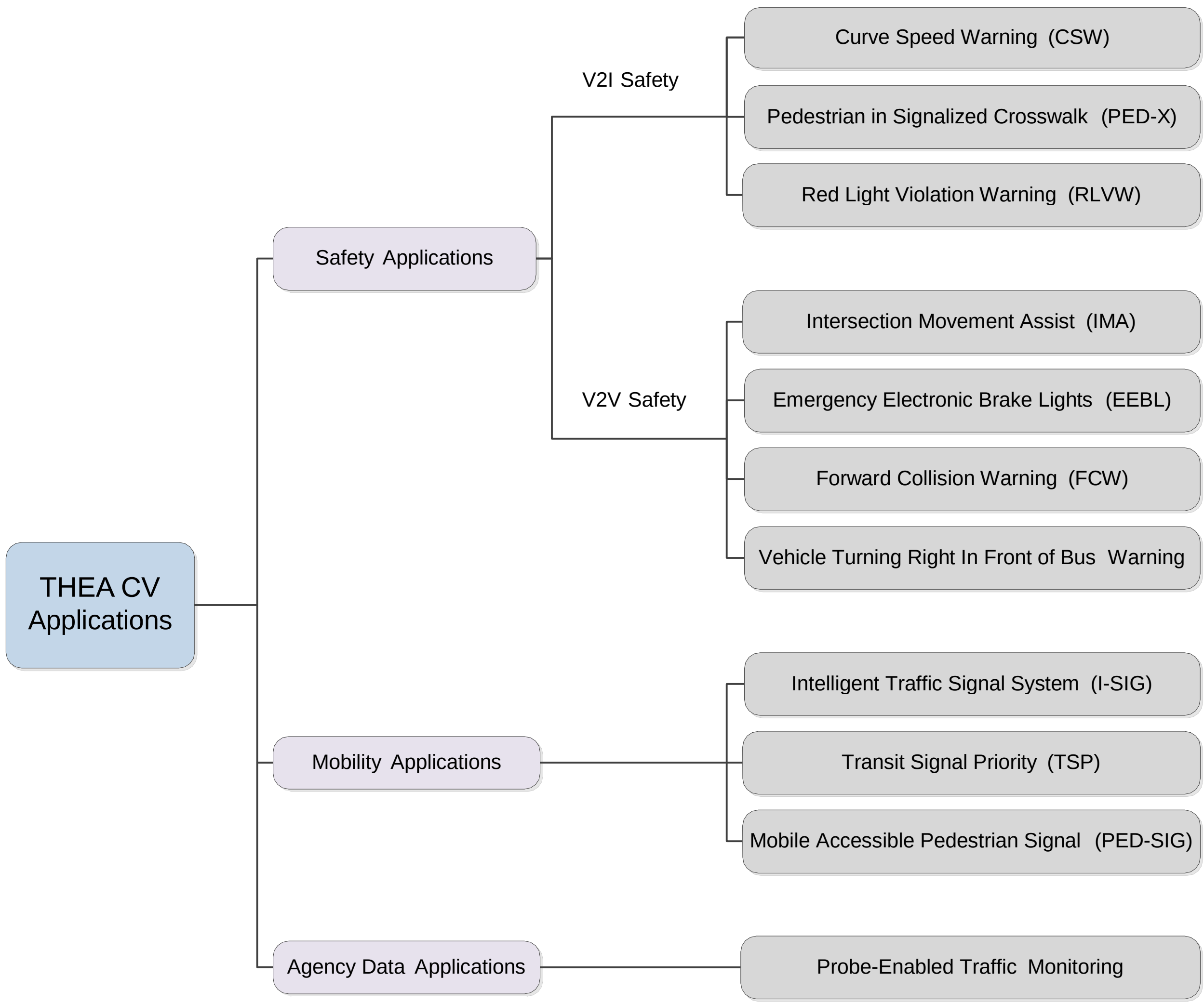
2 Overview of Applications

The following section gives a general overview of all of the CV applications that are being deployed in the pilot effort and how they will be utilized.

2.1 Applications Deployed

THEA intends to deploy 11 different CV applications in the Tampa pilot region that fall under the four categories of V2I safety applications, V2V safety applications, mobility applications, and agency data applications. These categories and the applications that are organized under them are depicted in Figure 2-2.

Figure 2-1: THEA CV Applications



Source: THEA, HNTB, Siemens

2.1.1 V2I Safety Applications

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 a 360-degree awareness and inform vehicle operators through advisories and warnings of hazards and situations they cannot see. The THEA CV pilot team plans to deploy four V2I safety applications. These applications are described briefly below.

2.1.1.1 Curve Speed Warning (CSW)

The CSW application notifies a CV that it is approaching a curve and provides a recommended speed for that curve. This capability allows the vehicle to provide a warning to the driver when approaching a curve at a speed that may be too high for safe travel through that curve. In Tampa, this application will be used at the end of the REL at Meridian and Twiggs to help reduce morning traffic backups on the REL by Twiggs Street. I-SIG at Twiggs and Meridian, as well as Twiggs at Nebraska, will monitor queue backups and send this queue information as inputs to CSW application, which resides in the equipped vehicles to adjust curve speed advice to the safe stopping distance as per the Florida Drivers Manual. The RSU will send a message to the vehicle OBU, which adjusts the CSW output according to the vehicle type. The application will then inform the driver approaching the exit curve on a safe entry speed for the available stopping distance behind the queues.

2.1.1.2 Pedestrian in Signalized Crosswalk (PED-X)

The PED-X Warning application provides the CV (i.e., OBU) information from infrastructure (i.e., RSU) that indicates the possible presence of pedestrians in a crosswalk. The infrastructure-based indication will include the outputs of pedestrian sensors or simply an indication that the pedestrian call button has been activated. This application has been defined for transit vehicles, but will be expanded to other vehicle classes. The application will also provide warning information to the pedestrian regarding crossing status or potential vehicle infringement into the crosswalk. Twiggs Street at the Hillsborough County Courthouse has a mid-block pedestrian crossing. This creates pedestrian safety issues as they traverse Twiggs Street. Additionally, pedestrians are crossing at unmarked locations, further complicating the pedestrian safety concern. This application will be used at the crosswalk on Twiggs Street near the courthouse and on Twiggs approaching the courthouse to help alert drivers and pedestrians, thus reducing the potential of a pedestrian being struck by a vehicle.

2.1.1.3 Red Light Violation Warning (RLVW)

The RLVW application enables a CV approaching an equipped signalized intersection to receive information from the infrastructure regarding the signal timing and the geometry of the intersection. The application in the vehicle uses its speed and acceleration profile, along with the signal timing and geometry information, to determine if it appears likely that the vehicle will enter the intersection in violation of a traffic signal. If the violation seems likely to occur, a warning can be provided to the driver. This application will be adapted to warn drivers of wrong way entries onto the REL. The entrance/exit point of the REL at Meridian Avenue and Twiggs Street is a potential site for wrong-way entries, specifically during inbound operations (6:00 am – 1:30 pm weekdays). At the exit to the REL on 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 REL exit to prevent drivers from entering the REL going the wrong way. Drivers traveling on East Twiggs Street approaching the intersection where the REL ends and Meridian Street begins can mistakenly enter the REL going the wrong way. Drivers approaching this intersection coming from downtown can inadvertently make a left turn onto the REL exit. Conversely, drivers on East Twiggs Street approaching this intersection going towards downtown can inadvertently make a right turn onto the REL exit. Finally, drivers approaching the intersection on Meridian can potentially veer slightly to the left onto the REL exit. When a wrong way driver is identified, the wrong way driver receives an immediate warning from the RSU that detected the wrong way driver. When a wrong way alert is triggered, a Traveler Information Message (TIM) will notify law enforcement and send a wrong way warning message to the selected RSU. This message will then be broadcasted to drivers in the lane MAP geometry of the wrong way driver.

2.1.2 V2V Safety Applications

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, trucks, transit vehicles, and motorcycles – will be able to communicate with other vehicles. This rich set of data and communications will support a suite of active safety applications and systems. Vehicles will communicate with one another and broadcast basic safety messages. These applications will only function when the involved vehicles are both equipped with V2V devices. The THEA CV pilot team plans to deploy four V2V safety applications. These applications are described briefly below.

2.1.2.1 Emergency Electronic Brake Light (EEBL)

The Emergency Electronic Brake Light (EEBL) application alerts drivers to hard braking in the traffic stream ahead. This provides 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 in order 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, 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.

2.1.2.2 Forward Collision Warning (FCW)

The Forward Collision Warning (FCW) application warns the vehicle driver of an impending rear-end collision with another vehicle that is ahead of them in the same lane and direction in traffic. The application uses data received from other vehicles to determine if a forward collision is imminent. FCW is intended to advise drivers to take a specific action in order to avoid or mitigate rear-end vehicle collisions in the forward path of travel by lane. Similar to the EEBL application, FCW will be used to increase safety by reducing accidents during peak traffic hours on the REL. As vehicles 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 hard brake. The FCW will send warnings to the driver if a vehicle ahead brakes suddenly.

2.1.2.3 Intersection Movement Assist (IMA)

The Intersection Movement Assist (IMA) application warns the driver of a CV when it is not safe to enter a roadway due to high collision probability with other vehicles at a stop sign controlled intersection – for example, when a driver's view of opposing or crossing traffic is blocked. This application can provide collision warning information to the operator, who may perform actions to reduce the likelihood of crashes at the intersection. The application will be used to assist in warning pedestrians. The application will improve safety at intersections where there might be potential conflicts between equipped vehicles.

2.1.2.4 Vehicle Turning Right in Front of a Transit Vehicle (VTRFTV)

The Vehicle Turning Right in Front of a Transit Vehicle (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 TECO Line Trolley, 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 trolley crossing. However, right turn on red is typically a legal move, which may cause a motorist – unaware of the trolley's presence – to turn right into the trolley's path.

2.1.3 V2I Mobility Applications

V2I mobility applications communicate operational data between vehicles and infrastructure, 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 CV pilot team plans to deploy three V2I mobility applications. These applications are described briefly below.

2.1.3.1 Intelligent Traffic Signal System (I-SIG)

The Intelligent Traffic Signal System (I-SIG) application uses vehicle location and movement information from CVs as well as infrastructure measurement from non-equipped vehicles (e.g., standard detection devices) to improve traffic signal control operation and maximize flows in real time. The application utilizes vehicle information to adjust signal timing for an intersection or group of intersections in order to improve traffic flow and allow platoon flow through the intersection. The application serves as an over-arching system optimization application, accommodating other mobility applications – such as Transit Signal Priority, Freight Signal Priority, Emergency Vehicle Preemption, and Pedestrian Mobility – to maximize overall arterial network performance. Furthermore, the application may consider additional inputs such as environmental situation information or the interface (i.e., traffic flow) between arterial signals and ramp meters.

2.1.3.2 Transit Signal Priority (TSP)

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 a number of factors. The proposed application allows transit vehicles to request priority to roadside equipment via an on-board device. The application provides feedback to the transit driver indicating whether the signal priority has been granted. This application can contribute to improved transit vehicle operating performance by reducing the time spent stopped at a red light. This application will be used by HART buses in the Marion Street use case, a primary route where buses and traffic signals communicate. BRT routes increase efficiency and mobility. However, during peak periods, the BRT service suffers from poor transit travel time and travel time reliability due to poor signal progression from heavy pedestrian and passenger vehicle volumes, as well as vehicles blocking access to bus stops; which will flush the queue. Once TSP is implemented, if a bus is behind schedule, the traffic signal system will give the bus priority assuming there are no other higher priorities (such as a preemption request or an on-going pedestrian phase).

2.1.3.3 Mobile Accessible Pedestrian Signal (PED-SIG)

The Mobile Accessible Pedestrian Signal (PED-SIG) application will integrate traffic and pedestrian information from roadside or intersection detectors with new forms of data from wirelessly connected pedestrian (or bicyclist) carried mobile devices (nomadic devices) to request dynamic pedestrian signals or to inform pedestrians when to cross based on real-time signal phase and timing (SPaT) and MAP information. In some cases, priority will be given to pedestrians, such as persons with disabilities who need additional crossing time, or in special conditions (e.g., weather) where pedestrians may warrant priority or additional crossing time. This application may also support the accommodation of safe and efficient pedestrian movement of a more general nature. This application will enable a "pedestrian call" to be routed to the traffic controller from a nomadic device of a registered person with disabilities, after confirming the direction and orientation of the roadway that this pedestrian is intending to cross. The application also provides warnings to the personal information device user of possible crossing infringement by approaching vehicles. This application will also be used by the Twiggs Street use case near the courthouse and Channelside Drive where RSUs are deployed for Use Case 5 TECO Line Streetcar Trolley Conflicts.

2.1.4 Agency Data Applications

2.1.4.1 Probe Data Enabled Traffic Monitoring (PDETM)

This application utilizes vehicle situation/probe data to transmit real time traffic data between vehicles and roadside equipment. An application will typically take a snapshot of the data at a given interval. These snapshots will be bundled and sent to a data clearinghouse at specific intervals (or as possible based on available communications media). The THEA CV pilot will primarily focus on gathering vehicle situation/probe data packages transmitted to RSUs at the entrance/exit point of the REL at Meridian Avenue and Twiggs Street – the area of downtown Tampa from the Selmon Express Lanes along Twiggs Avenue to Marion Street and along Meridian Avenue to Channelside Drive – to reduce congestion and wrong way entries. Selected RSUs will issue a WAVE Service Announcement (WSA) indicating that devices can upload vehicle situation/probe data stored in the vehicle. Using CV data from vehicle probes, traversing downtown signal timing will be automatically adjusted at each equipped intersection based on the current traffic conditions.

2.2 Mapping to Use Cases

These applications work in harmony to achieve the objectives set forth by the use-cases. An expanded list of applications that reside on the hardware components that will be deployed and their locations are given in Appendix A. Table 2-1 provides a mapping of the use-cases to different applications.

Table 2-1. Mapping of Use Cases to Applications

Use Case No.	Description	Applications Involved
1	Morning Backup	Curve Speed Warning Intelligent Signal Control Emergency Electronic Brake Light Forward Collision Warning
2	Wrong-way Entry	Red Light Violation Warning Probe Data Enabled Traffic Monitoring Intelligent Signal Control Intersection Movement Assist
3	Pedestrian Safety	Pedestrian in a signalized crosswalk warning Mobile Accessible Pedestrian Signal Intelligent Signal Control
4	Transit Signal Priority	Intelligent Signal Control Transit Signal Priority Probe Data Enabled Traffic Monitoring Intersection Movement Assist

Use Case No.	Description	Applications Involved
5	Trolley Conflicts	Intelligent Signal Control Mobile Accessible Pedestrian Signal Pedestrians in Signalized Crosswalk Vehicle Turning in Front of a Transit Vehicle
6	Traffic Progression	Intelligent Signal Control Probe Data Enabled Traffic Monitoring Intersection Movement Assist

Source: THEA, HNTB, Siemens

3 Curve Speed Warning

The Curve Speed Warning (CSW) application allows CVs to receive information, including recommended speeds, when approaching a curve. This capability allows the vehicle to provide a warning to the driver regarding the curve and its recommended speed, if the speed is beyond safe-speed. In addition, the vehicle can perform additional warning actions if the actual speed through the curve exceeds the recommended speed. For the THEA implementation, the application will be deployed at the ramp from Selmon Expressway onto (or off-from) Meridian Avenue, as shown in Figure 3-1. The application works two ways, in the morning, it will use queue information from I-SIG and in the afternoon, the merge is to a freeway. The CSW application will also take into consideration queues developed at the Twiggs Street and Meridian Avenue intersection to refine the recommended speeds.

Figure 3-1: Curve Speed Warning Location

Source HNTB

3.1 Description of the Application

This section describes how THEA will deploy the CSW application to help reduce morning traffic backups on the REL by Twiggs Street as well as to improve safety and rear-end collisions at the exit. The CSW application will monitor queue backups and update the information being sent to drivers about the recommended curve speed as they approach the backup. The RSU on the exit curve will broadcast the recommended speeds to CVs approaching the curve, which will inform the driver of a safe entry speed based on the curve geometry and the end of the queues that reduce the safe stopping distance per the Florida Drivers Manual.

3.1.1 Functional

The CSW application will be composed of a CSW application on the RSU, a CSW application on the OBUs, and an I-SIG application on downstream RSUs. As the queue begins to build in the right turn lane and onto the shoulder, exiting the REL, the RSU I-SIG application sends the queue length to the RSU CSW application. The RSU CSW application calculates the length of the queue and uses this length to calculate the available stopping distance. This distance is converted into a recommended speed, which is broadcasted to OBU-equipped vehicles.

When an OBU-equipped vehicle receives a recommended speed, the speed is converted into a warning speed compatible with the vehicle type (e.g., light vehicles, commercial vehicles, and transit). The vehicle-based application determines the true safe-speed of the vehicle based on its type. The warning speed is compared to the vehicle's actual speed. If the vehicle's actual speed exceeds the warning speed, an alert, containing the warning speed, is issued to the driver. It is up to the driver to decide what action to take when they receive a warning speed.

3.1.2 Interface

The following interfaces are required for the CSW application:

- The map is uploaded to the RSU CSW application (map to RSU CSW)
- The queue length within the map is sent from the RSU I-SIG application to RSU CSW application (RSU I-SIG to RSU CSW)
- The recommended speed is sent from the RSU CSW application to the OBU CSW application (RSU CSW to OBU CSW)
- The vehicle speed is sent from the vehicle through the OBD2 port to the OBU CSW (vehicle speed to OBU CSW).
- The OBU CSW uses Driver-Vehicle Interface (DVI) to alert the driver in unsafe situations using visual and audible feedbacks.

Further details on how the application fulfills the interface system requirements are depicted below:

- The map to RSU CSW sends the map for the intersection up the REL through the curve. This coverage is needed in order to determine the length of the queue.
- The RSU I-SIG to RSU CSW interface sends the queue length within the map so that the stopping distance can be calculated by the RSU CSW. Since queue-length differs from lane-to-lane, the maximum queue is used to improve safety of the application.
- The RSU CSW to OBU CSW interface sends the recommended speed so that the recommended speed can be compared to the vehicle speed.
- The vehicle speed to OBU CSW interface sends the vehicle speed for comparison to recommended speed.
- The OBU CSW to DRV interface sends the warning speed message to alert the driver they are exceeding the recommended speed which could result in a crash.

3.1.3 Performance

The CSW performs in real time. The queue length and recommended speed is continually broadcast so that the proper speed can be provided to drivers. Additional requirements are provided in the System Requirements (Task 6) document.

3.1.4 Data

Below is the CSW application data:

- Input: Map –provides the layout of the intersection curve radius
- Input: Coefficient of Friction: Road surface variations, such as grooved pavement versus asphalt. Modified based on the length of the queue.
- Input: Length of queue on the most-queued lane.
- Output: Recommended Speed – provided to the OBU CSW application to compare to the vehicle speed.

3.2 Description of the Components of the Application

This section gives a detailed description of the hardware and software components of the application, including interfaces, data inputs, and data outputs.

Hardware Components:

- RSU1: Installed on the REL
- RSU2: Installed at the intersection of Twiggs Street and Meridian Avenue
- RSU3: Installed at the intersection of Twiggs Street and Nebraska Avenue
- OBU1: Class 1 as part of OEM vehicle system
- OBU2: Class 2 installed as aftermarket device
- Weatherproof enclosures and mounting hardware for RSU1 and RSU2.

Software Components:

- CSW1: Application installed in RSU1
- CSW2: Application installed in OBU1 and OBU2
- I-SIG1: Application installed in RSU2 and RSU3
- MAP1: REL lane geometries from the Selmon to Twiggs Street.

Interfaces:

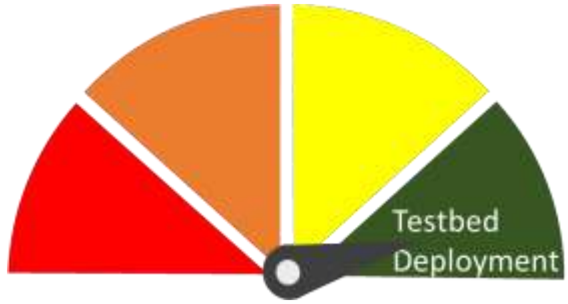
- Input to CSW1: MAP1
- Output from I-SIG1: Queue length within MAP1
- Input to CSW1: I-SIG1 queue length within MAP1
- Output from CSW1: CSW message to OBU1 and OBU2
- Input to OBU1 and OBU2: CSW message from CSW1.

Operational Description:

- CSW1 continually broadcasts curve speed advice for MAP1 based on Florida practices
- I-SIG1 continuously sends the queue length within MAP1 to CSW1
- CSW1 continually receives the queue length within MAP1 from I-SIG1
- CSW1 subtracts the queue length from the MAP1 length, resulting in the available stopping distance
- CSW1 calculates advice speed for available stopping distance, Florida Drivers Handbook, Chapter 5
- CSW1 broadcast to OBUn is continually adjusted to the advice speed
- OBUn continually receive the advice speed from CSW1
- OBUn adjusts the advice speed based on the individual vehicle type to create the warning speed
- OBUn compares the warning speed to the real-time vehicle speed
- OBU issues a driver warning if the vehicle speed exceeds the warning speed.

3.2.1 Maturity Level of the Application

Based on the available sources, the current level of maturity for CSW can be defined as **Test Bed Deployment**.



Source: Booz Allen Hamilton Siemens

CSW is part of the Connected Vehicle Reference Implementation Architecture (CVRIA). The physical, functional, communications, and enterprise architecture views for CSW are based on the following the Federal Highway Administration (FHWA) systems engineering documents:

- Accelerated V2I Safety Applications ConOps
- Accelerated V2I Safety Applications System Requirements.

It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities. CSW is also available on the OSADP through the Retrofit Safety Device (RSD) project. The RSD project was developed and deployed on commercial vehicles as part of the USDOT Connected Vehicle Safety Pilot to gain insight on aspects of deploying CV technology in a commercial vehicle environment.

Additionally, the application will utilize queue information at signalized intersections provided by the I-SIG application (which is also mature to testbed deployment level) and the code is available in the OSADP portal.

3.2.2 Required Development Work

Minimal development work will be done on the CSW application owing to its maturity and availability from previous pilot studies. The development work will concentrate around modifying the existing code available, as part of the RSD package, from the OSADP to incorporate queue information from subsequent I-SIG applications to adjust the stopping sight distance in calculations.

Note the CSW application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

3.2.3 Specific Hardware and Software Needs

There are specific hardware and software needs for this application, including the following:

- Hardware compliance to RD[1][1]
- Software compliance to RD[1]
- Software Development Kit (SDK) for each device in order to install applications. The SDK is needed to compile and configure the applications.

3.2.4 Required Interfaces, Inputs and Outputs

Table 3-1 lists the required I/O interfaces.

[1] Tampa Hillsborough Expressway Authority. (Draft -- March 2016). Connected Vehicle Pilot Deployment Program Phase I: System Requirements – Tampa (THEA). Federal Highway Administration (FHWA), USDOT

Table 3-1: CSW Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Medium
1	O	RSU2	Queue length within MAP1	DSRC
2	I	RSU1	Queue length within MAP1	DSRC
3	I	RSU3	Queue length within MAP2	DSRC
4	I	RSU1	Queue length within MAP2	DSRC
5	O	RSU1	CSW speed advice	DSRC
6	I	OBU1 and OBU2	CSW speed advice	DSRC
7	O	OBU1 and OBU2	Audible Warning	Acoustic
8	O	OBU1	Visual Warning	Visual

Source: THEA, HNTB, Siemens

3.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- CSW1: Siemens product or CAMP under distribution license
- CSW2: Siemens product or CAMP under distribution license
- I-SIG1: OSADP
- MAP1, MAP2: USDOT CV Tool Library, ISD Message Creator.

3.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This mode guarantees that, in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. If the CSW application fails or enters an error state, it will restart. Since very few vehicles will be OBU equipped, there is no danger as the driver is responsible for their actions regardless of whether the application is functioning or not. The application on the RSU will auto restart if the application fails or enters an error state. If the OBU or RSU hardware fails, the same scenario is true for the driver.

3.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE), and Test Reports (TR) will be required as follows:

- MTP
- LTP for I-SIG1
- LTP for CSW1
- LTP for CSW2
- LTP for MAP1
- LTP for I-SIG to CSW1 subsystem
- LTP for CSW1 to CSW2 subsystem
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP
- TR for each LTP.

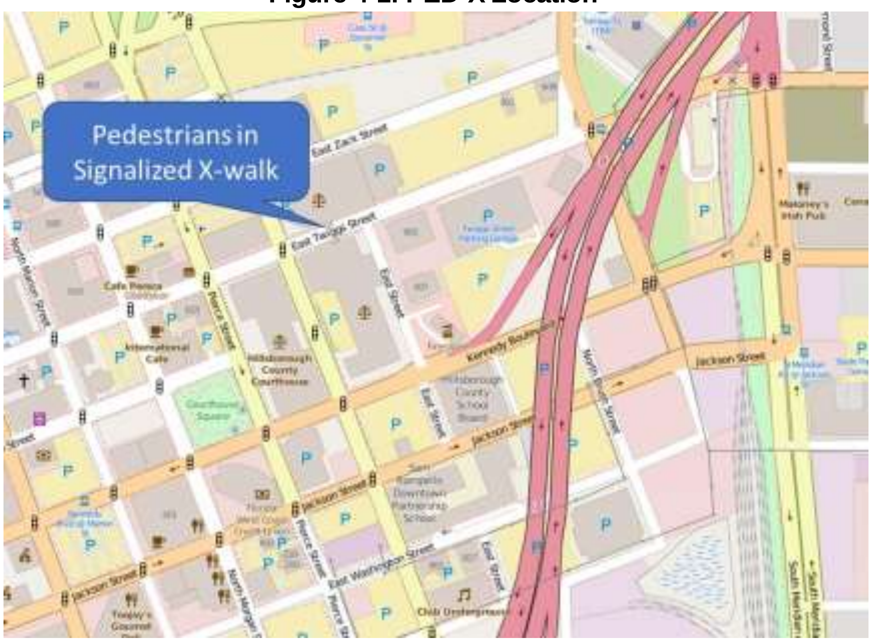
For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G
- Section 3.8 Installation and Operational Readiness Testing –Task 2-H

4 Pedestrian in Signalized Crosswalk

The Pedestrian in Signalized Crosswalk (PED-X) application provides information from infrastructure to the CV indicating the possible presence of pedestrians in a crosswalk at a signalized intersection. The infrastructure-based indication will include the outputs of pedestrian sensors or simply an indication that the pedestrian call button has been activated (i.e., to sense the crosswalk, curbside near the crosswalk, and jaywalkers outside of the crosswalk). This application has been defined for transit vehicles, but can be applicable to any class of vehicle. The PED-X application will also provide warning information to the pedestrian regarding crossing status or potential vehicle infringement into the crosswalk. The THEA deployment will focus on the isolated signalized crosswalk at East Twiggs Street near the courthouse, as shown in Figure 4-1.

Figure 4-1: PED-X Location



Source: HNTB

4.1 Description of the Application

This section describes how THEA will deploy the PED-X application at the crosswalk on Twiggs Street near the courthouse to help alert drivers and pedestrians to reduce the potential of a pedestrian being struck by a vehicle. The application provides the CV (i.e., OBU) information from infrastructure (i.e., RSU) that indicates the possible presence of pedestrians in a crosswalk at a signalized intersection. The infrastructure-based indication will include the outputs of pedestrian sensors or simply an indication that the pedestrian call button has been activated. The application will also provide warning information to the pedestrian regarding crossing status or potential vehicle infringement into the crosswalk.

4.1.1 Functional

As OBU equipped vehicles and personal information device (PID) equipped pedestrians approach one another near the crosswalk, each one of these devices are broadcasting position information. The PID position broadcast is received by the RSU over Wi-Fi. The RSU then converts it into a standard BSM, referred to as a Personal Safety Message (PSM). The RSU broadcasts the PSM over dedicated short range communications (DSRC). OBUs within range receive the PSM as well as other OBU BSMs.

Using a pedestrian detector at the crosswalk, the RSU receives an indication that a pedestrian has entered or going to enter the crosswalk. The RSU then generates Personal Safety Messages (PSM) indicating the pedestrian's presence to the equipped vehicle approaching the crosswalk received on its OBU. BSMs are used to continually calculate trajectories and determine if a potential collision is about to occur. If the OBU determines a collision is about to occur, the driver is issued an alert. The pedestrians will receive BSMs from vehicles that are approaching the crosswalk via the PIDs. The PIDs, similar to the vehicle OBUs, use BSMs to calculate trajectories and determine if a potential collision is about to occur. If the PID determines a collision is about to occur, the pedestrian is issued an alert. For equipped vehicles, this is done using the RSU that will receive BSMs from the vehicles. For unequipped vehicles, this is done using proxy BSMs generated by vehicle detectors.

4.1.2 Interface

The following interfaces are required for a PED-X application:

- Vehicle OBU BSMs to RSU
- Pedestrian PID location to RSU
- Vehicle detection to RSU
- Pedestrian detection to RSU
- RSU pedestrian PID location to RSU standard BSM
- RSU standard BSM to RSU pedestrian location
- RSU vehicle detection to RSU proxy BSM
- RSU pedestrian detection to RSU PSM
- RSU PSM to vehicle OBU
- RSU converted BSM to PID
- OBU to driver
- PID to pedestrian.

4.1.3 Performance

The performance of the PED-X application is twofold. The BSMs broadcast via DSRC will be transmitted at a rate of ten times per second. Similarly, the PID location data will be broadcast at a similar rate using Wi-Fi. These rates are necessary to provide the best opportunity to determine whether a crash may occur and to provide sufficient time for the person to react. Additional requirements are provided in the System Requirements (Task 6) document.

4.1.4 Data

The PED-X application provides the following data:

- Standard BSM – transmitted by OBU equipped vehicles. The primary fields used are the latitude, longitude, heading, and speed.
- Pedestrian PID location – provides the location of the pedestrian. The expected data is the latitude, longitude, heading, and speed.
- Proxy BSM – provides a BSM for unequipped vehicles/ pedestrians in the crosswalk. The primary data is the latitude, longitude, heading, and speed.
- Crash Alert Message – provides a warning to the driver that a potential crash is about to occur.

- Crash Alert with Vehicle Message – provide a warning to the pedestrian that a potential crash is about to occur.

4.2 Description of the Components of the Application

This section is to give a detailed description of the hardware and software components of the PED-X application, including interfaces and data inputs and outputs.

Hardware Components:

- RSU3: Installed within wireless range of the crosswalk
- OBU1: Class 1 as part of OEM vehicle system
- OBU2: Class 2 installed as aftermarket device
- OBU3: Class 3 installed as application on nomadic device
- VEH1: Vehicle detector
- PED1: Pedestrian detector
- Weatherproof enclosures and mounting hardware.

Software Components:

- LOC1: Location service installed in OBU1
- LOC2: Location service installed in OBU2
- LOC3: Location service installed in OBU3
- Translator (TRX)1: Wi-Fi to DSRC media translator installed in RSU3
- TRX2: DSRC to Wi-Fi media translator installed in RSU3
- PRX1: Vehicle proxy installed in RSU3
- PRX2: Pedestrian proxy installed in RSU3
- FCW1: Application installed in OBU1 and OBU2
- FCW3: Application installed in OBU3
- MAP2: Lane geometry of crosswalk.

Interfaces:

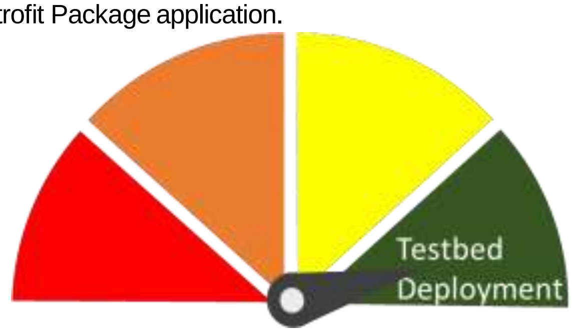
- Output from LOC1: BSM
- Output from LOC2: BSM
- Output from LOC3: PSM
- Input to TRX1: PSM
- Output from TRX1: BSM
- Input to TRX2: BSM
- Output from TRX2: PSM
- Output from VEH1: Vehicle Occupancy
- Input to PRX1: Vehicle Occupancy
- Output from PRX1: BSM and PSM
- Input to PRX2: Crosswalk Occupancy
- Output from PRX2: BSM and PSM
- Input to FCW1: BSM
- Output from FCW1: Forward crash warning
- Input to FCW3: PSM
- Output from FCW3: Pedestrian crash warning.

Operational Description:

- LOC1 continually broadcasts BSM from vehicle systems
- LOC2 continually broadcasts BSM from aftermarket OBU
- LOC3 broadcasts PSM from nomadic device when within MAP2
- TRX1 continually translates received PSM to transmitted BSM
- TRX2 continually translates received BSM received to transmitted PSM
- VEH1 continually sends occupancy bit per detection zone to PRX1
  - PRX1 compares occupied zone locations to BSMs
  - If occupied zone location matches any BSM, occupancyfor the equipped vehicle is discarded
  - If occupied location does not match any BSM, a proxy BSM for unequipped vehicle is sent
- PED1 continually sends occupancy bit per detection zone to PRX2
  - PRX2 compares occupied zone locations to BSMs
  - If occupied location matches any BSM, occupancy for the equipped pedestrian is discarded
  - If occupied location does not match a BSM, a proxy BSM for unequipped pedestrian is sent
- FCW1 continually calculates crash trajectories towards all BSM
- FCW1 activates forward crash warning if on crash trajectory with any BSM
- FCW3 continually calculates crash trajectories towards all PSM
- FCW3 activates forward crash warning if on crash trajectory with any PSM.

4.2.1 Maturity Level of the Application

Based on the available sources, the current level of maturity for PED-X can be defined as **Testbed Deployment** since it was deployed to a limited extent at the USDOT's Safety Pilot Model Deployment in Ann Arbor as a Transit Safety Retrofit Package application.



Source: Booz Allen Hamilton Siemens

PED-X is part of the CVRIA, which has based the physical, functional, communications, and enterprise architecture views from the following FHWA systems engineering documents and Society of Automotive Engineers (SAE) standards.

- Transit Safety Retrofit Package Development TRP Concept of Operations
- Transit Safety Retrofit Package Development Architecture and Design Specifications
- Transit Safety Retrofit Package Development Applications Requirements
- SAE J3067- Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary (SAE J2735) Using Systems Engineering Methods.

It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities.

4.2.2 Required Development Work

The team will use CAMP's PED-X application and build additional functionalities on it. This application is already well tested for transit vehicles. The team will add use of proxy BSMs from unequipped vehicles and PSMs from equipped pedestrians as additional inputs to the application.

Note the PED-X application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

4.2.3 Specific Hardware and Software Needs

This application has the following specific hardware and software needs:

- RSU hardware compliance to RD[1]
- RSU software compliance to RD[1]
- RSU includes Wi-Fi
- Vehicle detector includes Ethernet IP access to occupancy for each detection zone
- Pedestrian detector includes Ethernet IP access to occupancy for each detection zone
- SDK for each device in order to install applications.

4.2.4 Required Interfaces, Inputs and Outputs

Table 4-1 lists the required I/O interfaces.

Table 4-1: PED-X Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Media
1	O	OBU1	BSM	DSRC
2	I	OBU1	BSM	DSRC
3	O	OBU2	BSM	DSRC
4	I	OBU2	BSM	DSRC
5	O	OBU3	PSM	Wi-Fi
6	I	OBU3	PSM	Wi-Fi
7	O	VEH1	Occupancy	Ethernet
8	O	PED1	Occupancy	Ethernet
9	I	RSU3	PSM	Wi-Fi
10	O	RSU3	BSM	DSRC
11	I	RSU3	BSM	DSRC
12	O	RSU3	PSM	Wi-Fi
13	I	RSU3	VEH1 Occupancy	Ethernet
14	I	OBU1	PED1 Occupancy	Ethernet
15	O	OBU1	Forward Crash Warning	Acoustic
16	O	OBU1	Forward Crash Warning	Visual
17	O	OBU2	Forward Crash Warning	Acoustic
18	O	OBU3	Forward Crash Warning	Acoustic
19	O	OBU3	Forward Crash Warning	Visual

Source: Siemens

4.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- LOC1: Included in Class 1 OBU vehicle system
- LOC2: Included in Class 2 OBU license
- LOC3: Included in nomadic device license agreement
- TRX1: Siemens under distribution license
- TRX2: Siemens under distribution license
- PRX1: Siemens under distribution license
- PRX2: Siemens under distribution license
- FCW1: CAMP under distribution license
- FCW3: CAMP under distribution license
- MAP2: USDOT CV tool library, ISD message creator.

4.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the Pedestrian in a Signalized Crosswalk application, if the application on the PID, RSU, or OBU fail or enter into an error state, the application will restart. Since very few pedestrians and vehicles will be equipped, there is no additional danger to the driver or the pedestrians as the drivers and pedestrians are responsible for their actions regardless of whether the application is functioning or not. If the RSU or OBU hardware fails, the same scenario is true for the drivers and pedestrians.

4.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE), and Test Reports (TR) will be required as follows:

- MTP
- LTP for LOC1
- LTP for LOC2

- LTP for LOC3
- LTP for TRX1
- LTP for TRX2
- LTP for PRX1
- LTP for PRX2
- LTP for FCW1
- LTP for FCW3
- LTP for MAP2
- LTP for VEH1 to RSU3 subsystem
- LTP for PED1 to RSU3 subsystem
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP
- TR for each LTP.

For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G

Section 3.8 Installation and Operational Readiness Testing –Task 2-H

5 Red Light Violation Warning

Wrong Way Warnings are enabled by the Red Light Violation Warning (RLVW) application which enables a CV approaching an instrumented signalized intersection to receive information from the infrastructure regarding the intersection's signal timing and the geometry. In this Use Case, the RLV application in the vehicle uses its speed and acceleration profile, along with the signal timing and geometry information to determine if it appears likely that the vehicle will enter the REL in violation of the legal traffic direction at that time of day. If the violation seems likely to occur, the application will send a warning to the driver. The application will be deployed at the REL exits towards Meridian Avenue, as shown in Figure 5-1.

Figure 5-1: Wrong Way Warning Location

Source: HNTB

5.1 Description of the Application

This section describes how THEA will deploy the RLVW application, which will be adapted to warn drivers of wrong way entries onto the REL. The entrance/exit point of the REL at Meridian Avenue and Twiggs Street is a potential site for wrong-way entries, specifically during inbound operations (6:00 am – 1:30 pm weekdays). At the exit to the REL on 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 REL exit to prevent drivers from entering the REL going the wrong way. Additionally, drivers traveling on East Twiggs Street approaching the intersection where the REL ends and Meridian Street begins can mistakenly enter the REL going the wrong way. Drivers approaching this intersection coming from downtown can inadvertently make a left turn onto the REL exit. Conversely, drivers on East Twiggs Street approaching this intersection going towards downtown can inadvertently make a right turn onto the REL exit. Finally, drivers approaching the intersection on Meridian can potentially veer slightly to the left onto the REL exit.

5.1.1 Functional

As OBU equipped vehicles approach the REL at Twiggs Street intersection, the OBUs receive SPaT from the RSU. The OBUs also receive the MAP from the RSU. The RLVW application uses SPaT and MAP to determine if the vehicle is going to “run a red light” or, in this case, drive the wrong way and into oncoming traffic. If an RLVW is detected, the OBU issues a wrong way driver alert to the driver.

The green and red phases are reversed twice a day to account for the reversal of the express lane.

5.1.2 Interface

The RLVW interfaces are as follows:

- RSU to OBU
- OBU to driver.

Further details on how the application fulfills the interface system requirements are depicted below:

- The OBU to RSU interface provides the communication between the intersection RSU and the OBUs via DSRC. The SPaT and MAP messages are broadcast from the RSU and received by the OBUs.
- The OBU to driver interface provide the communication between the OBU and the driver via an audio and/or a visual warning. The OBU provides a wrong way warning to the driver.

5.1.3 Performance

The RSU/OBU communication is performed via DSRC at a rate of ten times per second. The OBU/driver communication is performed in real time. Additional requirements are provided in the System Requirements (Task 6) document.

5.1.4 Data

The RLVW application provides the following data:

- SPaT – the current signal phase and timing data
- MAP – the geometry of the intersection
- Red Light Violation Warning – the alert to the driver and the TMC operator and to trigger an alert to approaching drivers. The TMC operator alerts law enforcement (e.g., Tampa Police Department, Florida Highway Patrol, Sherriff Department).

5.2 Description of the Components of the Application

Hardware Components:

- RSU4: Installed at REL entrance at Twiggs Street
- OBU1: Class 1 installed as part of vehicle system
- OBU2: Class 2 installed as aftermarket device
- Weatherproof enclosures and mounting hardware for RSU2.

Software Components:

- BSM: Installed in OBU1 and OBU2

- SPaT: Installed in CU to send signal state and countdown to change
- MAP3: Geometry of lane placement approaching the REL from Twiggs Street
- Two phase signal control application
- RLV: Red light violation installed in OBU1 and OBU2.

Interfaces:

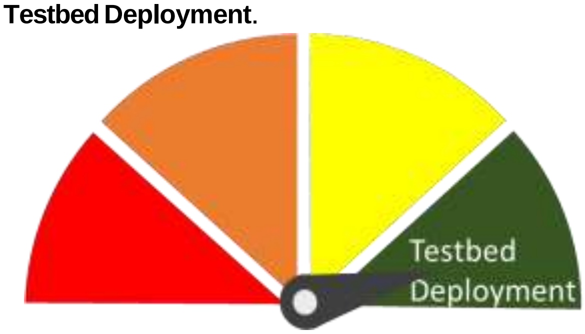
- OBU1 and OBU2 Input: SPaT
- OBU1 and OBU2 Input: MAP
- RSU4 output: MAP3
- Output from RLV: RLV warning to driver.

Operational Description:

- OBU1 and OBU2 receive SPaT from RSU4
- OBU1 and OBU2 receive MAP from RSU4
- RLV predicts Red Light at arrival based on MAP, SPaT, location, heading and speed
- If predicted to Red at arrival, RLV issued driver warning
- CU signal control changes inbound and outbound phases from Red to Green twice per day.

5.2.1 Maturity Level of the Application

The maturity level of Red Light Violation Warning (RLVW) application, from which RLVW application will be adapted, can be defined as **Testbed Deployment**.



Source: Booz Allen Hamilton Siemens

The application has been prototyped and was deployed to a limited extent in the Michigan Safety Pilot Model. The system architecture is provided in the CVRIA and has based the physical, functional, communications, and enterprise architecture views for RLVW from the following FHWA documents and SAE standards:

- Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications Concept of Operations
- SAE J3067- Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary (SAE J2735) Using Systems Engineering Methods.

It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities.

5.2.2 Required Development Work

The team will leverage existing CAMP or Siemens RLVW applications; therefore minimal development and testing will be required to restructure the application for the specific intersection.

Note the RLVW application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

5.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- RSU hardware compliance to RD[1]
- RSU software compliance to RD[1]
- SDK for each device in order to install applications.

5.2.4 Required Interfaces, Inputs and Outputs

Table 5-1 lists the required I/O interfaces.

Table 5-1: Red Light Violation Warning Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Media
1	O	CU	SPaT	Ethernet
2	I	RSU4	SPaT	Ethernet
3	O	RSU4	SPaT	DSRC
4	I	RLV	SPaT	DSRC
5	I	RLV	MAP	DSRC
6	O	RLV	RLV Warning	Acoustic
7	O	RLV	RLV Warning	Visual

Source: Siemens

5.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- SPaT: Siemens on distribution agreement
- RLVW: CAMP on distribution agreement
- MAP: USDOT CV Tool Library, ISD Message Creator.

5.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the RLVW application, if the application itself fails or enters an error state, the application will restart. Since very few vehicles will be OBU equipped, there is no danger from the application that affects the driver. However, as the driver is headed in the wrong direction, both they and other nearby drivers are at risk. The wrong way driver is responsible for their actions regardless of whether the application is functioning or not. The application on the RSU will automatically restart if the application fails or enters and error state. If the OBU or RSU hardware fails, the same scenario is true for the driver.

5.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE) and Test Reports (TR) as follows:

- MTP
- LTP for SPaT
- LTP for MAP
- LTP for RLV
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP
- TR for each LTP

For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G
  Section 3.8 Installation and Operational Readiness Testing –Task 2-H.

6 Intersection Movement Assist

The Intersection Movement Assist (IMA) application warns the driver when it is not safe to enter an intersection due to high collision probability with other vehicles at stop sign controlled and uncontrolled intersections. This application can provide collision warning information to the driver. The driver may then perform actions to reduce the likelihood of crashes at intersections. The team has identified two potential corridors for the deployment of this application – The Meridian Avenue corridor, including the REL exit onto Meridian, and Kennedy Boulevard corridor. Both of these potential corridors are shown in Figure 6-1.

Figure 6-1: Intersection Movement Assist Use Case Locations

Source: HNTB

6.1 Description of the Application

This section describes how THEA will deploy the IMA application to increase safety at six intersections along Meridian Avenue by warning drivers when it is not safe to enter an intersection due to high collision probability. The application will be deployed on Kennedy Boulevard, which is a one-way street and at the REL exit to assist in detecting wrong way drivers.

6.1.1 Functional

OBU equipped vehicles continuously broadcast BSMs. When approaching or at an intersection, the IMA application analyzes all OBU BMSs it receives. When the application determines that the intersection is clear of approaching or turning vehicles, it provides a message to the driver to proceed with caution, as there could be unequipped vehicles approaching as well. When conflicts are detected, the drivers will be alerted to stop.

6.1.2 Interface

The IMA interfaces are as follows:

- Vehicle OBU to vehicle OBU
- Vehicle OBU to driver.

Further details on how the application fulfills the interface system requirements are described below:

- The vehicle OBU to vehicle OBU is the communications between the OBUs via DSRC. These vehicles continuously broadcast BSMs that other OBUs receive.
- The vehicle OBU to driver interface is the communication between the IMA application and the driver via visual and/or audio means. The interface provides a message to the driver to proceed through the intersection with caution. It is up to the driver to be aware of approaching/turning vehicles that may be unequipped and take action and no response is required of the driver.

6.1.3 Performance

The performance of the DSRC communications is expected to be ten times a second. The communication with the driver will be real time. Additional requirements are provided in the System Requirements (Task 6) document.

6.1.4 Data

The IMA application provides the following data:

- BSM – contains latitude, longitude, heading, elevation, and speed
- Driver Intersection Message – contains the “proceed with caution” message to the driver.

6.2 Description of the Components of the Application

This section is to give a detailed description of the hardware and software components of the application, including interfaces and data inputs and outputs.

Hardware Components:

- OBU1: Class 1 as part of OEM vehicle system
- OBU2: Class 2 installed as aftermarket device.

Software Components:

- IMA: Application installed in OBU1 and OBU2
- BSM: Application installed in OBU1 and OBU2.

Interfaces:

- Output from OBU1 and OBU2: BSM
- Input to OBU1 and OBU2: BSM.

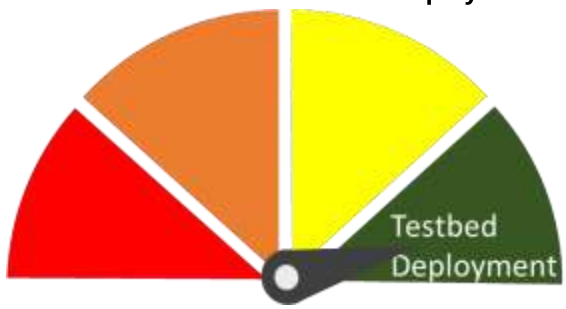
Operational Description:

- OBU1 and OBU2 continually broadcast BSM

- OBU1 and OBU2 continually receive BSM
- OBU1 and OBU2 continually analyze the position and movement of oncoming and crossing vehicles
- If no oncoming or crossing vehicles are present, driver is advised to proceed through intersection.

6.2.1 Maturity Level of the Application

The maturity level of IMA application can be defined as **Testbed Deployment**.



Source: Booz Allen Hamilton Siemens

IMA is in the CVRIA and has based the physical, functional, communications, and enterprise architecture views for IMA from the Vehicle Safety Communications Applications (VSC-A) Final Report. It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities. The team will utilize the CAMP's IMA application and modify it for the intersection in Tampa region.

6.2.2 Required Development Work

Even though the application is not available on the OSADP, the team will leverage the CAMP IMA application. Moderate development work may be expected on the following fronts:

1. Front end development for the driver-vehicle interface to provide visual and audible alerts.
2. Back end development for the algorithm that detects conflicts using trajectory projection and threat determination algorithm as stated in the Vehicle Safety Communications Applications (VSC-A) Report.

Note the IMA application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

6.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- OBU1 and OBU2: Location service accurate to 1 meter
- OBU1 and OBU2: Elevation required differentiating upper from lower levels.

6.2.4 Required Interfaces, Inputs and Outputs

Table 6-1 lists the required I/O interfaces.

Table 6-1: Intersection Movement Assist Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Media
1	I	OBU1 and OBU2	BSM	DSRC
2	O	OBU1 and OBU2	BSM	DSRC

3	O	OBU1 and OBU2	Driver Assist	Acoustic
4	O	OBU1 and OBU2	Driver Assist	Visual

Source: Siemens

6.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- BSM: CAMP on distribution agreement
- IMA: CAMP on distribution agreement.

6.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the IMA application, if the application itself fails or goes into an error state, the application will restart. Since very few vehicles will be OBU equipped, there is no danger to the driver or other drivers as the driver is responsible for their actions regardless of whether the application is functioning or not. If the OBU hardware fails, the same scenario is true for the driver.

6.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE) and Test Reports (TR) as follows:

- MTP
- LTP for BSM
- LTP for IMA
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP

- TR for each LTP.

For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G

Section 3.8 Installation and Operational Readiness Testing –Task 2-H

7 Emergency Electronic Brake Light

The Emergency Electronic Brake Light (EEBL) application enables a vehicle to broadcast a self-generated emergency brake event 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 in order 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, heavy rain). This application would be beneficial to vehicles exiting from the Selmon Expressway onto Meridian Avenue, as shown in Figure 7-1.

Figure 7-1: Emergency Electronic Brake Light Use Case Location

Source: HNTB

7.1 Description of the Application

This section describes how THEA will deploy the EEBL application 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. There are two levels of warning; cautionary, that warns the driver of vehicles that are braking hard that are out of lane, and imminent, that warns the driver if there is hard braking in their own lane.

7.1.1 Functional

The EEBL application provides warnings to drivers that a vehicle is braking ahead beyond a predefined threshold (defined as emergency braking). For all OBU equipped vehicles, when a vehicle (termed the lead vehicle) brakes, a braking message is broadcast from the lead vehicle. Vehicles behind the lead vehicle (termed trailing vehicles) will receive the lead vehicle’s braking message. The trailing vehicles process the message and determine if a warning message is warranted to the driver. If a warning message is required, the OBU alerts the driver of hard braking ahead.

7.1.2 Interface

The EEBL interfaces are as follows:

- Lead vehicle OBU to trailing vehicle OBU
- Trailing vehicle OBU to driver.

Further details on how the application fulfills the interface system requirements are depicted below:

- The lead vehicle OBU to trailing vehicle OBU interface is the communication between the OBUs performed via DSRC. The lead vehicle OBU broadcasts that it is braking. Trailing vehicle OBUs receive the broadcast. There is no response from the trailing vehicle OBUs to the lead vehicle OBU.
- The trailing vehicle OBU to driver interface is the communication from the OBU application to the driver via visual and/or audio means. The interface provides a warning to the driver of hard braking ahead. It is up to the driver to take action and no response is required of the driver.

7.1.3 Performance

The performance of the DSRC communications is expected to be ten times a second. The communication with the driver will be in real time. Additional requirements are provided in the System Requirements (Task 6) document.

7.1.4 Data

The EEBL application provides the following data:

- EEBL Message – contains the braking effort of the lead vehicle
- Driver Alert Message – contains the hard braking warning to the driver.

7.2 Description of the Components of the Application

This section is to give a detailed description of the hardware and software components of the application, including interfaces and data inputs and outputs.

Hardware Components:

- OBU1: Class 1 as part of vehicle system.
- OBU2: Class 2 installed as aftermarket device.

Software Components:

- EEBL.

Interfaces:

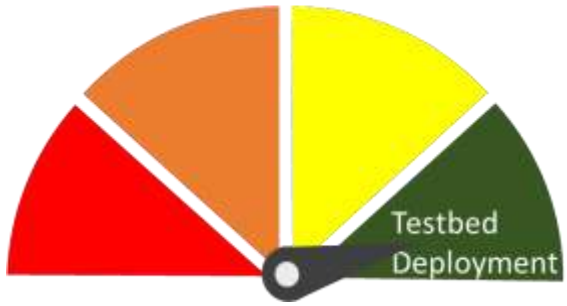
- Output from OBU1: EEBL
- Input to OBU1: EEBL.

Operational Description:

- Leading OBU1 sends EEBL proportional to brake effort
- Trailing OBU1 receives EEBL from braking vehicle
- Trailing OBU1 compares leading OBU1 braking effort to warning threshold
- If leading OBU1 braking effort exceeds the warning threshold, trailing OBU1 issues driver warning.

7.2.1 Maturity Level of the Application

Based on the available sources, the current level of maturity for the EEBL can be defined as **Test Bed Deployment**.



Source: Booz Allen Hamilton Siemens

EEBL is part of the CVRIA and has based the physical, functional, communications, and enterprise architecture views for EEBL from the Vehicle Safety Communications Applications (VSC-A) Final Report. CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities. EEBL is available on the OSADP through the RSD project. The RSD project was developed and deployed on commercial vehicles as part of the USDOT Connected Vehicle Safety Pilot to gain insight on aspects of deploying CV technology in a commercial vehicle environment. In addition to being on the OSADP, Safety Pilot data sets and data environments can be found on the RDE.

7.2.2 Required Development Work

Minimal development work will be done for the CAMP version of the application, since the OSADP version does not provide lane tracking. Modifications would be done to match vehicle physical characteristics that would be deployed in Tampa as CVs.

Note the EEBL application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

7.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- OBU1: Needs braking information from vehicle system data bus.

7.2.4 Required Interfaces, Inputs and Outputs

Table 7-1 lists the required I/O interfaces.

Table 7-1: Emergency Electronic Brake Light Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Media
1	I	OBU1	Braking effort	CAN bus
2	O	OBU1	EEBL	DSRC
3	I	OBU1	EEBL	DSRC
4	O	OBU1	Driver Warning	Acoustic
5	O	OBU1	Driver Warning	Visual

Source: Siemens

7.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for this application:

- EEBL: CAMP on distribution agreement.

7.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the EEBL application, if the application itself fails or goes into an error state, the application will restart. Since very few vehicles will be OBU equipped, there is no danger to the driver or other drivers as the driver is responsible for their actions regardless of whether the application is functioning or not. If the OBU hardware fails, the same scenario is true for the driver.

7.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE), and Test Reports (TR) will be required as follows:

- MTP
- LTP for EEBL
- LTP for Leading OBU1 to Trailing OBU1 EEBL
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP
- TR for each LTP.

For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G

Section 3.8 Installation and Operational Readiness Testing –Task 2-H

8 Forward Collision Warning

The Forward Collision Warning (FCW) application is intended to warn the driver of an impending rear-end collision with another vehicle ahead that is ahead in traffic, and in the same lane and direction of travel. The application uses data received from other vehicles to determine if a forward collision is imminent. FCW is intended to advise drivers to take specific action in order to avoid or mitigate rear-end vehicle collisions in the forward path of travel by lane. The application would benefit the vehicles exiting from the Selmon Expressway onto Meridian Avenue, as shown in Figure 8-1.

Figure 8-1: Forward Collision Warning Use Case Location

Source: HNTB

8.1 Description of the Application

This section describes how THEA will deploy the FCW application to increase safety by reducing accidents during peak traffic hours on the REL. As vehicles approach the REL exit, they may not be able to anticipate the location of the end of the queue for the right turn lane, potentially causing them to hard brake. The FCW will send warnings to the driver if a vehicle ahead brakes suddenly and if the time to collision is less than a prescribed number of seconds.

Note: FCW will only look at the lead vehicle. EEBL is a message sent to the following platoon of vehicles when an emergency braking event occurs.

8.1.1 Functional

The FCW provides a warning to a vehicle following/approaching a vehicle in front of it. The trailing vehicle and the lead vehicle are equipped with OBUs that are continually broadcasting BSMs. The trailing vehicle uses the lead vehicle's BSMs to calculate a trajectory and determine if the vehicles are on a crash course. If the trailing vehicle determines that it is on a crash course, the trailing vehicle OBU issues a warning to the driver. It is up to the driver to take the appropriate actions.

8.1.2 Interface

The FCW interfaces are as follows:

- Lead vehicle OBU to trailing vehicle OBU
- Trailing vehicle OBU to driver.

Further details on how the application fulfills the interface system requirements are depicted below:

- The lead vehicle OBU to trailing vehicle OBU is the communications between the OBUs via DSRC. These vehicles continuously broadcast BSMs that other OBUs receive.
- The trailing OBU to driver interface is the communication between the FCW application and the driver via visual and/or audio means. The interface provides a warning to the driver of a potential crash ahead. It is up to the driver to take action.

8.1.3 Performance

The performance of the DSRC communications is expected to be ten times a second. The communication with the driver will be real time. Additional requirements are provided in the System Requirements (Task 6) document.

8.1.4 Data

The FCW application provides the following data:

- BSM – contains latitude, longitude, heading, elevation, and speed
- Driver Alert Message – contains the potential crash warning to the driver.

8.2 Description of the Components of the Application

This section is to give a detailed description of the hardware and software components of the application, including interfaces and data inputs and outputs.

Hardware Components:

- OBU1: Class 1 as part of OEM vehicle system
- OBU2: Class 2 installed as aftermarket device.

Software Components:

- FCW: Application installed in OBU1 and OBU2
- BSM: Application installed in OBU1 and OBU2.

Interfaces:

- Output from OBU1 and OBU2: BSM
- Input to OBU1 and OBU2: BSM.

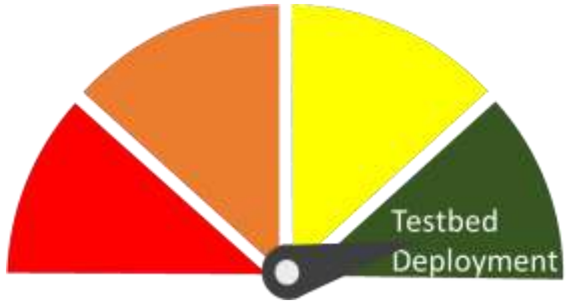
Operational Description:

- OBU1 and OBU2 continually broadcast BSM
- OBU1 and OBU2 continually receive BSM
- OBU1 and OBU2 continually calculate crash trajectories towards other BSMs.

If OBU1 or OBU2 is on crash trajectory, a FCW is issued to the driver.

8.2.1 Maturity Level of the Application

Based on the available sources and planned modifications, the current level of maturity for Forward Collision Warning (FCW) can be defined as **Test Bed Deployment**.



Source: Booz Allen Hamilton Siemens

FCW is part of the CVRIA, which has based the physical, functional, communications, and enterprise architecture views for FCW's architecture from the Vehicle Safety Communications Applications (VSC-A) Final Report. It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities.

FCW is available on the OSADP through the RSD project. The RSD project was developed and deployed on commercial vehicles as part of the USDOT Connected Vehicle Safety Pilot to gain insight on aspects of deploying CV technology in a commercial vehicle environment.

8.2.2 Required Development Work

Minimal development work will be done for the FCW application owing to its maturity and availability from previous pilot studies. The development work will concentrate around modifying the existing code available as part of the Retrofit Safety Device package from the OSADP. The modifications anticipated at this time are:

1. Modifications to match the SDK for the OBUs and RSEs that will be used in the THEA Deployment.
2. Modifications to front-end audible/visual warnings provided to drivers.
3. Modifications to match vehicle physical characteristics that would be deployed in Tampa as CVs.

Note the FCW application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

8.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- OBU1 and OBU2: Location service accurate to 1 m
- OBU1 and OBU2: Elevation required differentiating upper from lower levels.

8.2.4 Required Interfaces, Inputs and Outputs

Table 8-1 lists the required I/O interfaces.

Table 8-1: Forward Collision Warning Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Media
1	I	OBU1 and OBU2	BSM	DSRC
2	O	OBU1 and OBU2	BSM	DSRC
3	O	OBU1 and OBU2	Driver Warning	Acoustic
4	O	OBU1 and OBU2	Driver Warning	Visual

Source: Siemens

8.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- BSM: CAMP on distribution agreement
- FCW: CAMP on distribution agreement.

8.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the FCW application, if the application itself fails or goes into an error state, the application will restart. Since very few vehicles will be OBU equipped, there is no danger to the driver or other drivers as the driver is responsible for their actions regardless of whether the application is functioning or not. If the OBU hardware fails, the same scenario is true for the driver.

8.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE) and Test Reports (TR) as follows:

- MTP
- LTP for BSM

- LTP for FCW
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP
- TR for each LTP.

For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G
- Section 3.8 Installation and Operational Readiness Testing –Task 2-H

9 Vehicle Turning Right in Front of a Transit Vehicle

The Vehicle Turning Right in Front of a Transit Vehicle (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 to make a right turn. This application will help the transit vehicle determine if the area in front of it will not be occupied as it begins to pull away from a transit stop. The team will use this application to reduce the conflicts between right-turning CVs and the TECO trolley line, which runs parallel to the Channelside Drive at the four right-turning intersections, as shown in Figure 9-1 below.

Figure 9-1: Vehicle Turning in Front of a Transit Vehicle Use Case Locations

Source: HNTB

9.1 Description of the Application

This section describes how THEA will deploy the VTRFTV application. The application will be deployed along the TECO Line Trolley, which runs along Channelside Drive from the Amalie Arena area and past the Selmon Expressway. The trolley runs parallel to vehicle lanes with a common approach to traffic control signals. The signal will be red for all vehicle phases during the trolley crossing. However, right turn on red is typically a legal move, which may cause a motorist, unaware of the trolley's presence, to turn right into the trolley's path.

9.1.1 Functional

OBU equipped vehicles and trolleys continuously broadcast BSMs. When a trolley is approaching or at an intersection, the VTRFTV application analyzes all OBU BSMs it receives. If the application determines that a vehicle is turning right into the trajectory of the trolley, a warning is issued to the trolley operator. It is up to the trolley operator to take action.

9.1.2 Interface

The VTRFTV interfaces are as follows:

- Vehicle OBU to trolley OBU
- Trolley OBU to operator.

9.1.3 Performance

The performance of the DSRC communications is expected to be ten times a second. The communication with the operator will be real time. Additional requirements are provided in the System Requirements (Task 6) document.

9.1.4 Data

The VTRFTV application provides the following data:

- BSM – contains latitude, longitude, heading, and speed
- Vehicle Right Turn Message – contains the vehicle turning right warning message.

9.2 Description of the Components of the Application

This section is to give a detailed description of the hardware and software components of the application, including interfaces and data inputs and outputs.

Hardware Components:

- OBU1: Class 1 as part of OEM vehicle system
- OBU2: Class 2 installed as aftermarket device.

Software Components:

- VTRFTV: Application installed in OBU1 and OBU2
- BSM: Application installed in OBU1 and OBU2.

Interfaces:

- Output from OBU1 and OBU2: BSM
- Input to OBU1 and OBU2: BSM.

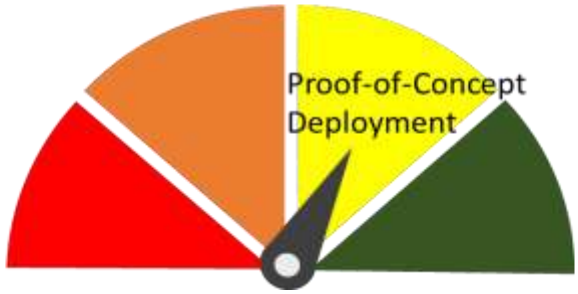
Operational Description:

- OBU1 and OBU2 continually broadcast BSM
- OBU1 and OBU2 continually receive BSM

- OBU1 and OBU2 continually analyze the position and movement of nearby vehicles
- When trolley is ready to move, trolley operator is warned of nearby vehicles on a crash trajectory to bus trajectory.

9.2.1 Maturity Level of the Application

Vehicle Turning in Front of a Bus, or more commonly referred to as Vehicle Turning Right in Front of a Transit Vehicle (VTRFTV), can be defined as **Proof-of-Concept Deployment.**



Source: Booz Allen Hamilton Siemens

VTRFTV is in the CVRIA and has based the physical, functional, communications, and enterprise architecture views for VTRFTV from the following FHWA documents and SAE standards.

- Transit Safety Retrofit Package Development Applications Requirements
- Transit Safety Retrofit Package Development Architecture and Design Specifications
- Transit Safety Retrofit Package Development TRP Concept of Operations
- SAE J3067- Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary (SAE J2735) Using Systems Engineering Methods.

It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities.

9.2.2 Required Development Work

The application has been deployed in Michigan as part of the Transit Safety Retrofit Package, but is not available for public use from the OSADP portal. The team will work acquire this package and adapt it for the use in Tampa. Additional development will be required to integrate them to transit on-board equipment (OBE) as well as to develop a transit driver-vehicle interface that will show the alerts and warnings.

Note the VTRFTV application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

9.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- OBU1 and OBU2: Location service accurate to 1 meter
- OBU1 and OBU2: Elevation required differentiating upper from lower levels.

9.2.4 Required Interfaces, Inputs and Outputs

Table 9-1 lists the required I/O interfaces.

Table 9-1: Vehicles Turning in Front of a Bus Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Media
1	I	OBU1 and OBU2	BSM	DSRC
2	O	OBU1 and OBU2	BSM	DSRC
3	O	OBU1 and OBU2	Bus Startup Warning	Acoustic
4	O	OBU1 and OBU2	Bus Startup Warning	Visual

Source: Siemens

9.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- BSM: CAMP on distribution agreement
- VTRFTV: CAMP on distribution agreement.

9.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the VTRFTV application, if the application itself fails or goes into an error state, the application will restart. Since very few vehicles will be OBU equipped, there is no danger to the driver or other drivers as the driver is responsible for their actions regardless of whether the application is functioning or not. If the OBU hardware fails, the same scenario is true for the driver.

9.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE) and Test Reports (TR) as follows:

- MTP
- LTP for BSM

- LTP for VTRFTV
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP
- TR for each LTP.

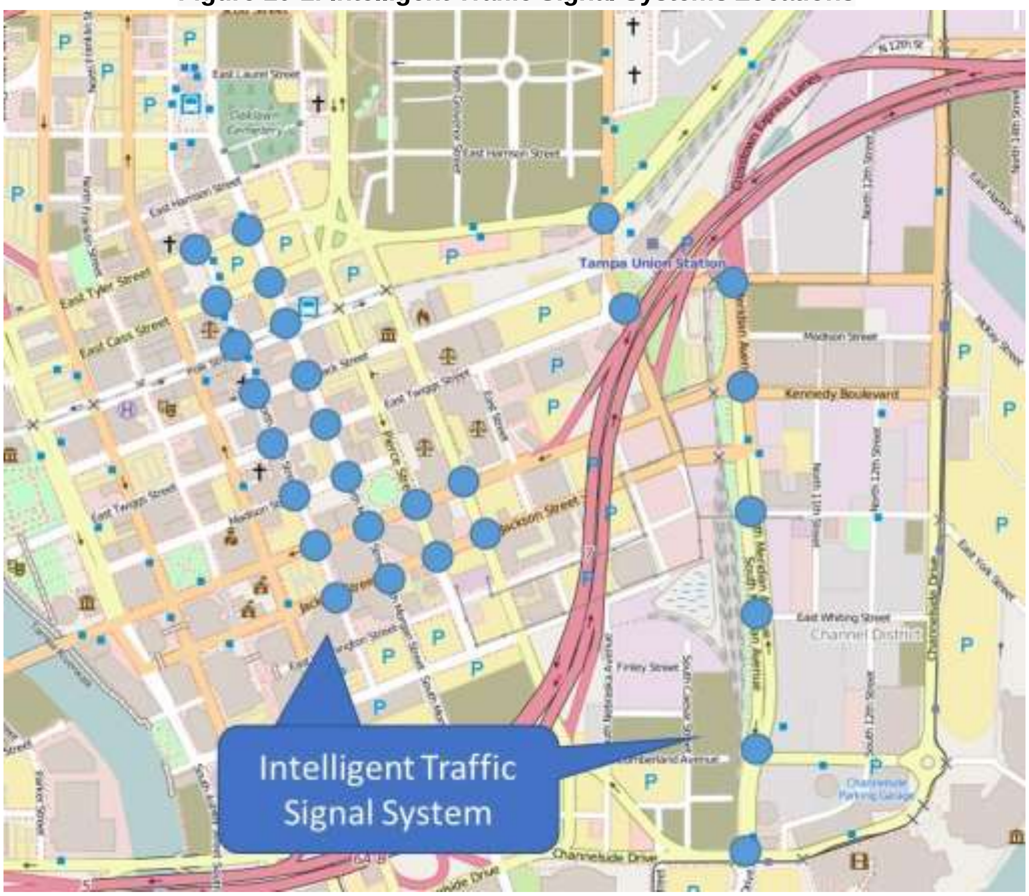
For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G
- Section 3.8 Installation and Operational Readiness Testing –Task 2-H

10 Intelligent Traffic Signal Systems

The Intelligent Traffic Signal System (I-SIG) application uses both vehicle location and movement information from CVs, as well as infrastructure measurement of non-equipped vehicles, to improve the operations of traffic signal control systems. The application utilizes the vehicle information to adjust signal timing for an intersection or group of intersections in order to improve traffic flow and allow platoon flow. The team has identified few corridors for potential deployment of the I-SIG systems, as shown in Figure 10-1.

Figure 10-1: Intelligent Traffic Signal Systems Locations



Source: HNTB

10.1 Description of the Application

This section describes how THEA will deploy the I-SIG application to improve the operations of traffic signal control systems and maximize flows in real time by using both vehicle location and movement information from CVs as well as infrastructure measurement of non-equipped vehicles for the following use cases:

1. Morning Back-up on REL, by re-optimizing the flow of traffic on Meridian Avenue and preventing back-up on Twiggs Street.
2. Wrong-way Entry/Traffic Progression, by smoothing the flow of traffic on Meridian Avenue.

3. Traffic Progression along Meridian Avenue and Downtown locations.
4. Transit Signal Priority at Marion and Morgan corridors and along Kennedy and Jackson corridors.

10.1.1 Functional

OBU equipped vehicles and PID equipped pedestrians are broadcasting position information. The PID is classified as an OBU nomadic device. The PID position broadcast, over Wi-Fi, is received by the RSU; which then converts it into a transmitted BSM; referred to as a Personal Safety Message (PSM). The RSU broadcasts the PSM over DSRC. OBUs within range receive the pedestrian BSM as well as other OBU BSMs.

Using vehicle detectors at the intersection, the RSU receives an indication that a vehicle has entered the detection zone. The RSU compares these positions to existing BSMs and if there is a match, it is assumed that an equipped vehicle is present. If no existing BSMs match, it is assumed that an unequipped vehicle is present and a proxy BSM is generated for the vehicle. These proxy BSMs are treated as any other BSM.

The RSU receives all BSMs. The I-SIG application uses the BSMs to determine which signal phase should be activated. I-SIG sends the phase request to the signal controller. The signal controller responds with an active phase when the phase is activated. The I-SIG application broadcast an SSM containing the active phase information.

OBU equipped emergency vehicles broadcast an SRM when they need priority to travel through the intersection. I-SIG receives the SRM and authenticates the requestor. I-SIG sends the emergency vehicle phase request to the signal controller. The signal controller responds with an active phase when the phase is activated. The I-SIG application broadcast an SSM containing the active phase information.

10.1.2 Interface

The following interfaces are required for the I-SIG application:

- Vehicle detector to RSU (proxy BSM)
- Vehicle BSM to RSU
- Emergency vehicle SRM to RSU
- RSU to I-SIG
- I-SIG to signal controller
- I-SIG SSM to RSU
- RSU to Emergency Vehicle OBU
- Emergency Vehicle OBU to driver.

Further details on how the application fulfills the interface system requirements are depicted below:

- The vehicle detector to RSU interface provides a notification from the vehicle detector to the RSU that a vehicle has entered a detection zone using proxy BSM.
- The vehicle BSM to RSU interface provides the vehicle's latitude, longitude, heading, and speed to the RSU.
- The emergency vehicle SRM to RSU interface provides the SRM of an emergency vehicle requesting priority to I-SIG.
- The RSU to I-SIG interface provides all the BSMs, PSMs, SRM and proxy BSMs to the I-SIG for optimization.
- The I-SIG to signal controller interface provides the NTCIP-specific commands from I-SIG to the signal controller.
- The I-SIG SSM to RSUs interface provides the SSM to the RSUs containing the active phase data.

- The RSU to Emergency Vehicle OBU interface communicates this phase data with the OBU.
- The Emergency Vehicle OBU to driver interface provides an active phase message to the driver.

10.1.3 Performance

The BSMs are broadcast via DSRC at a rate of 10 times per second. The driver interface provides updates in real time. Additional requirements are provided in the System Requirements (Task 6) document.

10.1.4 Data

The I-SIG application provides the following data:

- Standard BSM – transmitted by OBU equipped vehicles. The primary fields used are the latitude, longitude, heading, and speed.
- Proxy BSM – provides a BSM for unequipped vehicles in a detection zone. The primary data is the latitude, longitude, heading, and speed.
- SRM – provides the request to active a signal phase.
- SSM – provide the status of the active signal phase.
- Active Phase Message – provides a message to the driver of the active signal phase.

10.2 Description of the Components of the Application

This section is to give a detailed description of the hardware and software components of the application, including interfaces and data inputs and outputs.

Hardware Components:

- RSU2: Installed at each intersection
- OBU1: Class 1 as part of OEM vehicle system
- OBU2: Class 2 installed as aftermarket device
- OBU3: Class 3 installed or carried as nomadic device
- VEH1: Vehicle detector per MAP lane; using both camera-based and loop-based detectors.
- Weatherproof enclosures and mounting hardware for RSU2.

Software Components:

- I-SIG1: Application installed in RSU2
- PRX1: Vehicle Proxy installed in RSU2
- TRX1: PSM to BSM translator installed in RSU2
- MAP: Lane geometries, one MAP per intersection.

Interfaces:

- VEH1 Output: Presence per detection zone
- PRX1 Input: Presence per detection zone
- PRX1 Output: BSM for each unequipped vehicle
- I-SIG Input: BSM for each equipped and unequipped vehicle
- I-SIG Input: SRM for each emergency vehicle
- Output from I-SIG1: NTCIP phase selection
- Input to CU: NTCIP phase selection

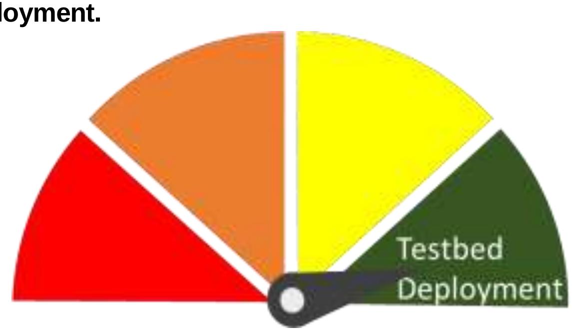
- Output from CU: Active phase
- Input to I-SIG: Active phase
- Output of I-SIG: SSM.

Operational Description:

- OBU1 continually broadcasts BSM from vehicle systems
- OBU2 continually broadcasts BSM from aftermarket OBU
- OBU3 broadcasts PSM from nomadic device when within MAP
- TRX1 continually translates received PSM to transmitted BSM
- VEH1 continually sends occupancy bit per detection zone to PRX1
    - PRX1 compares occupied zone locations to BSMs
    - If occupied zone location matches any BSM, occupancy for the equipped vehicle is discarded
    - If occupied location does not match any BSM, a proxy BSM for unequipped vehicle is sent
- I-SIG receives all BSM and proxy BSM
  I-SIG determines signal phase selection
- I-SIG sends phase selection to CU via NTCIP
- CU sends active phase to I-SIG via NTCIP
- I-SIG broadcasts SSM
- Emergency vehicles send SRM when in code
- I-SIG receives SRM
- I-SIG authenticates SRM VIN field
- I-SIG selects CU phase via NTCIP based on vehicle priority
- CU sends active phase to I-SIG
- I-SIG sends SSM to approaching vehicles.

10.2.1 Maturity Level of the Application

Based on the available sources, the current level of maturity for Intelligent Traffic Signal Systems (I-SIG) can be defined as **Test Bed Deployment.**



Source: Booz Allen Hamilton Siemens

I-SIG is part of the CVRIA, but is referred to as the Intelligent Traffic Signal System. CVRIA has based the physical, functional, communications, and enterprise architecture views for I-SIG and has based the architecture from the following FHWA systems engineering documents.

- Multi-Modal Intelligent Traffic Signal System (MMITSS) ConOps
- Multi-Modal Intelligent Traffic Signal System Final System Requirements
- Multi-Modal Intelligent Traffic Signal System- System Design.

It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities. In addition to the documents listed above, the Multi-Modal Intelligent Traffic Signal System (MMITSS) Impact Assessment also includes the I-SIG. The impact assessment evaluated the MMITSS prototype and identified potential impacts and benefits of the MMITSS technology, as well as the potential deployment of MMITSS applications. I-SIG is one of several applications used in the THEA pilot that was developed in the Multi-Modal Intelligent Traffic Signal System (MMITSS) bundle. Source code for I-SIG is available on the OSADP through the MMITSS-AZ 1.0 project, which provides allocation of green phase through the centralized closed-loop traffic signal control. The OSADP is expected to release the MMITSS-CA Field Test in March 2016, which will include source code for MMITSS prototype from California Field Test, including Intelligent Traffic Control, Priority Control, Pedestrians Smartphone app, and Performance Observer. In addition to being on the OSADP, MMITSS data sets and data environments can be found on the RDE.

10.2.2 Required Development Work

Owing to the limited deployment as part of the impact assessment, I-SIG application may require additional development to accommodate for city-wide infrastructure systems in the Tampa area. For example, the application is tied to the roadway geometry, approach configurations, controller software etc. These modifications need to be integrated to the application. Additionally, the team will also perform simulation-based analysis to identify priority corridors for the deployment of the applications.

Note the I-SIG application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

10.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- RSU hardware compliance to RD[1]
- RSU software compliance to RD[1]
- RSU includes Wi-Fi
- SDK for each device in order to install applications.

10.2.4 Required Interfaces, Inputs and Outputs

Table 10-1 lists the required I/O interfaces.

Table 10-1: Intelligent Traffic Signal Systems Required Interfaces, Inputs and Outputs

#	I/O	Device	Content	Media
1	O	I-SIG	SSM	DSRC
2	O	OBU2 emerg veh	SRM	DSRC
3	I	OBU2 emerg veh	SSM	DSRC
4	O	VEH1	Occupancy per zone	Ethernet
5	I	PRX1	Occupancy per zone	Ethernet
6	O	PRX1	Proxy BSM	Socket
7	I	I-SIG	Proxy BSM	Socket
8	I	I-SIG	BSM	DSRC
9	O	I-SIG	NTCIP phase select	Ethernet
10	I	CU	NTCIP phase select	Ethernet
11	O	CU	NTCIP active phase	Ethernet

Source: Siemens

10.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- I-SIG: OSADP
- BSM: CAMP on distribution agreement
- PRX1: Siemens on distribution agreement.

10.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the I-SIG application, if the application itself fails or enters an error state, the application will restart. Since very few vehicles will be OBU equipped, there is no danger to the driver or other drivers as drivers are responsible for their actions regardless of whether the application is functioning or not. The application on the RSU will auto restart if the application fails or enters and error state. If the OBU or RSU hardware fails, the same scenario is true for the driver.

10.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE) and Test Reports (TR) as follows:

- MTP
- LTP for BSM
- LTP for SRM
- LTP for SSM
- LTP for I-SIG
- LTP for Emergency Preemption subsystem
- LTP for Signal Control subsystem
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP

- TE for each LTP
- TR for each LTP.

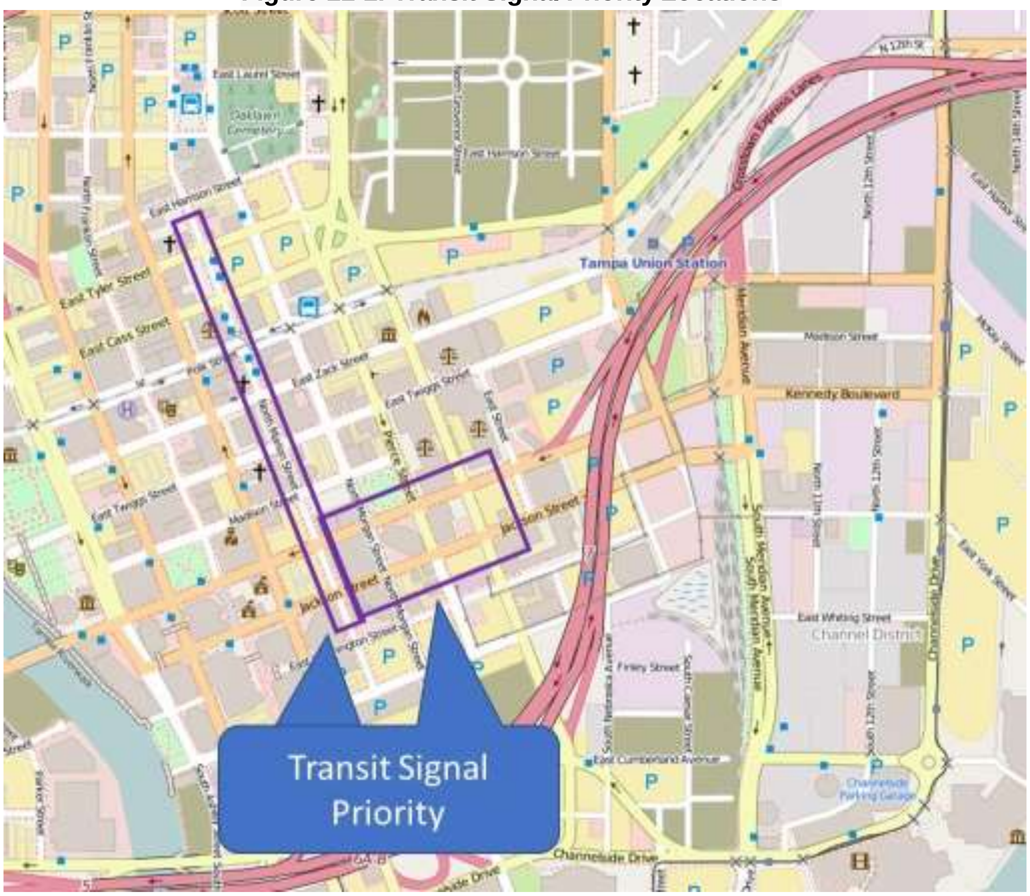
For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G
- Section 3.8 Installation and Operational Readiness Testing –Task 2-H

11 Transit Signal Priority

The Transit Signal Priority (TSP) application uses transit V2I communications to allow a transit vehicle to request a priority at one intersection or a series of intersections. The application grants priority only if the transit vehicle is behind schedule. This application can contribute to improved transit vehicle operating performance by reducing the time spent stopped at red lights. The team has identified potential bus corridors where the application can be deployed, as shown in Figure 11-1.

Figure 11-1: Transit Signal Priority Locations



Source: HNTB

11.1 Description of the Application

This section describes how THEA will deploy the TSP application for HART buses in the Marion Street use case, a primary route for buses, and where buses and traffic signals communicate. BRT routes offer efficiency gains in moving more people. However, during peak periods, the BRT service suffers from poor transit travel time and travel time reliability due to poor signal progression from heavy pedestrian and passenger vehicle volumes and vehicles blocking access to bus stops. If a bus is behind schedule, the traffic signal system will give the bus priority; which may include providing a green phase to flush the queue so that the bus can leave the bus stop. The application will work with I-SIG to reduce queue build-up on the corridor to further reduce delays, assuming there are no other higher priorities.

11.1.1 Functional

The TSP application analyzes requests from transit vehicles for priority, determines if priority is warranted, and issues a phase request to the signal controller to give priority to the transit vehicle. TSP application will be deployed as an adaptation to the I-SIG application. As a transit vehicle location matches a transit zone location, it broadcasts an SRM. The RSU receives the SRM and forwards it to transit central. Transit central determines which transit vehicle is requesting priority, compares the schedule time to the actual time, and determines whether to grant priority or not. If the transit vehicle is deemed to be on schedule, the request is ignored and no further action is needed. If the transit vehicle is behind schedule, the SRM is returned to I-SIG (RSU). TSP determines which signal phase is needed and sends a phase activation request to the signal controller. The signal controller receives the phase activation request and implements it. The signal controller returns an active phase message to TSP. TSP creates and broadcasts an SSM, containing the signal phase. The transit vehicle OBU receives the SSM and informs the operator that they have priority.

11.1.2 Interface

The following are the interface requirements forTSP:

- Transit Vehicle OBU to I-SIG
- I-SIG to Transit Central
- Transit Central to I-SIG
- I-SIG to Signal Controller
- I-SIG to Transit Vehicle OBU
- Transit Vehicle OBU to Operator.

11.1.3 Performance

The communication between the OBU and RSU is performed using DSRC at a rate of ten time per second. The communications between the RSU and Signal Controller and RSU and the Transit Central system is performed using Ethernet typically at a capacity of one gigabit. The communication between the OBU and the driver is performed in real time. Additional requirements are provided in the System Requirements (Task 6) document.

11.1.4 Data

The TSP application provides the following data:

- SRM – Requests priority for a transit vehicle pedestrian
- SSM – Provides priority to the transit vehicle
- Driver Priority Message – Provides the priority message to the driver
- Signal Phase Selection – Provides the requested phase to the signal controller
- Active Phase – Provides the confirmation the phase has been initiated.

11.2 Description of the Components of the Application

This section is to give a detailed description of the hardware and software components of the application, including interfaces and data inputs and outputs.

Hardware Components:

- RSU2: Installed at each intersection
- OBU2: Class 2 installed as aftermarket device on transit vehicle
- Weatherproof enclosures and mounting hardware for RSU2.

Software Components:

- I-SIG1: Application installed in RSU2
- MAP: Lane geometries, one MAP per intersection.

Interfaces:

- I-SIG Input: SRM for each transit vehicle
- Output from I-SIG1: NTCIP phase selection
- Input to CU: NTCIP phase selection
- Output from CU: Active phase
- Input to I-SIG: Active phase
- Output of I-SIG: SSM.

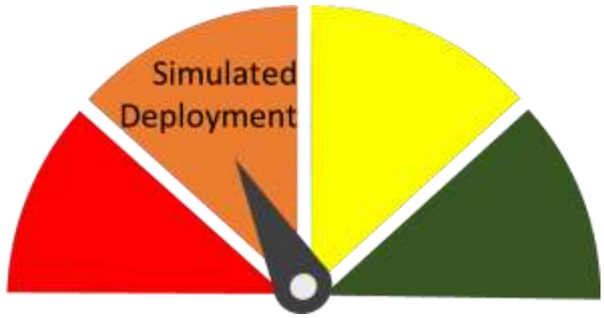
Operational Description:

- OBU2 of transit vehicle sends SRM to RSU2
- RSU2 checks for conflicting higher priority requests.
- In the absence of higher priority requests, SRM is forwarded to Transit Central
- Transit Central authenticates transit vehicle VIN
- Transit Central compares transit vehicle location to schedule
- If vehicle is ahead or on schedule, the SRM is discarded
- If vehicle is behind schedule, the SRM is returned to RSU2
- I-SIG receives returned SRM
- I-SIG determines signal phase selection
- I-SIG sends phase selection to CU via NTCIP
- CU sends Active phase to I-SIG via NTCIP
- I-SIG broadcasts SSM
- Transit vehicle OBU2 receives SSM
- OBU2 displays SSM to driver.

Note: I-SIG and TSP will both be installed in the RSU and priority will be given as: 1) Emergency Vehicle 2 TSP 3) I-SIG. Emergency Vehicle priority is reserved as a higher priority, but not included as a Use Case with an emergency district stakeholder

11.2.1 Maturity Level of the Application

Based on the available sources, the current level of maturity for Transit Signal Priority (TSP) can be defined as **Simulation Deployment**.



Source: Booz Allen Hamilton Siemens

TSP is part of the CVRIA and has based the physical, functional, communications, and enterprise architecture views for TSP from the following FHWA systems engineering documents:

- ConOps for Transit CV
- Multi-Modal Intelligent Traffic Signal System (MMITSS) ConOps
- Multi-Modal Intelligent Traffic Signal System Final System Requirements
- Multi-Modal Intelligent Traffic Signal System- System Design.

It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities. In addition to the documents listed above, the Multi-Modal Intelligent Traffic Signal System (MMITSS) Impact Assessment also includes TSP. The impact assessment evaluated the MMITSS prototype and identified potential impacts and benefits of the MMITSS technology, as well as the potential deployment of MMITSS applications. Furthermore, a variation of TSP can be found in the MMITSS Project on the OSADP. Signal Priority (SP), a more general form of TSP, provides priority to different modes of vehicles including transit, trucks, and emergency vehicles via DSRC. Source code for SP is available on the OSADP through the MMITSS-AZ 1.0 project. Also, OSADP is expected to release the MMITSS-CA Field Test in March 2016, which will include source code for MMITSS prototype from California Field Test, including Intelligent Traffic Control, Priority Control, Pedestrians Smartphone app, and Performance Observer. In addition to being on the OSADP, MMITSS data sets and data environments can be found on the RDE.

11.2.2 Required Development Work

Similar to I-SIG, TSP also requires modifications to match the specific controllers, lane/transit-line configurations prior to deployment. The team will also assess priority deployment corridors through small-scale simulation-based analysis.

Note the TSP application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

11.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- RSU hardware compliance to RD[1]
- RSU software compliance to RD[1]
- SDK for each device in order to install applications.

11.2.4 Required Interfaces, Inputs and Outputs

Table 11-1 lists the required I/O interfaces.

Table 11-1: Transit Signal Priority Required Interfaces, Inputs and Outputs

#	I/O	Device	Content	Media
1	O	I-SIG	SSM	DSRC
2	O	OBU2 transit veh	SRM	DSRC
3	O	RSU	SRM	To Central
4	I	RSU	SRM	From Central
5	I	OBU2 transit veh	SSM	DSRC
6	I	I-SIG	SSM	DSRC
7	O	I-SIG	NTCIP phase select	Ethernet
8	I	CU	NTCIP phase select	Ethernet
9	O	CU	NTCIP active phase	Ethernet

Source: Siemens

11.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- TSP: OSADP
- SRM: CAMP on distribution agreement
- SSM: CAMP on distribution agreement.

11.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the TSP application, if the application itself fails or enters an error state, the application will restart. There is no danger to the operator or passengers as the operator is responsible for their actions regardless of whether the application is functioning or not. The application on the RSU will auto restart if the application fails or enters and error state. If the OBU or RSU hardware fails, the same scenario is true for the driver.

11.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.

4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE) and Test Reports (TR) as follows:

- MTP
- LTP for BSM
- LTP for SRM
- LTP for SSM
- LTP for I-SIG
- LTP for Transit Priority subsystem
- LTP for Signal Control subsystem
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP

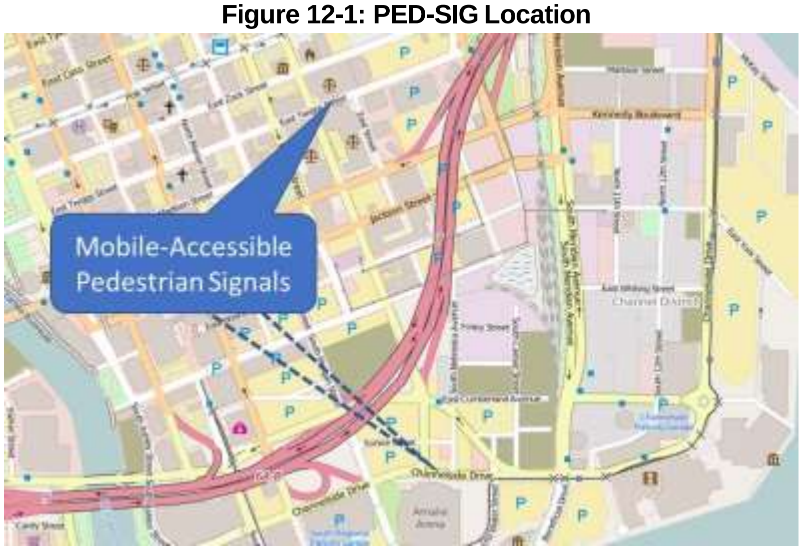
TR for each LTP. For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G
- Section 3.8 Installation and Operational Readiness Testing –Task 2-H

12 Mobile Accessible Pedestrian Signal

The Mobile Accessible Pedestrian Signal (PED-SIG) application will integrate traffic and pedestrian information from roadside or intersection detectors and new forms of data from wirelessly connected, pedestrian carried PIDs. These PIDs can request dynamic pedestrian signals and inform pedestrians when to cross and how to remain aligned with the crosswalk based on real-time Signal Phase and Timing (SPaT) and MAP information. In some cases, priority will be given to pedestrians, such as persons with disabilities who need additional crossing time, or in special conditions (e.g., weather) where pedestrians may warrant priority or additional crossing time. This application will enable a "pedestrian call" to be routed to the traffic controller from a PID of a registered person with disabilities after confirming the direction and orientation of the roadway that the pedestrian is intending to cross. The application also provides warnings to the PID user of possible infringement of the crossing by approaching vehicles. PED-SIG will be deployed at the signalized crosswalk at Twiggs Street between the courthouse buildings, as shown in Figure 12-1. The team will also look into deploying the application on Channelside Drive near the Amelia Arena, which is subject to lots of pedestrian traffic under non-recurring events.

Figure 12-1: PED-SIG Location



Source: HNTB

12.1 Description of the Application

This section describes how THEA will deploy the PED-SIG application on Twiggs Street and Channelside Drive for dynamic pedestrian signal requests, and to inform pedestrians when to cross and how to remain aligned with the crosswalk based on real-time SPaT and MAP information.

12.1.1 Functional

A PID equipped pedestrian nears an equipped intersection with the PED-SIG application running on the PID. The pedestrian points the PID in the direction they wish to cross the intersection and indicates to the application that they want to cross the intersection. The PID sends the information to the RSU. The RSU broadcasts the pedestrian's presence to any vehicles within range as a Personal Safety Message (PSM). The RSU broadcasts the vehicles' locations to pedestrians near the intersection. The RSU takes the pedestrian request information and if authenticated, a pedestrian call (walk request) is issued to the signal controller. The RSU monitors the signal controller until the walk request is initiated. The RSU sends a message to the PID to indicate to the pedestrian that it is safe to cross the intersection. The RSU monitors the pedestrian's progress across the intersection and once the pedestrian has cleared the intersection, the RSU sends a command to remove the walk request to the signal controller. The signal controller then returns to its next signal phase. PID also warns the pedestrian that there is an approaching vehicle to prevent jaywalking

12.1.2 Interface

The following interfaces are required for the PED-SIG application

- PID to RSU
- RSU to vehicle OBU
- RSU to signal controller.

Further details on how the application fulfills the interface system requirements are depicted below:

- The PID to RSU interface provides the communication between the PID and RSU using Wi-Fi. The PID transmits a system request message (SRM), or a request to cross the intersection, and transmits its latitude, longitude, heading, and speed. The RSU transmits a system status message (SSM) to the PID. The SSM contains a safe to cross. The RSU broadcasts the position of OBU equipped vehicles to the PID.
- The RSU to vehicle OBU interface provides the communication between RSU and the vehicle OBU via DSRC. The RSU broadcast a converted BSM containing pedestrian location information. The vehicle OBU, when in range, receives the converted BSM. The vehicle OBU broadcasts its position using the BSM to the RSU.
- The RSU to signal controller interface provides the communication between the RSU and the signal controller via NTCIP. The RSU issues a pedestrian call to the signal controller. The signal controller responds to the RSU when the walk phase is initiated. The RSU issues a request to remove the walk phase to the signal controller.

12.1.3 Performance

The performance of the DSRC communications is expected to be ten times a second. The Wi-Fi connection will be similar to the DSRC connection, but at a lower frequency (2 times a second). The Ethernet connection is typically at least 1 gigabit which should be ample capacity. Additional requirements are provided in the System Requirements (Task 6) document.

12.1.4 Data

The PED-SIG application provides the following data:

- Standard BSM – The BSM is transmitted by OBU equipped vehicles. The primary fields used are the latitude, longitude, heading, and speed.
- Pedestrian PID location – This message provides the location of the pedestrian. The expected data is the latitude, longitude, heading, and speed.
- SRM – The SRM requests a pedestrian call to provide the right of way to the pedestrian.
- SSM – The SSM provides the feedback on the SRM which will be in the form of a walk phase.

12.2 Description of the Components of the Application

This section gives a detailed description of the hardware and software components of the application, including interfaces and data inputs and outputs.

Hardware Components:

- RSU4: Installed within range of the crosswalk
- OBU3: Class 3 installed as application on nomadic device
- Weatherproof enclosures and mounting hardware.

Software Components:

- PED-SIG.

Interfaces:

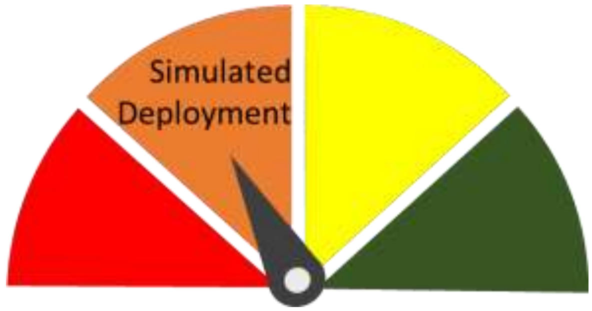
- Output from OBU3: SRM
- Output from OBU3: PSM
- Input to OBU3: SSM
- Input to RSU4: SRM
- Output from RSU4: SSM.

Operational Description:

- Based on the MUTCD definition of pedestrian presence:
  - Person within six feet from the face of the curb or the edge of the pavement if no curb
  - At the beginning of a WALK cycle
  - Walking speed of 3 feet per second
- Person(s) walk towards the intersection carries a nomadic device including PED-SIG registered client
- Pedestrian points the OBU3 towards the desired direction of travel
- Pedestrian presses the "service request" button
- PSM is broadcast if the pedestrian is present at the crosswalk
- PSM is received by RSU4 and broadcast as BSM to nearby vehicles
- BSM of nearby vehicles are received by RSU4 and broadcast as PSM to nearby pedestrians
- SRM is sent to the RSU4 if the pedestrian is present at the crosswalk consisting of:
  - BSM
  - Client registration number as the VIN field
- RSU4 authenticates SRM registration number
- If authenticated client, SRM is translated to a pedestrian call to the controller unit on that walk phase
- RSU4 retrieves walk phase status from controller unit
- When CU enters walk phase, RSU4 sends SSM to OBU3
- OBU3 indicates walk to the pedestrian
- RSU4 holds walk phase until pedestrian clears the crosswalk based on received BSM from OBU3
- RSU4 removes walk phase, controller unit moves to next signal phase.

12.2.1 Maturity Level of the Application

Based on the available sources, the current level of maturity for PED-SIG can be defined as **Simulated Deployment** since the Multi-Modal Intelligent Traffic Signal System's Impact Assessment was performed outside of PED-SIG's scope.



Source: Booz Allen Hamilton Siemens

PED-SIG is part of the CVRIA. PED-SIG is referred to Pedestrian Mobility within CVRIA. CVRIA has based the physical, functional, communications, and enterprise architecture views for Pedestrian Mobility from the following FHWA systems engineering documents:

- Multi-Modal Intelligent Traffic Signal System (MMITSS) ConOps
- Multi-Modal Intelligent Traffic Signal System Final System Requirements
- Multi-Modal Intelligent Traffic Signal System- System Design.

It is important to note that CVRIA diagrams are based on the most recently available application concepts that the CVRIA team has access to, and do not necessarily reflect prototypes or other in-development activities. In addition to the documents listed above, the Multi-Modal Intelligent Traffic Signal System (MMITSS) Impact Assessment was developed to assess the MMITSS prototype and identify the potential impacts and benefits of the MMITSS technology, as well as the potential deployment of MMITSS applications. However, since the impact assessment was based off of only real-world prototypes in Arizona, some of the applications within the MMITSS scenarios initially planned for testing were not yet ready, including coordinated signal operations, PED-SIG, Emergency Vehicle Preemption (PREEMPT), and any additional scenarios that would have required these component applications.

PED-SIG is one of several applications used in the THEA pilot that was developed in the Multi-Modal Intelligent Traffic Signal System (MMITSS) bundle. Source code for PED-SIG is available on the OSADP through the MMITSS-AZ 1.0 project and includes an RSU application that can send pedestrian signal requests. The OSADP is expected to release the MMITSS-CA prior to Phase 2 which will include source code for MMITSS prototype from California Field Test, including Intelligent Traffic Control, Priority Control, Pedestrians Smartphone app, and Performance Observer. In addition to being on the OSADP, MMITSS data sets and data environments can be found on the RDE.

12.2.2 Required Development Work

This application has not been subject to rigorous field deployment test so it requires moderate development and testing. At a high-level, the OSADP code should be adapted to the following:

1. Modifications required to incorporate new controller types used in the Tampa region (versus the current code is developed for Econolite Controllers).
2. Development of Tampa-specific vehicle and pedestrian front-end applications for detection, activation, and alerts.

Since the application has not been tested on field, further in-field testing would be required.

Note the PED-SIG application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

12.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- RSU hardware compliance to RD[1]
- RSU software compliance to RD[1]
- RSU includes Wi-Fi
- SDK for each device in order to install applications.

12.2.4 Required Interfaces, Inputs and Outputs

Table 12-1 lists the required I/O interfaces.

Table 12-1: PED-SIG Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Media
1	O	OBU3	PSM	Wi-Fi
2	I	OBU3	PSM	Wi-Fi
3	I	RSU4	PSM	Wi-Fi
4	O	RSU4	BSM	DSRC
5	I	RSU4	BSM	DSRC
6	O	RSU4	PSM	Wi-Fi
7	O	OBU3	SRM	Wi-Fi
8	I	RSU4	SRM	Wi-Fi
9	O	RSU4	SSM	Wi-Fi
10	O	RSU4	NTCIP Walk Phase	Ethernet
11	I	CU	NTCIP Walk Phase	Ethernet
12	O	CU	NTCIP Walk Phase Status	Ethernet
13	I	RSU4	NTCIP Walk Phase Status	Ethernet
14	I	OBU3	Service Request	Tactile
15	O	OBU3	Walk Status	Visual
16	O	OBU3	Walk Status	Audio

Source: Siemens

12.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- PED-SIG: OSADP
- Client: OSADP.

12.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the PED-SIG application, if the application on the PID, RSU, or OBU fail or enter into an error state, the application will restart. Since very few pedestrians and vehicles will be equipped, there is no danger to the driver or the pedestrians as the drivers and pedestrians are responsible for their actions regardless of whether the application is functioning or not. If the RSU or OBU hardware fails, the same scenario is true for the drivers and pedestrians. During the fail-safe mode, the intersection will act like a normal intersection where pedestrians watch for vehicles and wait for WALK sign before crossing the street.

12.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.
4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE), and Test Reports (TR) will be required as follows:

- MTP
- LTP for PED-SIG
- LTP for Client
- LTP for Client to PED-SIG subsystem
- LTP for PED-SIG to CU subsystem
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP
- TR for each LTP.

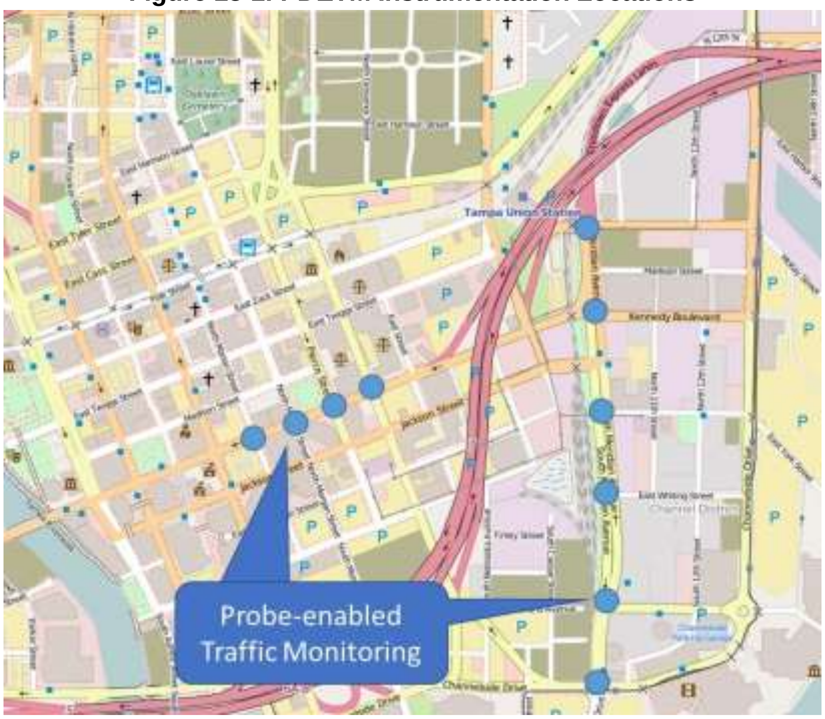
For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G
- Section 3.8 Installation and Operational Readiness Testing –Task 2-H

13 Probe Data Enabled Traffic Monitoring

The Probe Data Enabled Traffic Monitoring (PDETM) application will use CV data from probe vehicles to monitor traffic conditions and inform travelers of travel-times, congested links, and other conditions. The team will use Operational Data Environment (ODE) to feed in real-time CV data and route them through specific applications for traffic monitoring, travel time estimation, and state prediction systems. Figure 13-1 depicts the proposed PDETM instrumentation locations.

Figure 13-1: PDETM Instrumentation Locations



Source: HNTB

13.1 Description of the Application

This section describes how THEA will deploy the PDETM application to gather vehicle situation/probe data packages transmitted to RSUs at the following locations to reduce congestion and provide travel-time estimates to drivers. The application will utilize a mix of data from CVs at Meridian Avenue corridor and the Kennedy Boulevard corridor along with other forms of instrumentation to estimate congestion levels for TMC operations and provide travel-time estimates to drivers via the traffic monitoring application.

13.1.1 Functional

OBU equipped vehicles are continuously broadcasting BSMs. As these BSMs are received by the RSU, the BSMs are used to calculate travel times. Travel times are calculated by one tenth second incremental BSM movements to determine incremental travel time without identifying or tracking an individual devices over distance. The aggregation of many incremental times over the corridors creates a predicted travel time that is more useful than an end to end travel time that is historical. The travel times are broadcast from the RSU and received by OBUs. The OBU provides the travel times to the driver.

13.1.2 Interface

The PDETM interfaces are defined as follows:

- OBU to RSU
- OBU to driver.

Further details on how the application fulfills the interface system requirements are depicted below:

- The OBU to RSU interface provides the communication between the OBU and the RSU via DSRC. The OBU broadcasts BSMs received by the RSU. The RSU broadcasts travel times received by the OBUs.
- The OBU to driver interface provides the communication between the OBU and the driver. The OBU communicates with the driver via audio or visual methods to provide travel times.

13.1.3 Performance

The OBU/RSU communication is performed using DSRC at a rate of ten times per second. The OBU to driver communication is performed in real time. Additional requirements are provided in the System Requirements (Task 6) document.

13.1.4 Data

The PDETM provides the following data:

- Standard BSM – transmitted by OBU equipped vehicles. The primary fields used are the latitude, longitude, heading, and speed. Travel times are calculated by one tenth second incremental BSM movements to determine incremental travel time without identifying or tracking an individual devices over distance. The aggregation of many incremental times over the corridors creates a predicted travel time that is more useful than an end to end travel time that is historical.
- Travel Time Message – communicated to drivers in minutes.

13.2 Description of the Components of the Application

This section is to give a detailed description of the hardware and software components of the application, including interfaces and data inputs and outputs.

Hardware Components:

- RSU3: Installed at each intersection and along routes requiring travel time
- OBU1: Class 1 installed as part of vehicle system
- OBU2: Class 2 installed as aftermarket device
- Weatherproof enclosures and mounting hardware for RSU2.

Software Components:

- Travel Time: Installed in RSU3
- MAP: Lane geometries of travel route.

Interfaces:

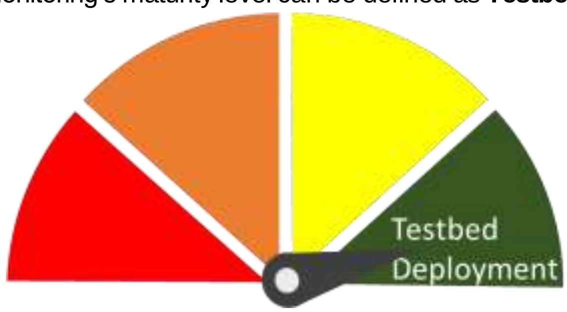
- OBU1 and OBU2 output: BSM
- Input to Travel Time: BSM
- Output from Travel Time: Travel Time.

Operational Description:

- OBU1 and OBU2 send BSM to RSU3
- Travel Time receives BSMs
- Travel Time calculates incremental movements of BSM within MAP
- Incremental BSM movements are time stamped
- Travel Time calculates incremental vehicle speeds based on time and distance between BSMs
- Travel Time projects travel time based on speed and MAP geometry
- Travel Time reports projected travel time for each route.

13.2.1 Maturity Level of the Application

PDETM will leverage THEA's existing travel time application that would be supplemented with CV data. Also, Booz Allen Hamilton and Siemens have implemented probe data applications on other corridors. Therefore Probe Data Enabled Traffic Monitoring's maturity level can be defined as **Testbed Deployment**.



Source: Booz Allen Hamilton Siemens

Several sources will help lay the foundation for this application. Vehicle Data for Traffic Operations (VDTO) is a similar application within CVRIA that uses probe data information obtained from vehicles in the network to support traffic operations, including incident detection and the implementation of localized operational strategies. CVRIA developed the physical, functional, communications, and enterprise architecture for VDTO based off SAE J3067- Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary (SAE J2735) Using Systems Engineering Methods.

13.2.2 Required Development Work

This application may require moderate development to develop systems to supplement existing travel-time estimation methods used by THEA to integrate CV Data.

1. Develop systems to perform real-time computations for the intended vehicle-based monitoring.
2. Develop systems to return travel time estimates to VMS units and equipped vehicles.

Note the PDETM application may need some level of modifications to fit the needs and meet the requirements. If it is determined that modifications are required this ADP will be updated in Phase 2.

13.2.3 Specific Hardware and Software Needs

Specific hardware and software needs for this application include the following:

- RSU hardware compliance to RD[1]
- RSU software compliance to RD[1]
- SDK for each device in order to install applications.

13.2.4 Required Interfaces, Inputs and Outputs

Table 13-1 lists the required I/O interfaces.

Table 13-1: Probe Data Enabled Traffic Monitoring Required Interfaces, Inputs, and Outputs

#	I/O	Device	Content	Media
2	O	OBU1 and OBU2	BSM	DSRC
3	I	RSU3	BSM	DSRC
8	O	RSU3	Travel Time	Ethernet

Source: Siemens

13.3 Intellectual Property Rights

Below is a depiction of the intellectual property rights for the various components of this application:

- BSM: CAMP on distribution agreement
- Travel Time: Siemens on distribution agreement.

13.4 Application Safety Plan

A fail-safe system mode will be provided for the THEA CV pilot deployment. This guarantees that in the event of a system failure, the system and devices will respond in a way that will cause no harm to the system, devices, participants, or other road users. For the PDETM application, if the application itself fails or enters an error state, the application will restart. Since very few vehicles will be OBU equipped, there is no danger to the driver or other drivers as the driver is responsible for their actions regardless of whether the application is functioning or not. The application on the RSU will auto restart if the application fails or enters and error state. If the OBU or RSU hardware fails, the same scenario is true for the driver.

13.5 Testing and Verification Requirements

The application setup will undergo four stages of testing during its pre-deployment life cycle. They are described below:

1. Unit Testing: The existing code and application components will undergo rigorous computer-based testing in a laboratory setting and additional testing for compatibility and performance.
2. Subsystem Verification: Once unit testing is complete, the application and associated hardware will undergo testing in a controlled environment to assess its performance under real-world conditions.
3. System Verification: At this stage, the application system will be integrated into real test vehicles to perform controlled system integration testing. This is when multiple applications will be integrated to the same system to find out conflicts and synergies.

4. System Validation: The system will undergo rigorous real world testing at the deployment locations by the owner/operators with operational databases to determine effectiveness and performance prior to the actual deployment.

Specifically, Master Test Plan (MTP) and Level Test Plans (LTP) per IEEE 829-2008 standard, including Test Cases (TC), Test Procedures (TP), Test Execution (TE) and Test Reports (TR) as follows:

- MTP
- LTP for BSM
- LTP for Travel Time
- LTP for system verification
- LTP for system validation with operational data
- TCs for each LTP
- TP for each LTP
- TE for each LTP
- TR for each LTP.

For more detailed information on the testing approach, see the following sections of the Comprehensive Deployment Plan

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation
- Section 3.7 Operational Readiness Test and Demonstration Planning–Task 2-G
- Section 3.8 Installation and Operational Readiness Testing –Task 2-H

14 Overall Plan Information

This section provides details for the applications as a group, including the required use of the SCMS, the overall software development process, and information on uploading to the OSADP and RDE.

14.1 Cross-Cutting Development Effort

The team will undertake several crosscutting development efforts to increase the effectiveness of CV application deployment in the region.

Some of the applications that affect specific traffic patterns and traveler types, such as I-SIG and TSP, will undergo thorough simulation-based testing before deployment. For example, I-SIG affects performance measures in complex ways – by improving arterial flows and decreasing queue lengths on side streets by intelligently switching phases. Understanding which corridors provide maximum return on investment is critical to the success of the deployment. The team has identified priority corridors on which I-SIG will be assessed prior to deployment.

Applications such as PDETM rely on real-time data from the entire deployment region. The team will develop an ODE to act as a real-time data router to serve client applications with high-quality sanitized CV data. The ODE will also provide a framework to support other data needs of the applications and bring in smarter functions, such as validation, integration, sanitization, and aggregation. The application deployment team will simultaneously undertake ODE development tasks since it serves as a data broker between the RSUs and applications. [Details on ODE are provided in the Performance Measurement and Evaluation Support Plan, Task 5].

The pilot team will use the following interfaces and standards while developing the interfaces for the applications discussed in this plan:

- CU to RSU SPaT: Reuse SPaT MIB developed on USDOT Contract No. DTFH61-06-D-00007
- RSU to CU Phase Set: Use NTCIP 1202 standardized objects
- CU to RSU Status Get: Use NTCIP 1202 standardized objects
- RSU to OBU Request: Use J2735 SRM
- OBU to RSU Status: Use J2735 SSM
- MAP Generation: Use USDOT MAP tool
- OBU Basic Safety: Use CAMP format for BSM of the new vehicles
- CU to RSU SPaT/MAP: Use CAMP format of the new vehicles
- Security Certificates: Use CAMP format of the new vehicles.

Standards Baseline: The THEA CV pilot team will use the most current balloted and published standards (e.g., J2735, J2945/1, IEEE 1609 suite) available at the beginning of Project Phase 2.

14.2 Security Credential Management System

All applications will use certificates to sign and authenticate messages. These certificates will be provided to devices through interactions with the SCMS POC. The only device that will not use the SCMS to download certificates is the PID. Within the applications that have the PID as a source or destination of information flows, PID functionality and information flows have been limited following the review of the initial security analysis. The initial security analysis of the PED-X and PED-SIG applications based on CVRIA-specified information flows resulted in a PID classification consistent with the OBU, VAD, and ASD. However, these devices require physical security protections equivalent to FIPS 140-2 Level 2. These physical security requirements would greatly limit the types of devices that could be used for the PID. By reducing the overall functionality and information flows for the PID, the THEA CV pilot team can greatly lessen the need for physical security requirements for the PID, as well as the need for the PID to send signed messages. As such, the PED-X and PED-SIG applications are the only applications that will use unsigned messages without certificates specifically for RSU to PID communications and vice versa. The remaining information flows within these applications (e.g., between the RSU and OBU) will still require the use of signed messages.

THEA CV pilot devices, except for the PID, must support requirements identified in the SCMS POC Implementation End Entity (EE) Requirements and Specifications Supporting SCMS Software Release 1.0 Appendix A and B to complete processes and use cases. These requirements and specifications enable devices to communicate with the SCMS POC to conduct the necessary processes and use cases to download certificates, the certificate revocation list (CRL), etc. Refer to the SCMS POC documentation for full requirements.

Processes and use cases include but are not limited to:

- Core Communication
    - Universal SCMS Handshake
    - File Download Operations
    - Sending SCMS Messages.
- Services
    - Provision Pseudonym Certificate Batch
    - Download.info file
    - Download Global Policy File
    - Download Pseudonym Certificate Batch
    - Retrieve Registration Authority Certificate.
- Use Cases
    - OBU
        - Bootstrapping
        - Initial Provisioning of Pseudonym Certificates
        - Misbehavior Reporting (Next SCMS POC revision will add further requirements)
        - CRL Download
        - OBU Revocation
        - Refresh Pseudonym Certificates
        - Update Pseudonym Certificate Request Parameters.
    - RSU
        - RSU Bootstrapping
        - RSU Application Certificate Provisioning
        - RSU Misbehavior Reporting
        - RSU CRL Check
        - RSU Application and OBU Identification Certificate Revocation
        - Refresh RSU Application Certificates.

To facilitate secure communications between devices which enable application functionality, all Wireless Access in Vehicular Environments (WAVE) devices shall comply with IEEE 1609.2: Standard for WAVE –

Security Services for Applications and Management Messages. ITS RE[2], TMC, and Transit MC should also comply with IEEE 1609.2 and contain the necessary libraries. The current working version of the standard is IEEE 1609.2 (2016). This standard describes secure message formats and processing for use by WAVE devices, including methods to secure WAVE management messages and application messages. It also describes administrative functions necessary to support the core security functions.

All pilot devices should be compliant with additional hardware and software requirements per the Privacy and Security Management Operating Concept and the Requirements Specification Document.

14.3 Software Development Process

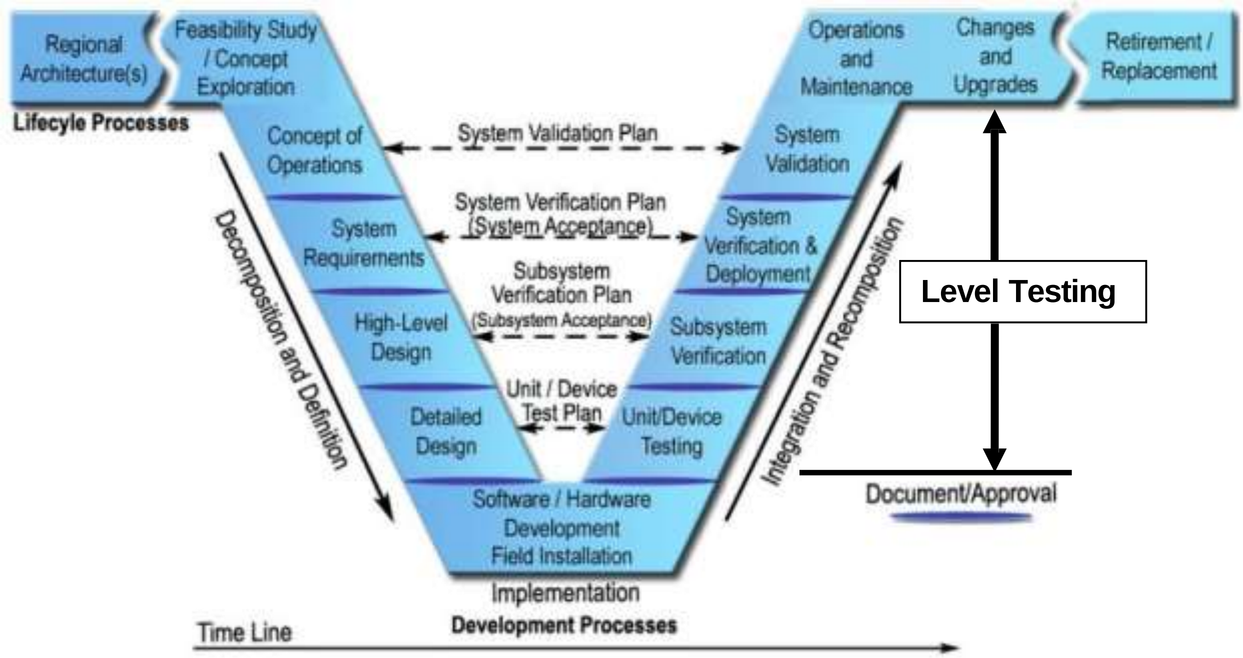
Overall project workflow conforms to the VEE model. This project picks up at Unit Level Test for each individual application. Each individual application previously developed should have an existing Level Test Plan, Level Test Cases, Level Test Procedures, and Level Test Report that verifies the expected performance. The project workflow proceeds as follows:

1. Inventory of existing applications needed for the Use Cases
2. Inspect each application for delivery of Level Test Report per IEEE-829
    a. If Level Test exists, archive the documents
    b. If Level Test does not exist, write Level Test Plan, Test Cases, and Test Procedures
3. For each application:
    a. Execute Level Test
    b. Ensure that Measured results match the Expected results
    c. If Measured ≠ Expected, write Anomaly Report for disposition by Stakeholders
    d. If Measured = Expected, archive Test Report
4. For each Subsystem:
    a. Write Level Test Plan, Test Cases, and Test Procedures per IEEE-829
    b. Execute Level Test for each Subassembly
    c. Ensure that measured results match the expected results
    d. If Measured ≠ Expected, write Anomaly Report for disposition by Stakeholders
    e. If Measured = Expected, archive Test Report
5. For each Integrated System, per Use Case site:
    a. Write Level Test Plan, Test Cases, and Test Procedures per IEEE-829
    b. Execute Level Test for each Integrated System, such as boundary conditions
    c. Ensure that measured results match the expected results
    d. If Measured ≠ Expected, write Anomaly Report for disposition by Stakeholders
    e. If Measured = Expected, archive Test Report

[2] ITS Roadway Equipment is based off the CVRIA definition “physical objects that represent all of the other ITS field equipment that interfaces with and supports the Connected Vehicle Roadside Equipment (RSE). This physical object includes traffic detectors, environmental sensors, traffic signals, highway advisory radios, dynamic message signs, CCTV cameras and video image processing systems, grade crossing warning systems, and ramp metering systems. Lane management systems and barrier systems that control access to transportation infrastructure such as roadways, bridges, and tunnels are also included. This object also provides environmental monitoring including sensors that measure road conditions, surface weather, and vehicle emissions. Work zone systems including work zone surveillance, traffic control, driver warning, and work crew safety systems are also included.”

6. To Validate System, per Use Case site:
    a. Write System Validation Test Plan, Test Cases, and Test Procedures per IEEE-829
    b. Execute Level Test for each Validated System, configured for installation on the street
    c. Ensure that measured results match the expected results
    d. If Measured ≠ Expected, write Anomaly Report for disposition by Stakeholders
    e. If Measured = Expected, archive Test Report
7. Field Test per Use Case site:
    a. Install Validated System at each Use Case site
    b. Repeat Validation Test after installation.

Figure 14-1: Systems Engineering Diagram – Level Testing



Source: HNTB

System integration will be performed as discussed in the following sections of the Comprehensive Deployment Plan:

- Section 3.5.1.1.2 WBS Phase 2C, Level 2: Hardware Device Level Test and Software Unit Level Test;
- Section 3.5.1.1.2 WBS Phase 2C, Level 3;
- Section 3.5.1.1.2 WBS Subsystem Level; Phase 2C, Level 5: System Validation

14.4 Plan for Uploading Relevant Materials to OSADP and RDE

This section details the plan for uploading relevant code to the OSADP and the test and performance data to RDE.

As far as the development of application codes is concerned, the deployment of individual applications will undergo one of the following code development cycles:

1. **Existing code that will undergo minimal development work.** This will include applications such as Forward Collision Warning and others that are currently available as the Retrofit Safety Device

package, but will need minimal development to account for changes in hardware and software changes. For example, current RSD development is performed using Cohda's SDK platform. This might need to be changed or upgraded to the latest SDK platforms.

2. **Existing code that will undergo significant development work.** This will include applications such as Intelligent Traffic Signal Systems (I-SIG) that are currently available as the Software-in-the-Loop package for Econolite controllers. Such applications will need to undergo significant development efforts to integrate to existing control systems in the Tampa region as well as suit the state's device standards specifications.
3. **New code development based on existing algorithms.** This will include applications such as Intersection Movement Assist that are heavily researched and were part of previous deployments, but whose open-source code is not available for use. Such applications will have to be developed using system requirements documentation or other literature available.
4. **New code development based on non-existent or proprietary past research.** This includes applications such as Probe Data Enabled Traffic Monitoring, which are conceptualized, but are not available on OSADP or other open source documents that expand on the application logic.

The team will package the code development that was done as part of this project to share on the OSADP portal and will work with the OSADP administrator for prompt release of the code. For each code package, the team will add the following documents to support the users:

1. README.txt giving users, a brief summary of the open source package and other useful information.
2. RELEASE-NOTES.TXT describing incremental difference of this release and associated instructions. The team will add the changes made to the existing code to match the hardware and software requirements in Tampa.
3. LICENSE.TXT declaring the license under which the open source code is released and its associated terms and conditions. The team will likely use the Apache 2.0 license for its releases. It has to be noted that some of the code developed prior to this deployment and/or outside of this contract including specific device/software drivers and code by Siemens are not open source.
4. ATTRIBUTION.TXT acknowledging individuals, a group, or an organization that have contributed to the open source, or the algorithm itself.

Each application package will undergo the following release checklist as per OSADP specifications:

OSADP Release Checklist
1. Has this application been pre-approved by the USDOT for release to the OSADP via a response to the online upload request form? 2. Have you read and agree with the OSADP terms and conditions shown on the website? 3. Has the source code been verified and deemed functional and stable? 4. Is the source code technically reviewed and inspected to ensure that no malicious code is embedded? 5. Have you verified that no executable files or personal information are included? 6. Was the source code scanned for virus and no infected file found? 7. Is the complete open source code base or assets (code, files, images, tables, data, etc.) included? 8. Is a README.txt file included to provide basic information about the open source? 9. If this release is an incremental release to a previous version, has a Release-Notes.txt been included?

10. Is a LICENSE.txt file included with the open source license terms and conditions, such as Apache 2.0?

The team will also upload the application data (collected during testing and deployment) to the RDE. All data that was collected from the applications would be prepared for secure hosting to the RDE and will undergo several checks and procedures prior to submission to the repository. They are:

1. Documentation would be developed to support each data set including metadata and definitions of data variables.
2. Data would be structured and categorized in a manner that is understandable and useful as well as in manageable pieces.
3. Data elements are standard format (such as CSV, JSON etc.) that are codable and that enables other parties to read the data without the need for proprietary software.
4. The data is cleared for sharing with appropriate data sharing agreements between the data providers and the USDOT.
5. Data is cleaned of any Personally Identifiable Information. The pilot will be designed to avoid collection of any personally identifiable information. But the team will ensure that no data with PII is shared on RDE including sign-up data for volunteers, traveler/driver personal details etc.
6. Specific tags and keywords would be added to the data to enable search, query, and find functionality within the RDE.

There are two types of data documentation that will accompany each data environment on the RDE (and most other repositories): 1) metadata documentation; and 2) optional data handbook/dictionary documentation.

1. Metadata documentation is in a format derived from the ASTM 2468-05 standard metadata format, ensuring uniform content, structure, and format.
2. The optional data handbook / dictionary document contains some of the same information as the metadata document but with additional information regarding files and data elements that were collected. In some cases, the data provider's existing documentation could serve or be slightly modified to serve as this optional data handbook / dictionary documentation. The additional information provided by the data handbook also includes:
    a. Details about how the data were collected and processed
    b. Background information about the overall task that led to the collection of data being uploaded to the RDE
    c. Specifics regarding how the data was structured
    d. Supporting information as to how the aforementioned RDE requirements and procedures were completed for a particular data environment
    e. If a data handbook / dictionary document is being provided to the public via the USDOT, it must be in a Section 508 compliant format and must follow the USDOT publication process.

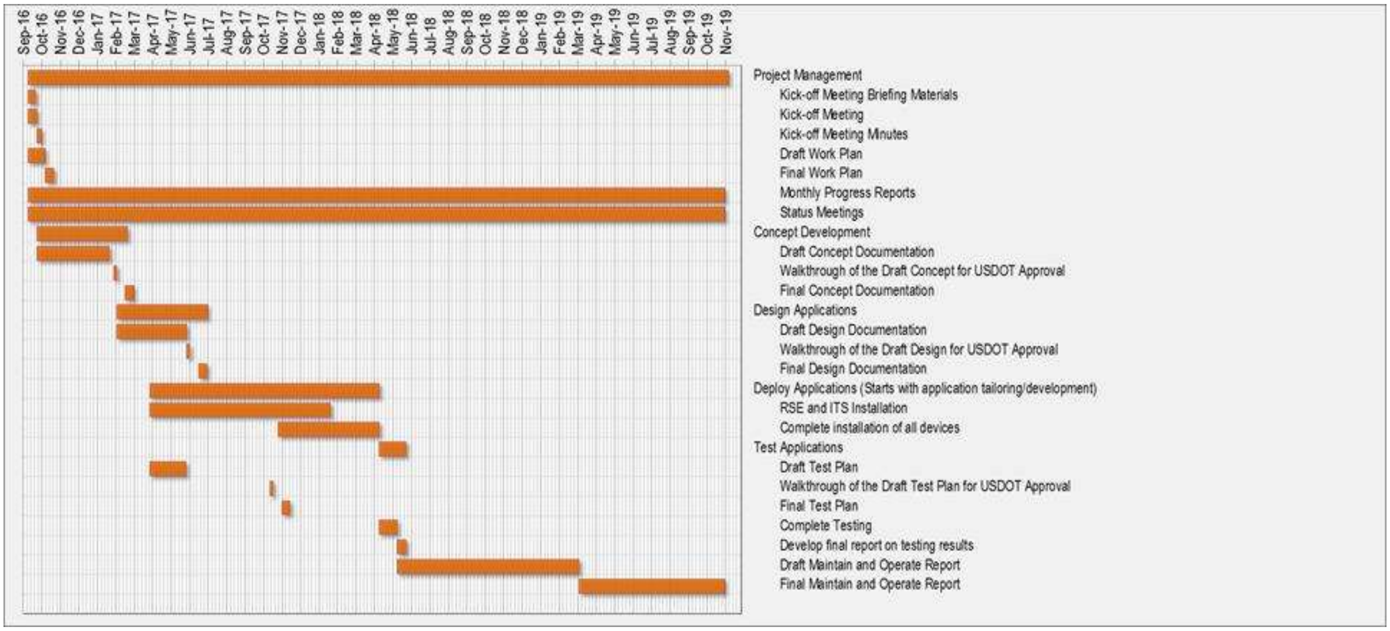
14.5 Overall Schedule

During the grant application, the THEA CV pilot team used the USDOT's CO-PILOT tool to estimate Phase 2 and 3 costs for the applications chosen. CO-PILOT is a high-level tool to support stakeholders considering CV pilot deployments. This tool allows cost estimation for 56 applications in the V2I safety, V2V safety, agency data, environment, road weather, mobility, and smart roadside application groups. These estimates are intended for high-level, preliminary planning purposes and outputs are intended to support long-range budget planning. They do not replace detailed cost structures that will be developed during Phase 2 (design/build/test), or Phase 3 (maintain and operate). The THEA Team will be meeting in June 2016 to produce a second high-level budget for Phase 2 based on the concept development through that time. This budget will be more granular than the initial grant application version, containing estimates of total OBU and RSU, but will still be high-level budget in need of additional review toward end of Phase 1.

The Phase 2 schedule is projected to begin in September of 2016 and run for up to 20 months. Phase 3 will run for up to 18 months.

While it is currently challenging to provide an accurate schedule for Phases 2 and 3 of the CV deployment, a projection has been provided for planning purposes. A preliminary list of activities and deliverables, along with expected time to complete, has been included here:

Figure 14-2: Preliminary Schedule for Phases 2 and 3 of the THEA Pilot Deployment



Source: HNTB

Appendix A. Use Cases and Deployment Locations

Table A-1: Hardware Objects and Software Applications

Use Case	Location	HW Object	SW Application	
Morning Backup	REL 27.954404, -82.448805	RSU 1	V2I	CSW
				RLVW
				Proxy
		Detector Lane 1 Detector Lane 2 Detector Lane 3	I	Vehicle Detection
		OBU	V2I	CSW
				RLVW
			V2V	EEBL
				FCW
Wrong-Way Entry	Twiggs & Meridian 27.952315, -82.449056	RSU 2	V2I	I-SIG
				RLVW
			Agency	PDETM
		OBU	V2V	IMA
			V2I	RLVW
Pedestrian Safety	Twiggs & Courthouse 27.950822, -82.453815	RSU 40	V2I	Proxy
		Crosswalk Detector Curbside Detector 1 Curbside Detector 2 J Walk Detector 1 J Walk Detector 2	I	I
		OBU / PSD	V2V	PED-Sig
				PED-X
				I-SIG
Transit Signal Priority	Marion & Tyler 27.952711, -82.458214	RSU 19	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Marion & Cass 27.952015, -82.457876	RSU 20	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Marion & Polk 27.951267, -82.457521	RSU 21	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Marion & Zack 27.950531, -82.457215	RSU 22	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Marion & Twiggs 27.949770, -82.456896	RSU 23	V2I	I-SIG
				TSP

Use Case	Location	HW Object	SW Application	
		OBU	V2I	TSP
	Marion & Madison 27.949011, -82.456561	RSU 24	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Marion & Kennedy 27.948281, -82.456253	RSU 25	V2I	I-SIG
				TSP
			Agency	PDETM
		OBU	V2V	IMA
			V2I	TSP
	Marion & Jackson 27.947523, -82.455931	RSU 26	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Morgan & Jackson 27.947806, -82.455082	RSU 27	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Pierce & Jackson 27.948095, -82.454242	RSU 28	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Jefferson & Jackson 27.948403, -82.453403	RSU 29	V2I	I-SIG
				TSP
		OBU	V2I	TSP
	Morgan & Kennedy 27.948575, -82.455406	RSU 30	V2I	I-SIG
				TSP
			Agency	PDETM
		OBU	V2V	IMA
			V2I	TSP
	Pierce & Kennedy 27.948857, -82.454581	RSU 31	V2I	I-SIG
				TSP
			Agency	PDETM
		OBU	V2V	IMA
			V2I	TSP
	Jefferson & Kennedy 27.949159, -82.453716	RSU 32	V2I	I-SIG
				TSP
			Agency	PDETM
		OBU	V2V	IMA
			V2I	TSP
Trolley Conflicts	Channelside & Morgan 27.943424, -82.453165	RSU 33	V2I	I-SIG
				PED Safety
				PED-X
	Channelside & Jefferson 27.943604, -82.452140	RSU 34	V2I	I-SIG
				PED-SIG
				PED Safety
	Channelside & Nebraska 27.943549, -82.451285	RSU 35	V2I	I-SIG
				PED-SIG
				PED Safety
	Channelside & Old Water 27.943525, -82.450382	RSU 36	V2I	I-SIG
				PED-SIG
				PED Safety

Use Case	Location	HW Object	SW Application	
		OBU / PSD	V2V	VTRFTV
	Channelside & Brorein 27.943755, -82.450395	RSU 37	V2I	I-SIG
				PED-SIG
				PED Safety
	Channelside & Caesar 27.943585, -82.449882	RSU 38	V2I	I-SIG
				PED-SIG
				PED Safety
	Channelside & North 12th 27.955866, -82.445567	RSU 39	V2I	I-SIG
				PED-SIG
				PED Safety
		OBU / PSD	V2V	VTRFTV
Traffic Progression	Kennedy & Meridian 27.950576, -82.449003	RSU 3	V2I	I-SIG
			Agency	PDETM
		OBU	V2V	IMA
	Washington & Meridian 27.948732, -82.448792	RSU 4	V2I	I-SIG
			Agency	PDETM
		OBU	V2V	IMA
	Whiting & Meridian 27.947184, -82.448675	RSU 5	V2I	I-SIG
			Agency	PDETM
		OBU	V2V	IMA
	Cumberland & Meridian 27.945015, -82.448765	RSU 6	V2I	I-SIG
			Agency	PDETM
		OBU	V2V	IMA
	Channelside & Meridian 27.943557, -82.448889	RSU 7	V2I	I-SIG
			Agency	PDETM
		OBU	V2V	IMA
	Nebraska & Cass 27.953322, -82.451271	RSU 8	V2I	I-SIG
	Nebraska & Twiggs 27.947184, -82.448675	RSU 9	V2I	I-SIG
	Nebraska & Kennedy 27.950303, -82.450353	RSU 10	V2I	I-SIG
	Florida & Tyler 27.952442, -82.459046	RSU 11	V2I	I-SIG
	Florida & Cass 27.951720, -82.458746	RSU 12	V2I	I-SIG
	Florida & Polk 27.950953, -82.458412	RSU 13	V2I	I-SIG
	Florida & Zack 27.950233, -82.458089	RSU 14	V2I	I-SIG
	Florida & Twiggs 27.949471, -82.457758	RSU 15	V2I	I-SIG
	Florida & Madison 27.948723, -82.457418	RSU 16	V2I	I-SIG
	Florida & Kennedy 27.947969, -82.457035	RSU 17	V2I	I-SIG
	Florida & Jackson 27.947229, -82.456796	RSU 18	V2I	I-SIG

Source: THEA, HNTB, Siemens

Appendix B. Acronyms

Table B-1: Acronyms

ACRONYM	DEFINITION
AET	All-Electronic Toll
ASD	Aftermarket Safety Device
BRT	Bus Rapid Transit
BSM	Basic Safety Message
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller-Area Network
CBD	Central Business District
CO-PILOT	Cost Overview For Planning Ideas & Logical Organization Tool
CRL	Certificate Revocation List
CSW	Curve Speed Warning
CU	Controller Unit
CV	Connected Vehicle
CVRIA	Connected Vehicle Reference Implementation Architecture
DAS	Data Acquisition System
DMA	Dynamic Mobility Applications
DRV	Driver-to-Vehicle
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EE	End Entity
EEBL	Emergency Electronic Brake Light
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FIPS	Federal Information Processing Standard
HART	Hillsborough Area Regional Transit
HMI	Human Machine Interface
I/O	Input and Output
IEEE	Institute of Electrical and Electronics Engineers
IMA	Intersection Movement Assist
IP	Internet Protocol
ISD	Intersection Situation Data
I-SIG	Intelligent Traffic Signal Systems
ITS	Intelligent Transportation Systems

ACRONYM	DEFINITION
JPO	Joint Program Office
LOC	Location
LOP	Location Obscurer Proxy
LTP	Level Test Plans
MA	Misbehavior Authority
MAFB	MacDill Air Force Base
MAP	Map Data Message
MC	Management Center
MIB	Management Information Base
MMITSS	Multi-Modal Intelligent Traffic Signal System
MTP	Master Test Plan
MUTCD	Manual of Uniform Traffic Control Devices
NTCIP	National Transportation Communications for Intelligent Transportation System Protocol
OBD	On-Board Device
OBE	On-Board Equipment
OBU	On-Board Unit
ODE	Operational Data Environment
OEM	Original Equipment Manufacturer
OSADP	Open Source Application Development Portal
PDETM	Probe Data Enabled Traffic Monitoring
PED-SIG	Mobile Accessible Pedestrian Signal System
PED-X	Pedestrian In Signalized Crosswalk
PID	Personal Information Devices
POC	Proof of Concept
PREEMPT	Emergency Vehicle Preemption
PRX	Proxy
PSM	Personal Safety Message
RD	Requirements Document
RDE	Research Data Exchange
RE	Roadway Equipment
REL	Reversible Express Lanes
RLVW	Red Light Violation Warning
RSD	Retrofit Safety Device
RSE	Roadside Equipment
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System
SDK	Software Development Kit
SE	System Engineering
SP	Signal Priority
SPaT	Signal Phase and Timing

ACRONYM	DEFINITION
SRM	System Request Message
SSM	System Status Message
TC	Test Cases
TE	Test Execution
THEA	Tampa Hillsborough Expressway Authority
TIM	Traveler Information Message
TIP	Transportation Incentive Program
TMC	Transportation Management Center
TP	Test Procedures
TR	Test Reports
TRP	Transit Safety Retrofit Package
TRX	Translator
TSP	Transit Signal Priority
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VAD	Vehicle Awareness Device
VDTO	Vehicle Data for Traffic Operations
VEE	Visual Engineering Environment
VEH	Vehicle
VIN	Vehicle Identification Number
VMS	Variable Message Sign
VSC-A	Vehicle Safety Communications Applications
VTRFTV	Vehicle Turning Right in Front of a Transit Vehicle
WAVE	Wireless Access In Vehicular Environments
WSA	WAVE Service Announcement

Appendix C. Glossary

Table C-1: Glossary

Term	Definition
1609.2 - IEEE Standard for Wireless Access in Vehicular Environments — Security Services for Applications and Management Messages	Secure message formats and processing for use by Wireless Access in Vehicular Environments (WAVE) devices, including methods to secure WAVE management messages and methods to secure application messages are defined in this standard. It also describes administrative functions necessary to support the core security functions.
Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications ConOps	Describes the concept of operations for three CV V2I safety applications (RLVW, SSGA, CSW) related to intersection safety and speed management.
Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications System Requirements	Describes the system requirements for three CV V2I safety applications (RLVW, SSGA, CSW) related to intersection safety and speed management.
Basic Safety Message (BSM)	The outgoing message sent by a vehicle that communicates information and data about its current state to a set of neighboring vehicles. That information or data is used by Vehicle-to-Vehicle (V2V) safety applications in the neighboring vehicles to warn users of crash-imminent situations.
Bootstrapping	The process of configuring and updating an uninitialized vehicle's on-board equipment (OBE), which results in the issuance of the OBE's enrollment certificate and transition to the Operating Mode.
Certificate Revocation List (CRL)	A list of certificate identifiers that the Misbehavior Authority (MA) function identifies to be misbehaving due to technical error or human malfeasance.
Dedicated Short Range Communications (DSRC)	The one-way or two-way short-to-medium range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards. DSRC is sometimes referred to as Wireless Access in Vehicular Environments (WAVE) in other literature.
FIPS Publication 140-2 Security Requirements for Cryptographic Modules	The FIPS protocol for computer security standard used to accredit cryptographic modules.
IEEE 829-2008 Standard for Software and System Test Documentation	Specifies the form of a set of documents for use in eight defined stages of software testing and system testing, each stage potentially producing its own separate type of document.
MMITSS-AZ 1.0	Source code for MMITSS prototype, including Intelligent Traffic Control, Priority Control, Pedestrians Smartphone app, and Performance Observer.
MMITSS-CA Field Test	Source code for MMITSS prototype for California Field Test, including Intelligent Traffic Control, Priority Control, Pedestrians Smartphone app, and Performance Observer.
Multi-Modal Intelligent Traffic Signal System (MMITSS)	Captures a vision and a roadmap for the development, deployment, operation and maintenance for MMITSS, which includes I-SIG, TSP,

Term	Definition
ConOps	Pedestrian Mobility, Freight Signal Priority, and Emergency Vehicle Priority
Multi-Modal Intelligent Traffic Signal System (MMITSS) Impact Assessment	Evaluates the potential network-wide impacts of the Multi-Modal Intelligent Traffic Signal System (MMITSS) based on a field data analysis utilizing data collected from a MMITSS prototype and a simulation analysis
Multi-Modal Intelligent Traffic Signal System Final System Requirements	Describes the systems requirements for the MMITSS, which includes the following CV applications I-SIG, TSP, Pedestrian Mobility, Freight Signal Priority, and Emergency Vehicle Priority
Multi-Modal Intelligent Traffic Signal System- System Design	Describes a high level system and software design for the MMITSS, which includes the following CV applications I-SIG, TSP, Pedestrian Mobility, Freight Signal Priority, and Emergency Vehicle Priority
On-Board Equipment (OBE)	The user equipment that provides an interface to vehicular sensors for safety measures, as well as a wireless communication interface to the Location Obscurer Proxy (LOP) for Security Credential Management System (SCMS) processes.
Open Source Application Development Portal (OSADP)	Designed to enable stakeholders to collaborate and share insights, methods, and source code on a set of research projects sponsored by the USDOT Dynamic Mobility Applications (DMA) program. The portal also contains test data sets for bench-marking the applications, procedures for testing the applications, and supporting documentation for running the test procedures.
Pseudonym Certificates	The implicit, short-term certificates used during message exchange in the pseudonym system. These certificates do not explicitly contain the holder's public key, but contain a reconstruction value which can be combined with the CA's public key to derive the holder's public key. They are smaller than traditional certificates which contain the holder's public key explicitly and offer performance advantages when messages are verified infrequently.
Research Data Exchange (RDE)	RDE is a transportation data sharing system that promotes sharing of both archived and real-time data from multiple sources (including vehicle probes) and multiple modes.
Retrofit Safety Device (RSD) Project	Source code and detail information on the RSD kits which includes a DSRC radio and antenna(s), GPS receiver and antenna, embedded gyroscope, J1939 Controller Area Network (CAN) interface, human machine interface (HMI), and interface to a Data Acquisition System (DAS).
Roadside Equipment (RSE)	An infrastructure node that serves as an intermediary in Vehicle-to-Vehicle (V2V) two-way communications between CMEs and vehicles. RSE may also send its own messages to OBE
SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary	Standards for DSRC to meet the requirements of applications that depend upon transferring information between vehicles and roadside devices as well as between vehicles themselves.
SAE J3067- Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary (SAE	Specifies dialogs, messages, and the data frames and data elements that make up the messages specifically for use by applications intended to utilize the 5.9 GHz DSRC for Wireless Access in Vehicular Environments (DSRC/WAVE, referenced in this document simply as "DSRC"), communications systems.

Term	Definition
J2735)Using Systems Engineering Methods	
Security Credential Management System (SCMS)	The set of organizations that house the various functions and activities necessary for the certificate management process.
Signal Phase and Timing (SPaT)	A message that is used to convey the current status of a signalized intersection. The receiver of this message is able to determine the current state of each phase and when the expected next phase is to occur.
Transit Safety Retrofit Package Development Applications Requirements	Describes the application requirements for the Transit Safety Retrofit Package, which includes five connected applications (PCW, VTRW, CSW, FCW, EEBL), focusing on system, hardware and software requirements.
Transit Safety Retrofit Package Development Architecture and Design Specifications	Describes the Architecture and Design Specifications, with design components including hardware and software overview, description of TRP inputs and outputs, detailed description at each of the architectural components, description of the external roadside equipment (RSE) that interfaces with the TRP for five connected applications (PCW, VTRW, CSW, FCW, EEBL).
Transit Safety Retrofit Package Development TRP Concept of Operations	Describes the concept of operations for five connected applications (PCW, VTRW, CSW, FCW, EEBL) related to transit.
Transportation Management Center (TMC)	The physical TMC room and communications infrastructure; excluding the existing TMC software system.
USDOT Connected Vehicle Safety Pilot	Research program that demonstrates DSRC-based CV safety applications for nationwide deployment.
Vehicle Safety Communications Applications (VSC-A) Final Report	Develop and test communications-based V2V safety systems to determine if DSRC at 5.9 GHz, in combination with vehicle positioning, can improve upon autonomous vehicle-based safety systems and/or enable new communications-based safety applications.
Vehicle-to-Everything (V2X)	The wireless communication exchange of messages and data between and among vehicles, infrastructure, and capable nomadic devices within the CV system.
Vehicle-to-Vehicle (V2V)	A dynamic wireless exchange of data between nearby vehicles that offers the opportunity for significant safety improvements.
WAVE Service Advertisement (WSA)	A message sent by DSRC Provider Terminals (e.g., Roadside Equipment (RSE)) announcing service and channel information so that DSRC User Terminals can determine which services are being offered on which service channels during the service channel interval.
Wireless Access in Vehicular Environments (WAVE)	The IEEE networking, upper messaging, and security layers associated with DSRC. Defines communications conforming to the IEEE 1609 protocol suite and IEEE Standard 802.11-2012, operating outside the context of a basic service set

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