Connected Vehicle Pilot Deployment Program Independent Evaluation

Mobility, Environment, and Public Agency Efficiency (MEP) Refined Evaluation Plan—Tampa

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16. Abstract

This report presents a refined evaluation plan documenting how to evaluate the mobility, environmental, and public agency efficiency (MEP) and cost-benefit impacts of the Tampa Hillsborough Expressway Authority Connected Vehicle Pilot Deployment (CVPD). The refined plan builds on the approaches outlined by Noblis in the *Mobility, Environment, and Public Agency Efficiency Preliminary Evaluation Plan: Tampa Pilot Site*. This plan focuses solely on the analyses related to quantifying the MEP benefits. This plan provides a high-level view of the activities to be conducted by Texas A&M Transportation Institute CVPD Evaluation Team as the independent evaluator for the United States Department of Transportation Joint Program Office. The details of the MEP approach will be provided in other plan documents such as the Survey Interview/Stakeholder Acceptance Plan, the Data Management Plan, and the Analysis, Modeling, and Simulation Plan. All of these plans will be integrated into a single Comprehensive Evaluation Plan. This refined evaluation plan document serves as the foundation for the development of the detailed plans.

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Table of Contents

List of Tables

List of Figures

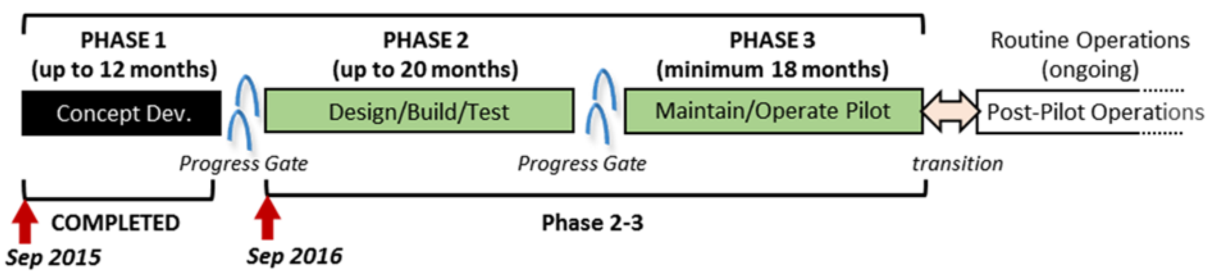
Chapter 1. Introduction

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

Background

On 14 September 2015, the Connected Vehicle Pilots Deployment (CVPD) Program initiated the pilot deployments of CV applications that synergistically capture and use new forms of CV, mobile device, and infrastructure data to improve multimodal surface transportation system performance and enable enhanced performance-based systems management.

The three selected sites (Wyoming Department of Transportation, New York City Department of Transportation, and Tampa Hillsborough Expressway Authority [THEA]) have completed the Concept Development Phase (Phase 1) and have now initiated the Design/Build/Test Phase (Phase 2). Figure 1 illustrates the life cycle of the CVPDs.



Source: USDOT/FHWA

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

The CV Pilots Deployment Program seeks to spur innovation among early adopters of CV application concepts. The pilot deployments are expected to integrate CV research concepts into practical and effective elements, enhancing existing operational capabilities. The pilot deployments will include site-tailored collections of applications that address specific local needs while laying a foundation for additional local/regional deployment, and they will provide transferable lessons learned for other prospective deployers across the nation. The intent of the pilot deployments is to encourage partnerships of multiple stakeholders (e.g., private companies, state and local agencies, transit agencies, commercial vehicle operators, and freight shippers) to deploy applications using data captured from multiple sources (e.g., vehicles, mobile devices, and infrastructure) across all elements of the surface transportation system (i.e., transit, freeway, arterial, parking facilities, and tolled roadways). The sites will demonstrate improved performance in one or more of the following areas: improved safety, mobility, public agency efficiency, or reduced negative environmental impact. Pilot deployers will identify a set of key quantitative performance measures and implement a system that supports continuous monitoring of observed data capable of quantifying the measures. Pilot deployments are expected to become part of a permanent CV capability that is fully integrated into routine operational practice at the pilot site and create a foundation for expanded and enhanced deployments. The deployers will identify and implement institutional and financial models that will enable long-term sustainability without the need for dedicated federal funding.

An evaluation of a project or a program is essential to discover how well it attains its goals. An *independent* evaluation by a third party who has no vested interest or stake in the project will eliminate potential bias in the findings. The USDOT has sponsored an independent evaluation of CVPD to help inform the USDOT of the following:

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

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

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

The USDOT Intelligent Transportation Systems (ITS) Joint Program Offices (JPO) selected the Texas A&M Transportation Institute (TTI) CVPD Evaluation Team to be independent evaluator for the CVPD. The team is composed of representatives from the following agencies were selected by USDOT ITS Joint Program office to the independent evaluators for the CVPD:

- TTI.
- Kittelson Associates, Inc.
- Gannet Fleming.
- The Cadmus Group.
- JMC Rota, Inc.

Working with the THEA CVPD Deployment Team and ITS JPO CVPD Team, the TTI CVPD Evaluation Team has developed an evaluation approach for assessing the mobility, environmental, and public agency (MEP) benefits associated with the THEA CVPD. The results of this analysis, along with the results of the independent evaluation of the New York City and Wyoming Pilot Deployments, are intended to feed the overall evaluation of the entire USDOT CVPD Program.

Organization of the Report

This report provides a refined evaluation plan for evaluating the MEP and cost-benefit impacts of the THEA CVPD. The detailed MEP approach will be integrated by the TTI CVPD Evaluation Team with the safety and non-safety related data collection activities being performed by Volpe into a Comprehensive Evaluation Plan for the Tampa site. Topics covered in this document include:

- Site overview and performance measurement plan summary (Section 2).
- USDOT goals and objectives for the deployment (Section 3).
  - Key hypotheses that should be tested.
  - Performance measures that underpin the hypotheses.
- Potential confounding factors and risks that may affect the evaluation (Section 4).
- Preliminary evaluation approach (Section 5).
- Descriptions of approach for:
  - Data collection (Section 6).
  - Observed data analysis (Section 7).
  - Simulation-based evaluation (Section 8).
  - Survey-based evaluation (Section 9).
  - Benefit-costs evaluation (Section 10).

Chapter 2. THEA Tampa CV Pilot System Overview

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

THEA is one of the first CV pilot sites selected to showcase the value of and to spur the adoption of CV technology in the United States. As described in the concept of operations (ConOps) (*1*), the THEA CVPD aims to create a connected urban environment by deploying several CV applications to mitigate several existing transportation challenges in the central business district (CBD) of Tampa.

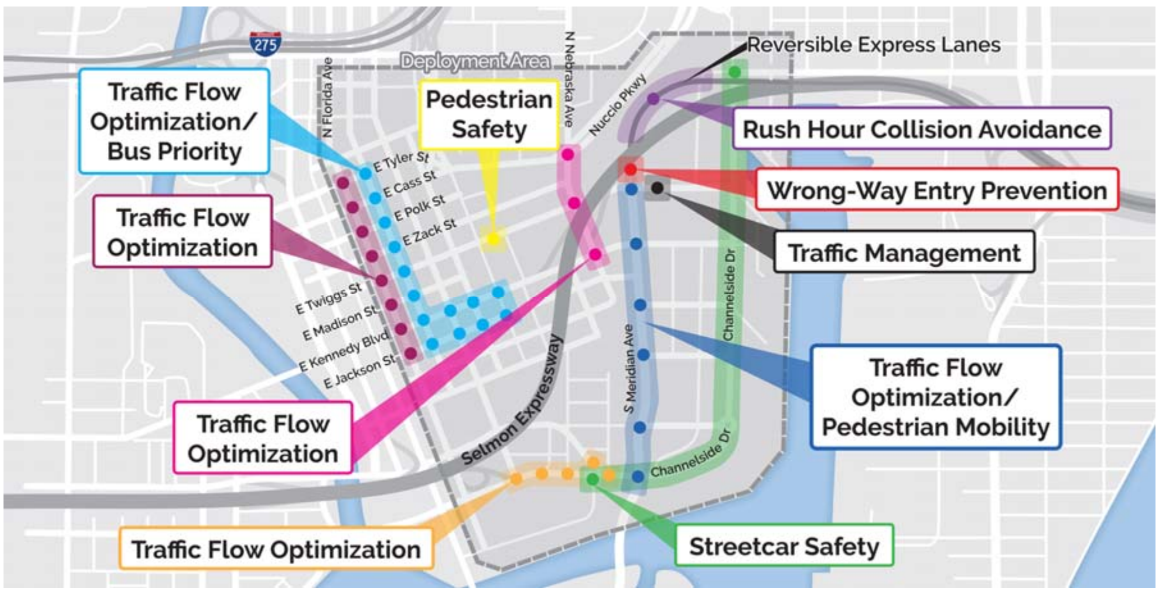
Site Description and Transportation Issues

The THEA CVPD site is located in downtown Tampa, which 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. In terms of transportation features of the Tampa downtown area, THEA owns and operates the Selmon Expressway and the Reversible Express Lanes (REL). The Selmon Expressway an elevated reversible and all-electronic toll facility that serves as a main commuter route, connecting the community of Brandon (a large residential area with a population of 103,000) and Interstate I-75 with downtown Tampa, the Tampa Cruise and Commercial Port, and MacDill Air Force Base (MAFB). MAFB is located 8 miles south of downtown Tampa adjacent to the western terminus of the Selmon Expressway. The base has a transportation incentive program in which about 1,450 base personnel use express buses or vanpools to commute to the base. The program provides monthly Hillsborough Area Regional Transit (HART) express bus passes to commuters who live in suburban areas east of Tampa. The vanpool program provides commuters, in groups of five or more, funding to secure a passenger van for their daily commute. The Tampa downtown area has a high volume of pedestrian activity around the courthouse, convention center, and arena. In addition to HART buses, there are streetcar lines that connect downtown Tampa with neighboring Ybor.

The area encapsulated by the THEA CVPD experiences several different mobility and safety issues on a daily basis (*1*). For example, in the morning commute, the endpoint of the Selmon's REL toll lanes is at the signalized intersection of Twiggs Street and Meridian Avenue. Twiggs Street and Meridian Avenue are also major routes for HART buses into and out of the downtown Tampa. Drivers experience significant delay during the morning peak hour resulting in and often caused by a correspondingly large number of rear-end crashes and red light running collisions. Also, Meridian Avenue and West Kennedy Blvd. experience transit signal delay, pedestrian conflicts, red light running, and signal coordination issues. At the Hillsborough County Courthouse on Twiggs Street, there is significant competing vehicular and pedestrian traffic during the morning peak hour. Similarly, commuters to MAFB who travel through the downtown area on the Simmons Expressway often encounter queues and delays where the REL exits into downtown. Also during the morning peak, THEA is also concerned with wrong-way entries into the REL in the downtown area. To improve mobility, enhance safety, mitigate the environmental impacts of queuing, and enhance agency efficiency, the THEA CVPD is deploying of number of CV applications and technologies to address the following operational issues in the deployment area:

- Congestion reduction and collision avoidance due to queuing on the exit ramp from the REL during the morning peak (Use Case #1).
- Wrong-way entries into the REL entrance/exit ramps during all hours of the day (Use Case #2).
- Pedestrian safety on E. Twiggs St. near the George E. Edgecomb Court House (Use Case #3).
- Transit Signal Priority (TSP) on the Marion Street Transitway (Use Case #4).
- Vehicle and pedestrian conflicts with the Tampa Historic Streetcars on Channelside Dr. (Use Case #5).
- Traffic flow optimization and signal progression on Meridian Ave., Nebraska Ave., Channelside Dr., and Florida Ave (Use Case #6).

Figure 2 shows the scope of the Tampa CV Pilot Deployment.



Source: *Tampa Connected Vehicle Pilot* Website. (*2*)

Figure 2. THEA CVPD Site

Goals and Objectives

Overall vision of the THEA CVPD is to improve the overall quality of life for Tampa Bay residents. Table 1 shows specific goals and objectives of the deployment team. Using a set of six use cases, the pilot will deploy a number of site-specific CV applications to address existing transportation issues. Note: The goals and objectives listed in Table 1 are based on the current version of the THEA's Phase I *Performance Measurement and Evaluation Support Plan* (*3*). The THEA CVPD Team will be updating this document as part of their Phase II activities.

Table 1. Local Stakeholder Goals and Objectives of the THEA CVPD.

Goal	Objectives	Use Case
Goal 1: Develop and Deploy CV Infrastructure to Support Applications Identified in Phase 1	1: Deploy dedicated short-range communication (DSRC) technologies to support vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-device (V2X) applications. 2: Upgrade traffic management center (TMC) software to ensure compatibility with CV applications. 3: Recruit a fleet of transit and private vehicle owners to participate in the CV Pilot by installing and using CV technology offered in the pilot.	All Use Cases
Goal 2: Improve Mobility in CBD	1: Replace existing traffic controllers and control systems at key intersections with Intelligent Traffic Signal System (I-SIG) CV technology to improve traffic progression. 2: Help HART buses stay on predictable schedule through TSP applications. 3: Improve bus rapid transit (BRT) operation and encourage ridership.	Use Case 1 Use Case 2 Use Case 3 Use Case 4 Use Case 6
Goal 3: Reduce Number of Safety Incidents within the Pilot Area	1: Detect pedestrians and provide warnings to drivers of potential pedestrian conflicts. 2: Detect potential vehicle conflicts and provide warnings to pedestrians. 3: Provide early detection of wrong way drivers and issue warnings to wrong-way drivers and upstream motorists. 4: Warn drivers of REL exit curve speed and stopped vehicles ahead. 5: Detect and warn of potential conflicts between streetcars, vehicles, and pedestrians.	Use Case 1 Use Case 2 Use Case 3 Use Case 5 Use Case 6
Goal 4: Reduce Environmental Impacts within the Pilot Area	1: Provide CV mobility and safety applications to improve overall mobility and reduce stops and idle time within the CBD, reducing emissions. 2: Provide TSP applications to reduce HART buses idle time. 3: Provide BRT applications to improve overall operation and encourage increased ridership.	Use Case 1 Use Case 2 Use Case 3 Use Case 4 Use Case 6
Goal 5: Improve Agency Efficiency	1: Improve data collection capability, reducing the costs of collecting data. 2: Reduce the number of incidents and police and rescue responses to incidents. 3: Reduce crashes and time agencies take to gather data. 4: Improve technology for crash statistics gathering. 5: Improve scheduling and dispatching of HART vehicles with improved trip times and vehicle information. 6: Reduce THEA's overhead in responding to wrong-way entries and crashes on REL exit ramp.	
Goal 6: Develop Business Environment for Sustainability	1: Work with Collision Avoidance Metric Partnership (CAMP), original equipment manufacturers (OEMs), and third party developers to develop business cases for advancing CV-ready vehicles. 2: Work with industry sectors that will benefit from CV implementation to provide education on the benefits and seek support for advancement of the system. 3: Work with chambers of commerce and other business organizations to educate members on the return on investment from increased mobility. 4: Work with state and local government to encourage positive legislation and funding in support of CV technology.	

Source: *CVPD Program Phase 1, Performance Measurement and Evaluation Support Plan – Tampa (THEA).* (*3*)

Proposed CV System Description

The proposed CV system consists of five main components. Each component is briefly described below. For detailed descriptions, please refer to THEA CVPD ConOps document (*1*).

Facilities

Facilities include the existing THEA/City of Tampa TMC, the Selmon Expressway REL, and streets and signals in the City of Tampa. The City of Tampa provides traffic management on city streets and operates the THEA TMC, which includes the lane reversal process. THEA owns and operates the Selmon Expressway, the Selmon REL, Brandon Parkway, and Meridian Drive.

Equipment and Computing Hardware

Equipment includes traffic signals, roadside units (RSUs), on-board units (OBUs), smartphones, and the TMC computers. The City of Tampa owns, operates, and maintains the signal system. The downtown signal software is an Urban Traffic Control System 1.5 Generation, but the City of Tampa plans to upgrade to an advanced traffic management system central system. RSUs will be supplied, installed, and maintained by Siemens during the CV Pilot, while BrandMotion will provide the OBUs. The TMC computer is in place and will not be augmented except with software modules. Table 2 summarizes all the devices that will be used for the THEA CVPD.

Table 2. Summary of Devices for Deployment.

Device Category	Tampa (THEA) – Devices	Estimated Number
Infrastructure	RSUs at Intersections	40
Infrastructure	LIDAR Equipped Pedestrian Detection Systems	2
Infrastructure	Video Detection Cameras	20
Vehicle	Light Vehicle Equipped with OBUs	1,600
Vehicle	HART Transit Bus Equipped with OBUs	10
Vehicle	Tampa Historic Streetcars Equipped with OBUs	10
V2X	Pedestrian Equipped with App in Smartphone	500+

Source: THEA (*5*)

Software

The THEA TMC uses proprietary software to run the TMC called DYNAC from Kapsch TrafficCom. The DYNAC software runs the Selmon Expressway REL gates and controls the closed-circuit television (CCTV) cameras. THEA and City of Tampa are currently evaluating Cameleon and other traffic management software systems for replacement of the current control software. Software for CV Pilot equipment and TMC alert notifications will be produced or facilitated by Siemens. Siemens will work closely with the TMC software maintenance professionals to add software modules to the TMC software that will classify, count, and distribute alerts to operators.

Participants

Participants in the CV Pilot study will include drivers, pedestrians, and bus/streetcar drivers. The THEA CVPD team is responsible for the recruitment of participants and their training.

Staff Personnel

The following are the staff personnel involved in the THEA CVPD:

- **TMC Staff**—Operators will not need to dedicate significant additional time to the CV pilot beyond their routine duties. TMC staff will perform their standard duties for incident detection, verification, and notification. They will follow up on alerts from CV devices just as they would from other sources, such as traffic detectors, CCTV cameras, and cellphone calls. The CV Pilot will add no new functions for the TMC personnel to perform. Collection of incident data is an ongoing routine in the TMC and the CV Pilot data processing will be automated.
- **Maintenance Personnel**—Maintenance of existing traffic signal systems and communication infrastructure is supported by dedicated staff from the City of Tampa. Maintenance requirements will need to be defined for RSUs including I-SIG hardware and software. City maintenance technicians will need to be trained by Siemens and others to maintain new TMC and RSU hardware, software, and communication infrastructure. Additionally, any needed maintenance tools, hardware, software, and spare replacement parts will need to be provided. Maintenance of the Selmon Expressway access and tolling system is provided by THEA's maintenance contractor. Any installation or maintenance involving Selmon Expressway infrastructure will include coordination and/or support between Siemens and the THEA maintenance contractor. Siemens will coordinate with HART to make use of the bus and streetcar maintenance staff.
- **Installers**—There will be a need to install OBUs and RSUs by City of Tampa traffic systems professionals working with Siemens installers. Maintenance of the Selmon Expressway access and tolling system is provided by THEA's maintenance contractor. Any installation or maintenance involving Selmon Expressway infrastructure will include coordination and/or support from the THEA maintenance contractor.

Proposed Applications

The THEA CVPD Team intends to deploy 13 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 (*5*). For detailed description of the CV applications, please refer to the *THEA CVPD Application Deployment Plan* document (*6*). Each of the four application categories and their respective CV applications to be deployed are briefly described below.

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, and transit vehicles—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 (BSMs). The BSM provides basic information about a vehicle's speed, heading, and location, and is updated every 1/10th of a second. These applications will only function when the involved vehicles are both equipped with V2V devices. The THEA CVPD Team plans to deploy four V2V safety applications. These applications are described briefly below.

Emergency Electronic Brake Light

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 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. If a vehicle is broken down on the shoulder of the road, the EEBL application will notify vehicles that may hit the stopped vehicle.

Forward Collision Warning

The 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 to avoid or mitigate rear-end vehicle collisions in the forward path of travel. 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.

Intersection Movement Assist

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 or uncontrolled 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 improve safety at intersections where there might be potential conflicts between equipped vehicles.

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 of the transit vehicle to make a right turn. This application will help the transit vehicle determine whether the area in front of the vehicle will be occupied as it begins to pull away from a transit stop. The Tampa Historical Streetcar line, which runs along Channelside Drive from the Amalie Arena to the Selmon Expressway, runs parallel to vehicle lanes with a common approach to traffic control signals. The signal will be red for all vehicle phases during the streetcar crossing. However, right turn on red is typically a legal move, which may cause a motorist—unaware of the streetcar’s presence—to turn right into the streetcar’s path.

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 enhanced awareness, and inform vehicle operators through advisories and warnings of hazards and situations they cannot see. The THEA CVPD team plans to deploy four V2I safety applications. These applications are described briefly below.

End of Ramp Deceleration Warning

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

Pedestrian in a Crosswalk Vehicle Warning

The pedestrian in a crosswalk vehicle warning (PED-X) 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. The application will also provide warning information to the pedestrian on 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, reducing the potential of a pedestrian being struck by a vehicle.

Wrong-Way Entry Warning

The Wrong-Way Entry (WWE) application is intended 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 a.m.–1:30 p.m. weekdays). At the exit to the REL on East Twiggs Street, the opportunity exists for a driver to become confused and attempt to enter the REL going the wrong way. Although gates exist on the entrance side (east side of the intersection) of the REL to prevent drivers from entering the REL going the wrong way, gates or barriers do not exist on the exit side of the REL (west side of the intersection). 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 toward 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. Wrong way entries are detected by sensors at the RSU. When a wrong way entry is detected, the RSU sends a traveler information message alert to law enforcement and the TMC. When a wrong way driver of a CV is identified, the wrong way driver receives an immediate warning from the RSU that detected the wrong way entry. Other CVs traveling the correct way on the REL will receive a warning of the approaching wrong-way driver. The TMC will broadcast a wrong-way driver alert using the variable message signs to warn all other drivers on the REL.

Pedestrian Collision Warning

The Pedestrian Collision Warning (PCW) application warns the driver when a pedestrian is using a crosswalk in the projected path of the CV. Sensors install adjacent to the crosswalk detect when a pedestrian is located in the crosswalk. The RSU then sends a message to the CV that a pedestrian is located in the crosswalk.

Pedestrian Transit Movement Warning

The Pedestrian Transit Movement Warning (PTMW) application warns pedestrian when a bus or streetcar is starting up or stopping at a nearby intersection.

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 CVPD team plans to deploy three V2I mobility applications. These applications are described briefly below.

Intelligent Traffic Signal System

The I-SIG application uses vehicle location and movement information from CVs and 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 uses vehicle information to adjust signal timing for an intersection or group of intersections 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 TSP, 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.

Transit Signal Priority

The Transit Signal Priority (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. Once TSP is implemented, if a bus is behind schedule, the traffic signal system will give the bus priority (assuming no other higher priorities such as a preemption request or an on-going pedestrian phase are active at the intersection), to flush the queue, shortening the wait time of the bus at the intersection.

Mobile Accessible Pedestrian Signal

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 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 configuration (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 Tampa Historic Streetcar Conflicts.

Probe Data Enabled Traffic Monitoring Application

The Probe-Data Enable Traffic Monitoring (PDETM) application uses 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 CVPD 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 Wireless Access in Vehicular Environments Service Announcement 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 current traffic conditions.

Performance Measurement by the THEA CVPD Team

Table 3 lists the performance measures that will be used by the THEA CVPD Team to ascertain the effectiveness of the use cases on the four pillars of mobility, safety, environment, and agency efficiency. Please refer to *Connected Vehicle Pilot Deployment Performance Measurement and Evaluation Support Plan – Tampa (THEA)* document for details (*3*). The measures noted below are derived from the THEA performance measurement plan and reflect only a subset of potential measures supporting a broader USDOT evaluation effort. The key performance measures for each of the performance categories include:

- **Safety –** Crash reduction, crash rate, type of conflicts/near misses, severity of conflicts/near misses, percent red light violations, and approaching speed number/frequency of wrong way entries.
- **Mobility** – Travel time, travel time reliability, queue length, vehicle delay, throughput, percent arrival on green (AOG), bus travel time, bus route travel time reliability, percent arrival on schedule, and numbers of signal priority being granted/denied.
- **Environmental –** Emission reduction in idle speed and emission reduction in running.
- **Public Agency Efficiency** – Customer satisfaction.

Proposed Data Collection

During the CV Pilot, data will be generated from multiple sources and received by multiple sources. It is anticipated that the majority of the data created and stored will be BSMs. Signal request messages and signal status messages are captured as well for priority assignments. There will be a master server located at the THEA TMC where the CV Pilot data are archived. OBUs will store data generated (e.g., BSMs), received (e.g., FCW, EEBLs, BSMs, TSP), and broadcasted (e.g., FCW, EEBLs, BSMs). Periodically, the OBUs will download their stored data to the master server. RSUs will store data generated (e.g., speed), received (e.g., BSMs), and broadcasted (e.g. BSMs). OBUs will use installed applications to inform the driver of potential conflicts/issues. It is expected that there will be over a thousand OBUs. RSUs will periodically connect to the master server to archive their stored data. Action logs will also be created to document protocols followed by participant (e.g., bus operators, passenger vehicle drivers, TMC operators) who interact with the system.

THEA CVPD site has agreed to support USDOT evaluation needs by providing data required for independent evaluation effort through established data sharing protocols in frequencies dictated by the TTI's contractual requirements. Details of the data elements to be provided by THEA to support the independent evaluation effort can be found in Chapter 9 of the *Connected Vehicle Pilot Deployment Program Phase 1, Performance Measurement and Evaluation Support Plan – Tampa (THEA)* (*3*). Data from THEA CVPD site will be cleansed and aggregated into data sets and then sent to the Connected Vehicle Performance Evaluation Platform (CV PEP). This platform will be the central repository of all evaluation data coming from the site. The Volpe Center will be responsible for developing, operating, and administering the CV PEP. The Volpe Center is working with all three of the CV Pilot Deployment Sites to develop procedures and protocols for aggregating, cleansing, and uploading the evaluation data to the CV PEP. All data uploaded to the CV PEP will be stripped of all potential personally identifiable information (PII) issues. If it is determined that some data cannot be completely stripped of PII issues and appropriate permissions cannot be obtained for sharing or storage, these data will not be shared and will be removed from the master server. Please note that these data are those slated for collection by the site to support their performance measurement activities.

This plan reflects the proposed evaluation for assessing the MEPs impacts only of the THEA CVPD. The Volpe Center is responsible for developing the plan for evaluating the safety impacts of the THEA CVPD. This evaluation plan is not scheduled to be completed in August 2017. TTI expects that additional data collection may be required to satisfy USDOT Safety evaluation objectives; however, at this time, these additional data needs are not known. This plan will be revised (if necessary) once the safety evaluation plan has been completed.

Table 3. Mapping of CV Applications to Performance Measures and Use Cases[1]

Use Case Description	Applications	Mobility Performance Measures	Safety Performance Measures	Emissions Performance Measures	Agency Efficiency Performance Measures
1. Morning Peak Hour Queues	• V2I Safety: ERDW and WWE • V2VSafety: EEBL and FCW	Travel time, travel time reliability,[2] queue length, delay, throughput, and percent AOG	Crash reduction, crash rate, type of conflicts/near misses, severity of conflicts/near misses, approaching speed on REL, and percent red light violations	Changes in idle speed emissions and changes in running emissions	Customer satisfaction
2. Wrong Way Entries	• V2I Safety: WWE • V2V Safety: IMA • Mobility: I-SIG • Agency Data: PDETM	Travel time delay	Crash reduction, crash rate, type of conflict/near misses, and number/frequency of wrong way entries	Changes in idle speed emissions	Customer satisfaction
3. Pedestrian Safety	• V2I Safety: PCW • V2X Safety: PED-X • Mobility: PED-SIG	Travel time, travel time reliability, queue length, vehicle delay, and throughput	Crash reduction, crash rate, type of conflicts/near misses, severity of conflicts/near misses, and reduction in approach vehicle speed toward crosswalk	Changes in idle speed emissions and changes in running emissions	Customer satisfaction
4. BRT Signal Priority	• V2V Safety: IMA • Mobility: I-SIG and TSP • Agency Data: PDETM	Bus travel time, bus route travel time reliability, percent arrival on schedule, percent AOG, and numbers of signal priority being granted/denied	n/a	Changes in idle speed emissions and changes in running emissions	Customer satisfaction

Use Case Description	Applications	Mobility Performance Measures	Safety Performance Measures	Emissions Performance Measures	Agency Efficiency Performance Measures
5. Streetcar Conflicts	• V2I Safety: PTMW • V2V Safety: VTRFTV • Mobility: I-SIG and PED-SIG	n/a	Crash reduction, crash rate, type of conflicts/near misses, and severity of conflicts/near misses	n/a	Customer satisfaction
6. Signal Coordination	• Mobility: I-SIG • Agency Data: PDETM	Travel time, travel time reliability, queue length, delay, throughput, and percent AOG	Crash reduction, crash rate, type of conflicts/near misses, severity of conflicts/near misses, vehicle speed, and percent red light violations	Changes in idle speed emissions and changes in running emissions	Customer satisfaction

1. This table is based on the Phase 1 *Connected Vehicle Pilot Deployment Performance Measured and Evaluation Support Plan*. The THEA CVPD Team will update this plan as part of their Phase II activities.
2. Travel Time reliability is defined as "the consistency or dependability of travel times, as measured from day-to-day and/or across different times of day" (*4*).

Applications (*5*)
ERDW = End of Ramp Deceleration Warning
FCW = Forward Collision Warning
I-SIG = Intelligent Traffic Signal System
TSP = Transit Signal Priority
WWE = Wrong Way Entry
PED-SIG = Pedestrian Mobility
PCW= Pedestrian Collison Warning
EEBL = Emergency Electronic Brake Light
IMA = Intersection Movement Assist
PDETM = Probe Data Enabled Traffic Monitoring
VTRFTV = Vehicle Turning Right in Front of Transit Vehicle
PED-X = Pedestrian in a Crosswalk Vehicle Warning
PTMW = Pedestrian Transit Movement Warning

Source: *CVPD Program Phase 1, Application Deployment Plan – Tampa* (*6*)

Chapter 3. USDOT Goals, Objectives, Hypotheses, and Performance Measures

This section identifies the key USDOT goals for CV pilots, and related objectives, hypotheses, and performance measures for the THEA CVPD. The USDOT evaluation effort is intended to leverage the site performance measurement activity outlined in Section 2 and to augment site performance measurement activity as required to address the set of broader federal evaluation goals.

Note that this section (and following sections) addresses the full range of USDOT objectives, including safety-related objectives and measures. Safety-related objectives are consciously included here to assist in the development of evaluation approaches that recognize and draw on the interplay of the full range of safety, mobility, environment, and public efficiency (SMEP) impacts. While the current task relates to the development of an approach for MEP impacts, a strong MEP approach must be developed cognizant of safety-related objectives and potential activity.

Definitions

The following definitions are used in the document for the various stakeholder groups (*3*):

- Pilot Deployer: These include pilot managers and decision-makers, partnering agencies, and technical staff involved in application design, development, and testing, etc.
- Transportation Managers: These include the TMC operators, BRT managers, maintenance personnel, etc.
- End users: These include operators of vehicles in which the CV technology was deployed. This includes private vehicle operators, HART transit vehicle operators, streetcar operators, and pedestrians.

USDOT Goals and Objectives for the THEA CVPD

USDOT identified the following primary goals associated with the THEA CVPD (*3*):

- Improve safety.
- Improve mobility.
- Reduce negative environmental impacts.
- Improve public agency efficiency and decision-making by transportation managers.
- Improve end-user satisfaction with their travel.

Based on these goals, USDOT identified the following as their primary deployment objectives for the THEA CVPD (*3*):

- Reduce vehicle-to-vehicle and vehicle-to-streetcar crashes and incidents (or other safety surrogate measures if crashes are rare) in the pilot deployment area through CV deployment.
- Reduce crashes and incidents (or other safety surrogate measures if crashes are rare) due to wrong-way entries into the REL.
- Reduce crashes and incidents (or other safety surrogate measures if crashes are rare) by giving drivers warnings of the REL exit curve speed and stopped vehicles ahead.
- Reduce pedestrian to vehicle and pedestrian to streetcar conflicts in the pilot deployment area by warning vehicles and pedestrians.
- Increase transit schedule reliability.
- Improve transit ridership.
- Improve traffic signal progression through use of CV data.
- Reduce negative environment impacts through reductions in crashes, improvement in signal progression, and resulting reductions in vehicle and bus idle times.
- Improve decision-making by transportation managers.
- Improve customer satisfaction of end users.

Using these as a starting point, the TTI CVPD Evaluation Team developed an evaluation plan that measures the extent to which the THEA CVPD achieved the goals and objectives specified by the USDOT. This evaluation plan focuses on assessing the MEP benefits associated with the deployment. The reader is referred to other documents to find information on how the Safety Benefits and End User Satisfaction with the THEA CVPD will be measured. These documents are currently under developed by Volpe.

Evaluation Hypotheses

Table 4 identifies the specific hypothesis that will be tested part of the TTI CVPD Evaluation Team's assessment of the THEA CVPD. These hypotheses will guide the development of the rest of the components of the evaluation plan. These hypotheses examine the extent to which the deployment achieved the overall goals and objectives defined by the USDOT. To the extent that the data will permit, the TTI CVPD Evaluation Team will first use observed data to assess the MEP impacts of the deployment. The TTI CVPD Evaluation Team will use simulation to extrapolate the MEP impacts seven years into the future. The TTI CVPD Evaluation Team will also examine the extent to which different market penetrations (a 0, 5, and 25 percent increase) of CV-equipped vehicles may affect the projected benefits into the future. Data will also be collected on what kinds of financial and institutional changes had to be made by the stakeholder agencies to support the deployment of the CV technologies in the Tampa area.

Table 4. Key Independent Evaluation Hypotheses for Tampa CV Deployment.

ID	Hypothesis
1	The pilot deployment will reduce vehicle to vehicle and vehicle to streetcar crashes and incidents (or other safety surrogate measures if crashes are rare) in the pilot deployment area.
2	The pilot deployment will reduce crashes and incidents (or other safety surrogate measures if crashes are rare) due to wrong-way entries into the REL.
3	The pilot deployment will reduce crashes and incidents (or other safety surrogate measures if crashes are rare) by giving drivers warnings of the REL exit.
4	The pilot deployment will reduce pedestrian to vehicle and pedestrian to streetcar conflicts in the pilot deployment area by warning vehicles and pedestrians.
5	The pilot deployment will increase transit schedule reliability through TSP.
6	The pilot deployment will improve transit ridership through TSP.
7	The pilot deployment will improve traffic signal progression through use of CV data.
8	The pilot deployment will reduce negative environment impacts through reductions in crashes, improvement in signal progression, and resulting reductions in vehicle and bus idle times.
9	As the market penetration of CVs increases, benefits will increase in terms of reduced stops, queues, delays, emissions, and increased vehicle throughput, transit schedule reliability, and travel time reliability.
10	As the market penetration of CVs increases, non-equipped vehicles traversing the pilot deployment area will see reductions in stops, queues, delays, and emissions.
11	Incremental increases in CV deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold, after which benefit-cost ratio will reduce.
12	The pilot deployment will result in improved public agency efficiency and decision-making by transportation managers.
13	Pilot deployers and transportation managers will find that their SMEP goals were met.
14	End users will be satisfied with performance of CV applications and with the impact of the CV deployment on their travel.
15	The pilot deployment will result in end users taking appropriate action based on alerts/warnings/advisories.*
16	End users will be satisfied with the performance of the CV devices.

* Note that in some cases no action may be an appropriate response.

Source: Adapted from *CVPD Program Phase 1, Performance Measurement and Evaluation Support Plan – Tampa (THEA)* (*3*)

Performance Measures

Table 5 identifies performance measures that help assess if the hypotheses presented in Table 4 are valid. The table highlights measures available from the site and which ones need to be measured by the independent evaluation team. Both quantitative and qualitative measures are presented.

Table 5. Key Performance Measures for Tampa CVPD.

ID	Hypothesis	Performance Measure	Suggested Data Source	Type
1	The pilot deployment will reduce V2V and vehicle to streetcar crashes and incidents (or other safety surrogate measures if crashes are rare) in the pilot deployment area.	• Changes in the number of vehicle to streetcar collisions in the deployment corridors • Change in the number of severe (KSI*) vehicle-streetcar collisions in the deployment corridor • Reduction in conflict exposures** • Change in probability of crash	• Collision Records System • Conflicts per V2V interaction • Harm Reduction Effectiveness***	• Volpe Safety Analysis
2	The pilot deployment will reduce crashes and incidents (or other safety surrogate measures if crashes are rare) due to wrong-way entries into the REL.	• Changes in the number of collisions attributed to wrong way entries at the REL exit ramp • Changes in the number of KSI collisions attributed to wrong way entries at the REL exit ramp • Reduction in conflict exposures • Change in probability of crash • Number of alerts/warnings issued at the signal due to potential wrong way entries	• Collision Records System • Conflicts per V2V interaction • Harm Reduction Effectiveness • RSU data logs	• Volpe Safety Analysis
3	The pilot deployment will reduce crashes and incidents (or other safety surrogate measures if crashes are rare) by giving drivers speed warning advice at the REL exit.	• Changes in the number of collisions attributed to wrong way entries at the REL exit ramp • Changes in the number of KSI collisions attributed to wrong way entries a the REL exit ramp • Reduction in conflict exposures • Change in probability of crash • Number of FCWs issued at when entering the REL exit curve	• Collision Records System • Conflicts per V2V interaction • Harm Reduction Effectiveness • RSU data logs	• Volpe Safety Analysis
4	The pilot deployment will reduce pedestrian to vehicle conflicts in the pilot deployment area by warning vehicles.	• Changes in the number of pedestrian-related conflicts with vehicles and streetcars • Number of pedestrian conflict warnings issued to vehicles	• Conflicts per pedestrian to vehicle interaction • Harm Reduction Effectiveness • OBU data logs from Streetcars	• Volpe Safety Analysis

ID	Hypothesis	Performance Measure	Suggested Data Source	Type
5	The pilot deployment will increase transit schedule reliability through TSP.	• Change in on-time performance in TSP corridor	• HART On-time Performance Logs • Transit BSMs	• Before/After Analysis
6	The pilot deployment will improve transit ridership through TSP.	• Change in average weekday boarding passengers	• HART Ridership Reports	• Before/After Analysis
7	The pilot deployment will improve traffic signal progression through use of CV data.	• Changes in average through trip travel time for each coordinated street	• Probe Vehicle Data • I-SIG Applications logs • City of Tampa's ATSPMS**** • City of Tampa's Traffic Signal System (Traffic count)	• Before/After Analysis
8	The pilot deployment will reduce negative environment impacts through reductions in crashes, improvement in signal progression, and resulting reductions in vehicle and bus idle times.	• See performance measures for hypotheses 1–7 above • Reductions in fuel consumption	• Emission estimates from MOVES	• Modeling Analysis
9	As the market penetration of CVs increases, benefits will increase in terms of reduced stops, queues, delays, emissions, and increased vehicle throughput, transit schedule reliability, and travel time reliability.	• Average trip time per vehicle (VHT/V) • Average vehicle hours traveled per mile (VHT/M) • Average user delay/wait time • Average speeds • Average vehicle-miles traveled per vehicle	• Total vehicle-hours traveled/ total vehicle count • Difference in VHT//M at speed limit and VHT/M • Vehicle-miles Traveled/vehicle-hours Traveled • Vehicle-miles traveled/total vehicle count	• Modeling Analysis
10	As the market penetration of CVs increases, non-equipped vehicles traversing the pilot deployment area will see reductions in stops, queues, delays, and emissions.	• Average VHT/V • Average user delay/wait time • Average speeds • Average throughput—see hypothesis 9	• Same as above but for non-equipped vehicles only	• Modeling Analysis

ID	Hypothesis	Performance Measure	Suggested Data Source	Type
11	Incremental increases in CV deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold, after which benefit-cost ratio will reduce.	• Benefit-cost ratio at various market penetrations of CVs and technology	• Cost data • Dollar values of benefits	• Modeling Analysis • B/C Analysis
12	The pilot deployment will result in improved public agency efficiency and decision-making by transportation managers.	• Changes in the quality of the information • Perceived usefulness of alerts/warnings/advisories • Changes in staff time to take appropriate action and disseminate information • Number of operational and business practice changes made by transportation managers • Nature of operational and business practice changes made by transportation managers • Perceived impacts of operational and business practice changes • Perceived improvements to decision-making abilities due to alerts/warnings/ advisories	• Interview Responses	• Stakeholder Interviews
13	Pilot deployers and transportation managers will find that their SMEP goals were met.	• Qualitative assessment of the extent to which SMEP goals were met • If SMEP goals were not met, factors or reasons why	• Interview Responses	• Stakeholder Interviews

ID	Hypothesis	Performance Measure	Suggested Data Source	Type
14	End users will be satisfied with performance of CV applications and with the impact of the CV deployment on their travel.	• Perception of whether advisories/alerts/warnings were: o Timely o Sufficiently detailed o Easy to understand o Accurate o Useful • Perceived impact (if any) that alerts/warnings/ advisories had on safety and/or mobility • Perception of whether trip expectations (e.g., red light violation, stopped vehicles on exit curve, pedestrian-vehicle conflicts) matched trip experiences	• Interview Responses	• Stakeholder Interviews
15	The pilot deployment will result in end users taking appropriate action based on alerts/ warnings/advisories.	• Number and type of actions in response to alerts/warnings/advisories • Reasons why no action was taken when alerts/warnings/advisories were received	• Data analysis of Action Logs • Interview Responses (may require surveying drivers immediately following a trip in which they received alerts/warnings/advisories/ traveler information)	• With/Without Comparison • Qualitative
16	End users will be satisfied with the performance of the CV devices.	• Overall satisfaction with performance of CV devices • Number and nature of problems with CV devices	• Interview Responses	• Qualitative

*KSI = Killed/Seriously injured.

**Conflict Exposure is the rate at which a vehicle is exposed to a potential conflict.

***Harm Reduction Effectiveness refers to the effectiveness of the application to reduce the adverse risks and harms associated with driving in the deployment corridors.

****ATSPMS – automated traffic signal performance measurement system. It is the understanding the TTI CVPD Evaluation Team that the City of Tampa will be installing a module in their traffic signal management system that will perform this function.

Chapter 4. Confounding Factors and Risks

This chapter identifies confounding factors external to the evaluation process. If not controlled, confounding factors have the potential to compromise the accuracy of estimated performance measures and resulting conclusions. A confounding factor is a variable that completely or partially accounts for the apparent association between an outcome and a treatment. This can lead to erroneous conclusions about the relationship between the independent and dependent variables. It is critical to identify confounding factors and isolate their impacts so that performance improvements are neither overstated nor understated. The effects of confounding factors can be subdued or eliminated by using an appropriate experimental design that accounts for these external factors. Since confounding factors are external to the experiment, they are usually not monitored during the experimental period. As a result, changes in these factors during experimental period may bias eventual findings. On the contrary, risks are internal factors in an experiment that can lead to erroneous conclusions.

Potential confounding factors and risks that may affect the Tampa Pilot deployment evaluation are discussed below. These are the minimum list of confounding factors and risks; additional ones may arise at later stages of the evaluation. Hence, confounding factors and risks should be identified and assessed at the outset of the evaluation effort and tracked throughout the project.

Key Confounding Factors

This section identifies several key confounding factors that can impact the Tampa Pilot deployment evaluation process. For a detailed discussion of the confounding factors, please refer the *CVPD Performance Measurement and Evaluation Support Plan – Tampa (THEA)* (*3*). This section also describes potential strategies to mitigate the impacts of identified confounding factors.

Variations in Travel Demands

Travel demand in southern Florida is highly seasonal. In Florida, traffic demands are generally the greatest during the winter months. Unexplained random variations in daily or peak period demands also exist due to factors outside the study area that can confound the study results.

Changes in Weather Conditions between the Pre- and Post-Deployment Periods

Tampa is characterized by a subtropical climate with hot and humid conditions from mid-May through mid-October coinciding with the rainy season. Summertime weather is consistent from June through September and is characterized by mid-afternoon thunderstorms. These weather conditions can affect vehicle travel speed (e.g., traveling slower than usual), pedestrian trip patterns, and bus boarding differently at either the origin or end of a trip. Not controlling for the effects of changes in weather conditions has the potential to invalidate conclusions about the effectiveness of the CV Pilot deployment in addressing the needs of the Pilot site. Comparisons must be made between similar (adverse/non-adverse) weather conditions to help ascertain the true impacts of CV technology.

Special Events

The CV Pilot Study Area is site to several attractions (e.g., Tampa convention center, Tampa museum of art, the Florida Aquarium, and others) that draw visitors and residents to attend leisure or business events, and generate additional non-seasonal traffic with the potential to introduce confounding information throughout the duration of the pilot. Some of the major planned events for 2016–2017 include:

- Florida's Largest Home Show (Sep. 2–5; attendance 35,000).
- Tampa Boat Show (Sep. 9–11; attendance 25,000).
- Publix Supermarkets Gasparilla Distance Classic (Feb. 24–25; attendance 30,000).
- 2018 NHL All-Star game (January 28, 2018).

These recurring events are likely to be repeated in 2018. It is essential that these events are monitored and accounted for in the impacts evaluation process.

Tampa Downtown Waterfront Planned Construction

New commercial and residential development is expected in the downtown area. The University of South Florida (USF) is planning to build a new facility to relocate the Morsani College of Medicine and USF Health Heart Institute, presently sited at the North Tampa Campus, in proximity to its teaching hospital, Tampa General Hospital. These plans are part of a larger development effort to construct 1.1 million square feet of office space and 660,000 square feet of residential space and turn downtown into a walkable, multimodal, and wellness centered city. The first phase of this construction will be in 2020. The construction mitigation plans are likely to affect traffic patterns in the deployment area. Completion of the planned construction will also commuters' habitual travel patterns in the downtown area too.

Unusually High/Low Crashes or Incidents

Incident or crash occurrence can vary substantially for no obvious reasons from one period to the other. These incidents/crashes affect the level of travel delay experienced on roadways. For example, as a result of regression to the mean, number of crashes may reduce significantly on a roadway during an analysis period. If not investigated correctly, these reductions may be wrongly attributed to some safety improvements project, which was deployed during the same analysis period. Issues of this nature can cause false conclusions to be made about the effectiveness of the CV Pilot deployment.

Economic Conditions

As was apparent during and following the last recession in the late 2000s, travel patterns (including volumes and modes, pedestrian and tourist demand, freight and construction activity) are closely tied with local, regional, and even national economic conditions. While these conditions can play a role on transportation activity, the effects of economic swings can be slow to materialize and dissipate.

Fuel Prices

Change in fuel prices can impact demand. For example, lowering prices may result in additional automobile trips while increasing may result in a shift to more fuel-efficient modes. While fuel prices may adjust more quickly than general economic conditions, the effects of changing fuel prices may be more noticeable over a longer timeframe than the 18-month Phase 3 performance reporting period.

Potential Mitigation Approaches

The effects of confounding factors can be minimized by using appropriate experimental designs or statistical techniques so that comparisons in data are done for similar conditions. To control for confounding factors such as uncertainty in decision making, the benefits seen during the transition period should be differentiated from that seen in the post transition period.

Experimental Designs with Control/Treatment Groups

Experimental designs that make use of control and treatment groups are the most effective in mitigating the impacts of variability in weather, traffic, and crash/incident conditions. These approaches compare trip outcomes of vehicles with the technology (treatment group) with those of vehicles without the technology (control group) traveling on the same road under similar road weather, traffic, and crash/incident conditions. By having both treatment and control group vehicles travel in similar conditions, the impact of weather, traffic, and crash/incident variability on performance measurement is minimized.

Statistical techniques

The TTI CVPD Evaluation Team will also consider use the following statistical techniques to mitigate the effects on confounding factors:

- **Statistical counterfactual**: In experimental designs that make use of control/treatment groups, the control group serves as the counterfactual. Alternately, counterfactuals can be developed using a statistical model, such as a regression analysis, to estimate what would have happened in the absence of an intervention.
- **Pairwise matching enabled by cluster analysis:** An evaluation design that makes use of the classic before/after analysis is not effective in controlling for confounding factors. However, statistical techniques (e.g., cluster analysis, propensity score matching) may be used to account for the impact of confounding factors. For example, cluster analysis may be performed to group data in the pre- (before) and post- (after) deployment periods into clusters such that data in each cluster have similar characteristics (i.e., similar traffic demand, freight demand, weather, incidents). Cluster analysis controls for the effects of confounding factors by ensuring that comparison is only made between pairs of before and after data within each cluster.

Traffic Simulation Tools

Traffic simulation tools can be used to mitigate for weather, traffic, and crash/incident condition variability. Driver behaviors in these conditions with and without alerts can be collected and used to calibrate the simulation model. With a calibrated simulation model, different CV strategies and operational scenarios can be tested under the same weather, traffic, and crash/incident conditions. Counterfactuals are established by disabling or de-activating the modeled CV applications and estimating performance measures, while keeping everything else (i.e., network demand, vehicle split) the same.

Key Risks

This section discusses key risks that may impact the evaluation effort. Although the TTI CVPD Evaluation Team independent evaluator may not be in a position to address some of these risks, the evaluator should discuss these risks and others, as soon as these are identified, with the deployers so that the deployers can avoid, control, or mitigate these risks.

Participants Exploiting Limits of Application

Some participants may develop a false sense of complacency from a perceived protection afforded by CV technology and applications, and may demonstrate risky driving behaviors. For example, a driver may drive at a relatively higher speed on a curve because he/she knows that a FCW will be issued if there is a vehicle in front. If these risky behaviors are not controlled, there may be an increase in crashes. Appropriate participant training by the deployers may be needed.

Uncertainty in Decision Making During Transition Period

The adoption of CV technology will provide decision makers such as TMC operators, maintenance personnel, highway patrol personnel, with considerable amount of time and location information. It is unknown how this information will affect the decision making process in terms of provision of advisories to drivers, incident response, maintenance, etc. However, it can take time to understand the system and make decisions. There is a period of learning. If the incoming CV data and information are not used effectively, benefits of CV technology will be reduced. Failure to distinguish between the transition period and the post-transition period can result in an underestimation of benefits.

Participant Attrition

Once enrolled as participants, some individuals will likely exit the study due to triggering events, such as a change of job leading to a different commute pattern, vehicle replacement, lack of interest, or other similar factors. When measuring performance at the individual level, statistical methods (e.g., unbalanced panel data methods) should be employed to reduce the impact of ensuing confounding factors.

Measurement Errors due to Concurrent Use of Applications to Measure Performance

The concurrent use of different applications to measure performance can lead to data integration issues and measurement error. These issues should be identified during the data collection and cleaning process prior to performance evaluation.

Data Limitation for Safety Analysis

Because of the limited sample size of vehicle and the rarity of actual collision, it may be difficult to determine actual crash reduction factors associated with the deployment. Volpe, who is conducting the safety analysis for this deployment, is developing an evaluation plan that is investigating not only actual reductions in crashes, but also potential reductions in crashes through reductions in conflicts and other measures. While these may not represent actual crash reductions, the TTI CVPD will use this information to estimate the mobility benefits associated with potential reductions in crashes. These mobility improvements due to safety improvements represent only estimates of the potential benefits and may not reflect actual benefits associated with the deployment.

Chapter 5. Evaluation Design

This chapter provides a discussion of the evaluation design(s) chosen to account for confounding factors and other threats to the validity of evaluation.

The Tampa Deployment Team has proposed evaluation designs to measure the performance of their system. These designs are constrained by resources and schedule, and hence suffer from one key challenge—there is limited ability to estimate system-wide measures. Randomized or quasi experimental designs are not feasible for generating system-wide measures. While THEA is developing a microscopic model of the downtown Tampa areas, the Tampa Deployment Team is not proposing to use traffic simulation tools to evaluate system-wide measures.

Potential Experimental Designs

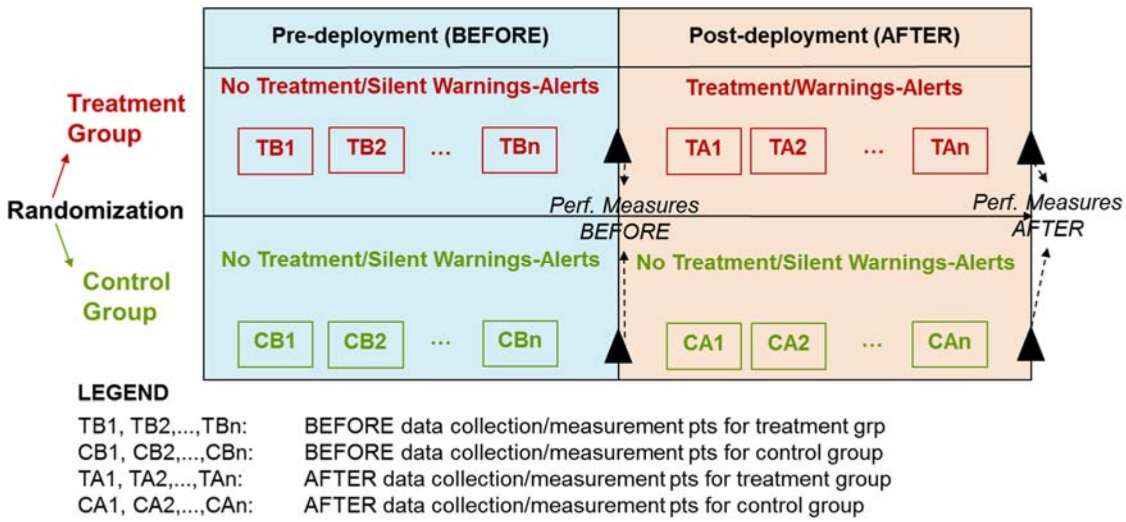
This section briefly discusses three key designs that may be applied to the pilot deployment evaluation. The Independent Evaluator should expand this section to include additional designs, as needed.

Randomized Experiments

In randomized experiments, study subjects are randomly assigned to the control group (i.e., the group that does not receive any intervention or treatment) and the treatment group (i.e., the group that receives the intervention). Data for each group are collected before (pre-test or pre-implementation) and after the treatment (post-test or post-implementation). At the end of the experiment, differences between the treatment and control groups can be attributed directly to the effect of the treatment, if the sample is large enough. Randomization ensures the control and treatment groups are equivalent for all factors other than whether they received the treatment. Here, the control group serves as the counterfactual of what would have happened in the absence of the treatment, which is a key requirement in determining whether a treatment caused a particular outcome. Please see Figure 3 for a graphical illustration of the design.

An example application of such a design is to assess if an in-vehicle variable speed limit application is beneficial or not. Test drivers are randomly assigned to the control group or the treatment group. In the pre-test period, neither the control group nor the treatment group drivers receive any messages. In the post-test period, the control group drivers do not receive the variable speed limit message, while the treatment group drivers receive the variable speed limit message. Data are collected for both groups and performance measures (e.g., emissions) are calculated for the pre-test period and the post-test period. A comparison of the differences in the performance measures between the control and treatment groups reveals whether the changes observed are due to the variable speed limit application or confounding factors.

This type of evaluation design provides the most assurance that outcomes are the result of the treatment (or the pilot deployment). However, these types of evaluation efforts can be expensive.



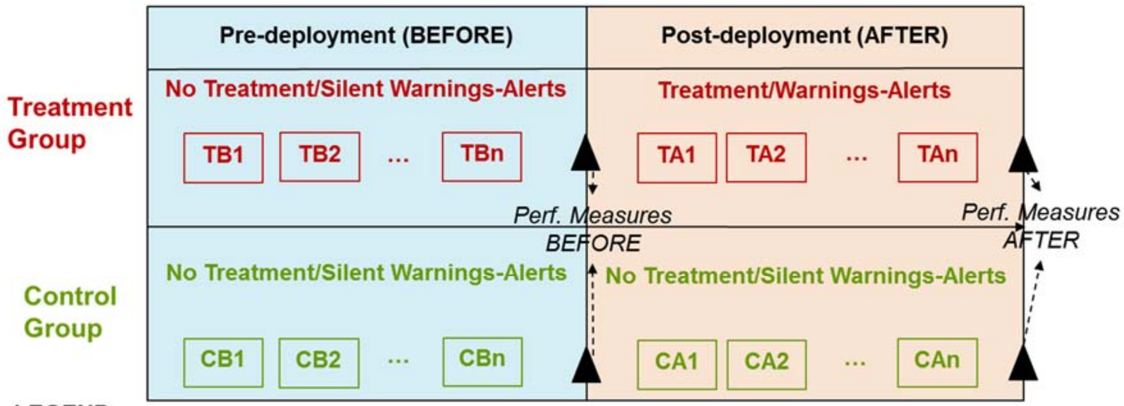
Source: Noblis

Figure 3. Randomized Experimental Design

Quasi-Experiments

Quasi-experimental design is an approximation of the randomized experiment. Quasi-experimental designs use control and treatment groups, but assignment to the groups is non-random (unlike randomized experiments). The control and treatment groups cannot be assumed to be similar. Results may not be conclusive, since there may be a possible selection bias. Hence, the differences in the two groups must be assessed during the pre-test and accounted for in the analysis. Please see Figure 4 for a graphical illustration of the design.

Continuing with the earlier example where in-vehicle variable speed limit application is to be evaluated, test drivers are assigned *without randomization* to the control group and the treatment group. As seen in the previous example, in the pre-test period, neither group receives any messages. In the post-test period, the control group drivers do not receive the message, while the treatment group drivers receive the message. Data are collected for both groups and performance measures (e.g., emissions) are calculated for the pre-test period and post-test period. An assessment of the characteristics (e.g., age, familiarity with the facility) of the test drivers in the control and treatment groups is conducted during the pre-test period to determine the differences between the two groups. This is accounted for in any changes in the performance measures between the control and treatment groups during the post-test period. This design can be termed as the pre-test/post-test design with no random assignment.



LEGEND

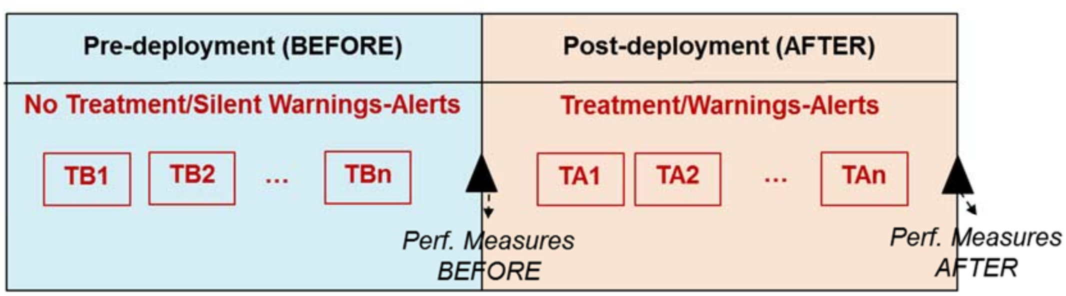
TB1, TB2,...,TBn: BEFORE data collection/measurement pts for treatment grp
CB1, CB2,...,CBn: BEFORE data collection/measurement pts for control group
TA1, TA2,...,TAn: AFTER data collection/measurement pts for treatment group
CA1, CA2,...,CAn: AFTER data collection/measurement pts for control group

Source: Noblis

Figure 4. Quasi-Experimental Design

Non-Experimental Design

In this design, the impact of the treatment is assessed by examining changes in the post-test period given the trend in the pre-test period. The non-experimental design does not include a control group, making it the weakest study design. Without a control group, it is difficult to assess what would have happened in the absence of the improvements. It does not account for confounding factors and does not control for other threats to internal validity, possibly leading to false conclusions. Before-after studies and longitudinal studies are examples of such a design. See Figure 5 for a graphical illustration of the design.



LEGEND

TB1, TB2,...,TBn: BEFORE data collection/measurement pts
TA1, TA2,...,TAn: AFTER data collection/measurement pts

Source: Noblis

Figure 5. Non-Experimental Design

Planned Evaluation Designs

The following section describes the types of experimental plans that will be used by the TTI CVPD Evaluation Team to conduct the assessment of the THEA CVPD.

Before and After Analysis

Because of the way the applications are being implemented and because of potential safety concerns of not providing alerts to all participants, several of the applications can be evaluated using only a before-and-after evaluation methodology (the non-experimental plan approach discussed above). These include the following:

- Use Case 2: Wrong-way.
- Use Case 3: Pedestrian Safety in Crosswalk.
- Use Case 5: Vehicle Turning in Front of Bus (Streetcar).

As noted by the Tampa Deployment Team, a before-and after analysis technique would be the best way to assess the performance of Use Cases 2 and 3 (the wrong-way entries and pedestrians in the crosswalk applications). In the case of Use Case 2, wrong-way events are rare occurrences and the deployment team expects to observe very few instances (perhaps none at all) where study participants might face a wrong-way entry state of activation. In the case of Use Case 3 (pedestrian safety in the crosswalk), the likelihood that an equipped vehicle and an equipped pedestrian arrive at the crosswalk at the same time is also rare. As a result, the TTI CVPD Evaluation Team expects to use a traditional before-and-after evaluation to analyze the impacts of this application.

For vehicle turning in front of streetcar applications, all streetcars operating in the corridor will be equipped with the technologies, so it is not possible to select which vehicles would be operated with and without the technology active. Furthermore, the drivers of the vehicles cannot be randomly assisted to these vehicles; so the TTI CVPD Evaluation Team will use a traditional before-and-after analysis to assess the MEP associated with deploying these technologies.

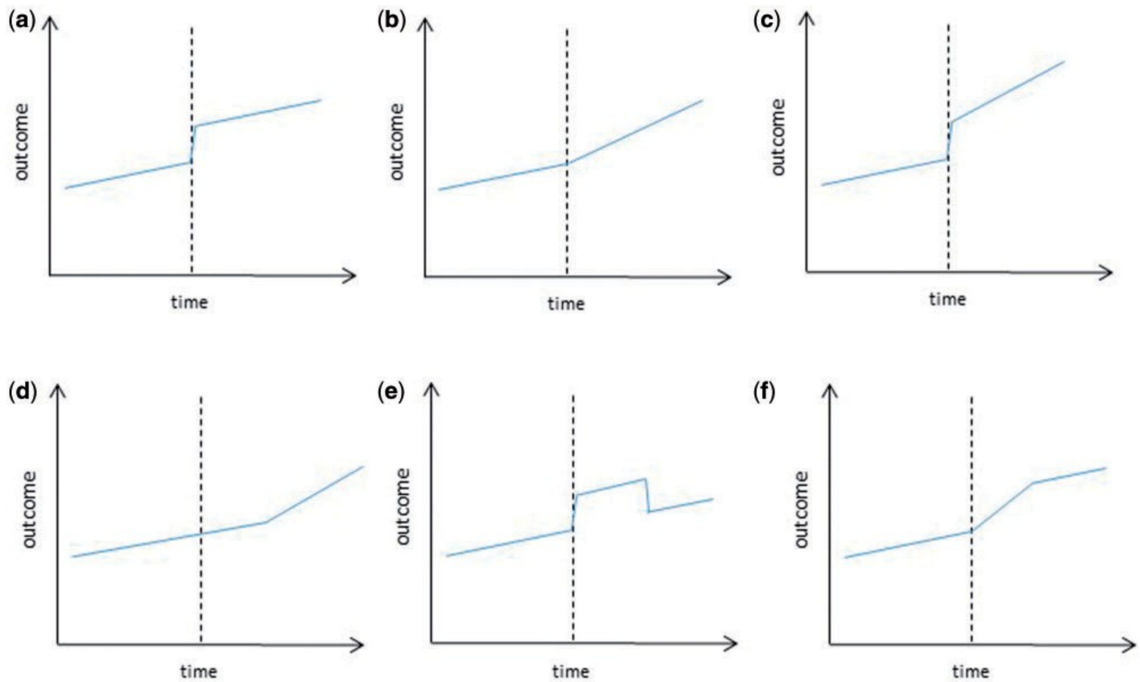
Quasi-Experimental Design

An interrupted time series design is a quasi-experimental method used to determine the impact of an intervention where multiple observations have been made over time, both before and after the intervention has been made. In an interrupted time series design, observations are made prior to the treatment to establish an underlying trend, which is then interrupted by an intervention (in this case the activation of the CV applications) at a known point in time. The idea of an interrupted time series analysis is that trends established in the data prior to the intervention would continue to exist over time if it had not been for the intervention. Figure 6 shows some potential impact models that can be interpreted using an interrupted time series analysis. The interrupted time series approach tends to lend itself well to evaluating the following Use Cases in the Tampa Deployment:

- Use Case 1: Morning Peak Hour Queues.
- Use Case 4: TSP in the Marion Transitway.
- Use Case 6: Enhance Signal Coordination and Traffic Progression.

To use an interrupted time series analysis, the following conditions must be satisfied (*11*):

- A clear differentiation must exist between the pre-intervention and post-intervention periods.
- The effects of the intervention are expected to change either relatively quickly after an intervention is implemented or after a clearly defined lag.
- Sequential measures of the outcome are available both before and after the interventions.



Source: J.L. Bernal, S. Cummins, A Gasparrini (*11*)

Figure 6. Examples of Intervention Effects in an Interrupted Time Series.

A generalized linear segment regression analysis can be used to determine the statistical significance of the intervention. The following equation represents the minimum general form of the regression analysis:

$$Y_t = \beta_0 + \beta_1 T + \beta_2 X_t + \beta_3 T X_t$$

Where,

T = the time elapses since the start of the study with the unit representing the frequency with which the observations are taken (e.g., month or year).

X_t = a dummy variable indicating the pre-intervention period (coded as “0”) or post-intervention period (coded as “1”).

Y_t = the outcome at time t.

In this form of the regression model, β_0 represents the baseline level at T=0, β_1 represents the change in outcome associated with a time unit increase (representing the underlying pre-intervention trend), β_2 represents the level change following the activation of the CV applications, and β_3 represents the slope change following the activation of the applications.

While the above model can provide an indication of the potential association between the intervention (the activation of the CV applications) and the outcomes (travel times, speeds, etc.), a number of confounding factors, such as seasonality, economic factors, and traffic growth trends, can affect the interpretation of the impacts of the treatment. In this particular case, changes in land-use or development trends may also be a confounding factor. Many methods exist for controlling for seasonality and other long-terms, including stratifying the data by calendar month or using Fourier functions to transform the data. Other approaches that could be used to control for confounding factors include the following:

- Using a control group, which is not affected by the intervention.
- Using a multiple baseline design whereby the intervention is introduced in different locations and/or times.

As part of the Tampa deployment, CV technologies will be installed in approximately 1,600 vehicles. The Tampa Deployment Team plans to divide the study participants into two user groups: one group that will receive alerts produced by the application, and another group that will not receive alerts. This second group will serve as a control group for the active group (i.e., the group that will actively receive the alerts from the devices). While the Tampa Deployment Team plans to deploy the CV technologies in the control group vehicles, it will function in the silent mode, so while applications will function as designed in the vehicles, alerts will not be issues to the drivers. This will allow a direct comparison of the performance of vehicles with and without the CV applications active. Depending upon the number of individuals assigned to the control group, it may be possible to use that group to control for effects of confounding factors in the corridor as both the treatment and control group would be experiencing the same conditions in each of the study corridors throughout the study period. One issue of concern is the potential attrition of users, particularly in the control group. As these individuals will be receiving direct alerts from the technology, the concern is that they will remove the technology from their vehicles, thereby reducing the number of vehicles in the control group. The TTI CVPD Evaluation Team will have to wait until the data are collected to determine if the sample size of observations in this group is available to complete this type of analysis.

For the both the TSP and the I-SIG applications, the TTI CVPD Evaluation Team plans to use an interrupted time series with no control group to analysis impacts of the deployment. In the TSP application, all transit vehicles using corridor will be equipped with the CV technologies, so the potential does not exist to have a control group. The I-SIG application combines information from equipped vehicles and traditional detection devices to adjust the signal timings in the deployment corridors. These signal timings impact equipped and unequipped vehicles equally. The CVs—whether they are in in the treatment group and in the control group—do not receive any special information over and above what the non-equipped vehicles would receive. Because both non-equipped and equipped vehicles receive the same benefit from the applications in the after activation of the I-SIG application, only a before-and-after assessment is planned. For this analysis, the TTI CVPD Evaluation Team plans to use data from traditional sources (i.e., Bluetooth travel time monitoring devices) to assess the impacts of deploying the I-SIG applications.

One potential strategy for confounding factors in the I-SIG application includes using another corridor with similar operating conditions as a control corridor. Under this study design, the TTI

CVPD Evaluation Team would compare mobility measures in both the deployment corridors and in corridors were the applications would be active. This approach is most viable for analyzing the effects of the I-SIG application. In this approach mobility measures (such as travel time) would be compared in an interrupted time series analyses in two corridors: one in which the application (in this case the I-SIG application) was active, and another in which traditional signal timing strategies are deployed. The corridors would have to be similar in terms of length, level and type of traffic, similar development patterns, etc. With this particular approach, mobility measures (such as travel times) would have to be collected using non-CV-based performance monitoring system to eliminate measurement tool biases. The TTI CVPD Evaluation Team would have to work with the Tampa Deployment Team and the City of Tampa to determine if such a corridor existed in or near the deployment area.

Chapter 6. Data Sources

This section identifies the primary sources of data that will be used to conduct the independent evaluation of the Tamps CV Pilot deployment. This section identifies and lists major sources of data. The TTI CVPD Evaluation Team is scheduled to develop a Data Collection/Data Management Plan in subsequent tasks. That plan will contain specific details related to data collection plans and procedures, data privacy, data QA/QC, data management, and data dissemination. That plan will expand and add to the sections below, based on further discussions with the Pilot Deployers and the USDOT Evaluation Team.

Data Available from Pilot Deployment Site

The following represents the data that the TTI CVPD Evaluation Team expects the Tampa Deployment Team to provide.

CV System Logs

CV system logs will be a critical source of data for assessing the performance of the deployment. Table 6 shows the CV data that will be collected and stored by the RSUs. These data will be uploaded to the THEA's Master Server and then up to the CVPD Evaluation Data Portal. The Evaluation Team will access these data through the Data Portal.

The TTI CVPD Evaluation Team expects that these data will be stored in Tampa's Master Server and will be uploaded to the CVPD PEP once it is developed. The TTI CVPD Evaluation Team expects all PII will be removed from the data before they are posted in the CVPD Data Management Portal. The CVPD Team expects to process these data from within this data portal.

City of Tampa Transportation Management System Data

City of Tampa's Centracs Traffic Signal Management Report

As part of this deployment, the City of Tampa will be adding performance monitoring functions to their central traffic signal management system (Centracs). These reports use timestamp stop-bar and advance detection data collected from signal controllers to produce the following traffic signal operations characteristics:

- Purdue coordination diagram.
- Flow rate.
- Cycle length.
- Green times.
- Volume-to-capacity.
- Split failures.
- Percent pedestrian calls.

Table 6. Types of CV Data Collected and Stored by the RSUs in the THEA CVPD.

Application	Logged Data Elements
End of Ramp Deceleration Warning (ERDW)	• Timestamp • Queue length • Recommended speed advice • OBU data received for upload to the Master Server
Wrong-Way Entry (WWE)	• Timestamp • Wrong way data (including travel information message containing location, elevation, speed, and travel direction of wrong-way vehicle) • Map Data Message • All BSMs received • OBU data received for upload to Master Server
Mobile Accessible Pedestrian Signal (PED-SIG)	• Timestamp • Pedestrian call request • Direction to cross intersection • Crossing time (seconds) • Extension time as needed (seconds)
Pedestrian in Signalized Crosswalk (PED-X)	• Timestamp • Personal safety message (PSM)[1] • Proxy PSMs • LIDAR data[2] • BSMs • Proxy BSMs[3]
Transit Signal Priority (TSP)	• Timestamp • Signal request messages • Signal status messages
Intelligent Signal System (I-SIG)	• Queue length • BSM counts
Probe Data Enabled Traffic Monitoring	• Speed vectors (travel times) aggregated from the BSMs within range of the RSU • BSM

[1] PSM is a particular DSRC messages set used to broadcast safety data on the kinematic state of various types of vulnerable road users, such as pedestrians, cyclists, or road workers. It would include information such as the position, speed, heading, and path history of that specific vulnerable road user. In this deployment, the vulnerable road user will be pedestrians.

[2] LIDAR is an acronym for Light Detection and Ranging. LIDAR is an optical remote-sensing method that uses laser light to sample objects in the field of view to produce highly accurate X-Y-A measurements.

[3] Proxy BSMs are messages used to convey PSM-type information to the OBUs. These messages are generated by pedestrian detectors and contain information such as the latitude, longitude, evaluation, speed, heading of pedestrians that have been detected by the pedestrian detectors.

Source: *CVPDProgram Phase 2, Data Management Plan – Tampa (THEA)* (*8*)

The Florida Department of Transportation is paying for the installation of traffic detection cameras at around 20 intersections. These cameras will provide detector inputs into the City of Tampa's traffic signal system. The traffic signal system will use these data to adapt the signal timing strategies to meet current traffic demands. The data from these detectors will also be used to generate traffic signal performance metrics.

City of Tampa's Active Transportation Management

Another potential source of data that could be valuable to the TTI CVPD Evaluation Team is the City of Tampa's Active Transportation Management (ATM) report. This report produced twice a day—after the a.m. and p.m. peaks, respectively—lists the major issues the TMC operators had to deal with during their shift. It contains information related to the prevailing weather conditions, significant events and incidents impacting traffic operations, active road closures and construction activities, major issues associated with the REL operations, etc. These logs, which are emailed to City of Tampa's DOT administrators, could be helpful in identifying different operational scenarios. Figure 7 shows a sample of this report.

These logs should be collected daily and indexed by a date/timestamp for processing by the TTI CVPD Evaluation Team.

Other Data Sources

The following provides a list of the other data sources that could potentially be used by the TTI CVPD Evaluation Team in assessing the mobility and environmental impacts of the deployment.

511 Travel Times

Florida operates a 511 system that provides real-time information on travel times, congestion, incidents, and construction activities on many of the major roadways throughout the state. Travel time information is provided on many of the major streets in the downtown area, including the following:

- REL Exit Ramp.
- N. Meridian Ave.
- N. Morgan Ave.
- N. Nebraska Ave.
- N. Florida Ave.
- N. Ashley Dr.
- E. Jackson St.
- E. Kennedy Blvd.
- N. Jefferson St.

AM ATM Report

Weather-Clear

Observations and Actions:

- 774-Don Gill, Comm-Jose Castillo

Blue Toad:

- N. Dale Mabry Hwy. is reporting increased travel times northbound between W. Columbus. Dr. and W. Hillsborough Ave. at 6:40 a.m. No issues were reported in the area and no issues were observed on CCTV.

Road Closures/Construction:

- N. Armenia Ave. from W. LaSalle St. to W. Green St.—One southbound lane on N. Armenia Ave. between W. Green St. and W. La Salle St. will close at 9:00 a.m. on May 4, 2017, due to a water main repair. It is anticipated that all lanes on N. Armenia Ave. will be open to traffic by 4:00 p.m. on Monday, 5/29/17.
- E. Cumberland Ave. at S. Caesar St.—The intersection of E. Cumberland Ave. at S. Caesar St. will close starting at 9:00 a.m. on Monday, 5/8/17 due to infrastructure and roadway repairs. E. Cumberland Ave. is expected to re-open at 4:00 p.m. on Friday, 5/19/17.
- S. Plant Ave. between W. Grand Central Ave. and W. Brorein St.—A portion of Plant Avenue from Cleveland Street to Grand Central Avenue will close on Monday, May 15, 2017, for utility construction starting at 7:30 p.m. This will be a multiday repair project, with repair work expected to be completed by 5:30 a.m. on Saturday, 5/20/17.

REL Operations:

- During the 10:00 a.m. split change, the westbound gates at the 78th Street slip ramp will be shut due to Transcore working on the gantry, shutting down traffic to the downtown area. Motorists will still be able to use the 301 slip ramp to travel east toward the Brandon area. The REL will be placed into normal eastbound operation at 1:00 p.m.

Events:

- Convention Center-SOFIC (10k) 7:00 a.m. to 11:00 p.m.
- Channelside-Flicks and Food Trucks (500) 6:00 p.m. to 10:00 p.m.

Source: City of Tampa (*9*)

Figure 7. Sample of City of Tampa's ATM Report

NOAA Historical Weather Data

The Tampa International Airport maintains a weather station in the Tampa area. These data are fed into the National Oceanic and Atmospheric Administration (NOAA) Climate Database. This database can be accessed to download the following available weather data types:

- Air temperature.
- Precipitation.
- Sky cover and clouds.
- Weather types.
- Wind (speed and direction, gusts).

Crash and Incident Histories for City of Tampa

The TTI CVPD Evaluation Team also needs to collect crash and incident histories before and after the deployment. Crash and incident histories are needed to conduct cluster analysis of the data to identify operational scenarios to be explored in the modeling analysis.

HART Transit Schedule and Bus Ridership Logs

HART schedule data will need to be available for each day of the evaluation. The schedule information needs to include a bus identification number that can be used to link bus schedules to bus BSM data. Information on bus ridership levels for each bus using the Marion Transit mall is also required.

New Sources of Data to be Deployed

Currently, the TTI CVPD Evaluation Team does not foresee the need to install any additional data collection capabilities to collect data for the independent evaluation. It appears that all data can be supplied by the current or planned systems and technologies in the deployment area; however, additional data may need to be collected to support this safety evaluation.

If the decision is made to include a control corridor to assess the I-SIG application, the corridor would need to be equipped to collect travel time data. Bluetooth readers (or similar technologies) may be needed so that travel time through the control corridor could be monitored.

Chapter 7. Observed Data Analysis

This section describes how the observed data will be used to measure performance and to evaluate the THEA CVPD. This section describes the methods used for estimating performance measures.

Mobility Measures

Travel Times

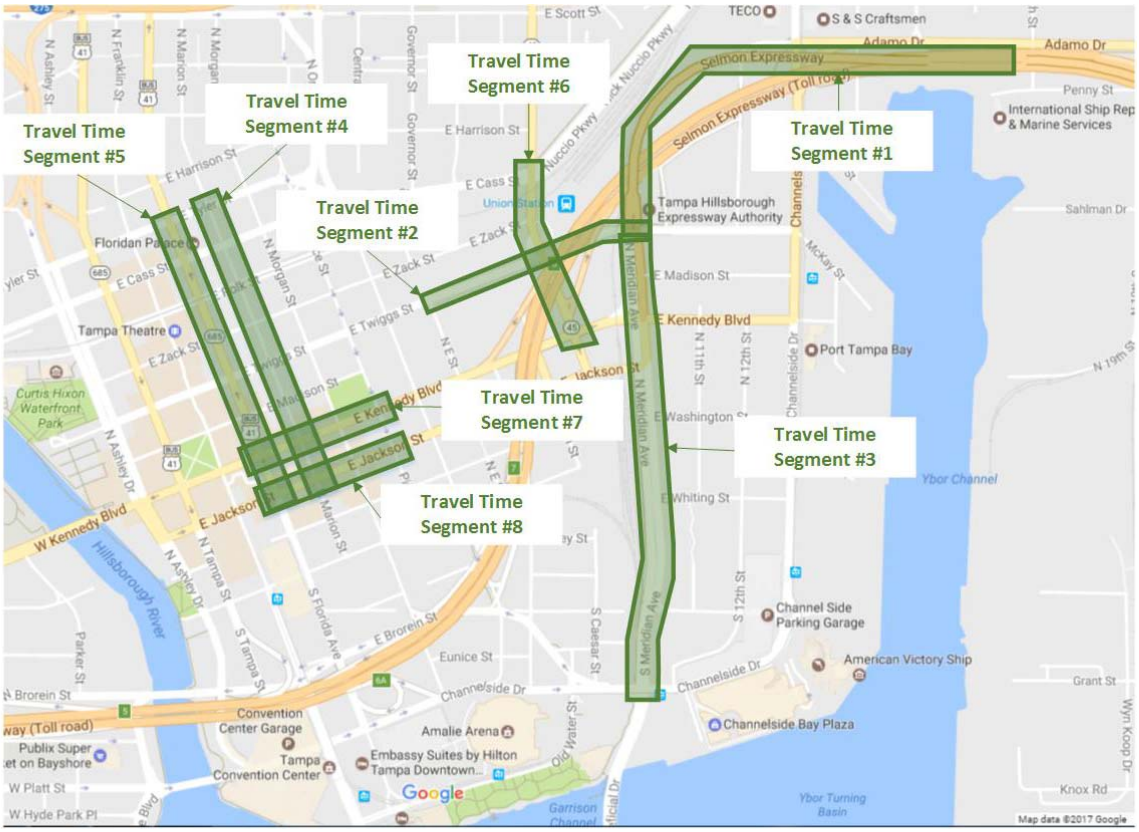
Travel times are one of the primary measures of performance that will be used to assess the mobility benefits of the CV pilot deployment at the link or segment levels. Two levels of analysis will be performed: one focused at the aggregate, system-wide impacts of the deployment (comparing before and after travel times of all vehicles, both equipped and unequipped); and the other focused on individual benefits of vehicles equipped with the technology (comparing the performance of vehicles with and without the technology). Different data sources will be used to obtain the data for these analyses.

In assessing the system-wide impacts, travel time data generated by the traditional travel time monitoring systems will be compared using an interrupted time series analysis. The intent with this level of analysis is to determine if all vehicles (even the unequipped vehicles) see an improvement in performance as a result of deploying the technology. For this analysis, travel times will be measured for all vehicles traveling on segments of the network where the CV technologies are expected to have an impact on operations. These include the following links:

- Travel Time Segment #1: Selmon Expressway's Reversible Express Lane (REL) from 1,500 ft upstream of the gore of the westbound REL terminus to the stop bar at the intersection of the westbound REL off-ramp and E. Twiggs St.
- Travel Time Segment #2: E. Twiggs St. from the REL exit to N. East St.
- Travel Time Segment #3: N. Meridian Ave. from E. Twiggs St. to Channelside Dr.
- Travel Time Segment #4: N. Marian St. from the Marian Transit Center to E. Jackson St.[1]
- Travel Time Segment #5: N. Florida Ave. from E. Tyler St. to E. Jackson St.
- Travel Time Segment #6: N. Nebraska Ave. from E. Tayler St. to E. Jackson St.
- Travel Time Segment #7: E Kennedy Blvd. from N. Florida St. to N. Jefferson St.
- Travel Time Segment #8: E. Jackson St. from N. Florida St. to N. Jefferson St.

[1] N. Marian St. is a transit way, reserved for use by transit vehicles only, so these travel times and travel time reliability measures will be for buses only.

Figure 8 highlights the location of each segment in the downtown Tampa area. For those roadways that are two way, travel time data will be assessed in both directions of travel.



Source: Texas A&M Transportation Institute

Figure 8. Location of Travel Time Analysis Segments for the THEA CVPD

For this analysis, the CVPD Evaluation Team plans to compare average (mean) travel times of all vehicles (equipped and unequipped) for the same periods (peak and off-peak) before and after deployment of the CV technologies. These data will be collected using either the probe vehicle data logs or vehicle re-identification systems, such as Bluetooth or similar vehicle tracking systems. Typically, these data measurements are aggregated into 5-minute periods throughout the entire day. These data are generally collected automatically by the systems and can be aggregated to the appropriate analysis period (peak hour, peak period, etc.) desired by the evaluation team. A cluster analysis will be applied to data to determine the effects that confounding factors (such as incidents, weather, special events, etc.) have on the travel time data. A separate analysis will be performed for normal conditions (no backups) and congested conditions (when the applications are most likely to be issuing alerts).

In addition to examining the system-wide impacts of the deployment, the TTI CVPD Evaluation Team will also specifically compare travel time performance of vehicles equipped with the CV technologies to those not equipped.

Delay

Delay is another common measure of mobility, particularly at signalized intersections. Delay is the difference in travel time that a user experiences between free-flow (unimpeded) conditions and current conditions. At signalized intersections, factors that influence the amount of delay experienced by a user include the following:

- Signal control and timing.
- Queues that impede travel.
- Factors such as bus blockages, crossing pedestrian traffic, parking maneuvers, etc.

While the Tampa Deployment Team plans to use video to measure vehicle delays at some intersections, the collection of intersection approach delays should be automated. It may be possible that the City of Tampa's traffic signal monitoring system could be configured to collect these data automatically. Delay values can also be estimated using microscopic simulation. Delay measurement would be needed from each of the following intersections:

- The REL exit from the Selmon Expressway at E. Twiggs St. (UC 1/UC 6).
- N. Meridian Ave. at E. Kennedy Blvd. (UC 6).
- N. Meridian Ave. at E. Jackson St. (UC 6).
- N. Meridian Ave. at E. Washington St. (UC 6).
- N. Meridian Ave. at E. Cumberland Ave. (UC 6).
- N. Meridian Ave. at E. Channelside Dr. (UC 6).
- N. Florida Ave. at E. Taylor St. (UC 6).
- N. Florida Ave. at E. Cass St. (UC 6).
- N. Florida Ave. at E. Polk St. (UC 6).
- N. Florida Ave. at E. Zack St. (UC 6).
- N. Florida Ave. at E. Twiggs St. (UC 6).
- N. Florida Ave. at E. Madison St. (UC 6).
- N. Florida Ave. at E. Kennedy Blvd. (UC 6).
- N. Florida Ave. at E. Jackson St. (UC 6).
- N. Nebraska Ave. at E. Cass St. (UC 6).
- N. Nebraska Ave. at E. Twiggs St. (UC 6).
- N. Nebraska Ave. at E. Kennedy Blvd. (UC 6).
- E. Kennedy Blvd. at N. Morgan St. (UC 4/UC 6).
- E. Kennedy Blvd at N. Pierce St. (UC 4/UC 6).
- E. Jackson St. at N. Morgan St. (UC 4/UC 6).
- E. Jackson St. at N. Pierce St. (UC 4/UC 6).

Delay values should be measured on each intersection approach in 5-minute intervals between the hours of 6:00 a.m. and 7:00 p.m. Intersection delay shall should be measured both peak periods for each day of the week in both the before and after portions of the deployment.

Back of Queue/Queue Length

The Back of Queue is “the maximum backward extent of queued vehicles during a typical cycle, as measured from the stop line to the last queue vehicle” (*13*). Through the I-SIG application, back of queue (or queue length) measures will be provided at the following intersections:

- The REL exit from the Selmon Expressway at E. Twiggs St. (UC 1/UC 6).
- N. Meridian Ave. at E. Kennedy Blvd. (UC 6).
- N. Meridian Ave. at E. Jackson St. (UC 6).
- N. Meridian Ave. at E. Washington St. (UC 6).
- N. Meridian Ave. at E. Cumberland Ave. (UC 6).
- N. Meridian Ave. at E Channelside Dr. (UC 6).
- N. Florida Ave. at E. Taylor St. (UC 6).
- N. Florida Ave. at E. Cass St. (UC 6).
- N. Florida Ave. at E. Polk St. (UC 6).
- N. Florida Ave. at E. Zack St. (UC 6).
- N. Florida Ave. at E. Twiggs St. (UC 6).
- N. Florida Ave. at E. Madison St. (UC 6).
- N. Florida Ave. at E. Kennedy Blvd. (UC 6).
- N. Florida Ave. at E. Jackson St. (UC 6).
- N. Nebraska Ave. at E. Cass St. (UC 6).
- N. Nebraska Ave. at E. Twiggs St. (UC 6).
- N. Nebraska Ave. at E. Kennedy Blvd. (UC 6).
- E. Kennedy Blvd. at N. Morgan St. (UC 4/UC 6).
- E. Kennedy Blvd at N. Pierce St. (UC 4/UC 6).
- E. Jackson St. at N. Morgan St. (UC 4/UC 6).
- E. Jackson St. at N. Pierce St. (UC 4/UC 6).

According to the *CV Pilot Deployment Phase 2, Data Management Plan – Tampa (THEA)*, back of queue measures will be computed by the I-SIG applications. Back of queue information is used in the queue warning application to provide end of queue alerts to vehicles on the REL exit ramp to E. Twiggs St. Back of queue information is expected to be delivered once every minute to vehicles using this application. The TTI CVPD Evaluation Team will use the back of queue measures from these locations to examine how they change after the deployment of the CV technologies compared to before.

Maximum back of queue (or maximum queue lengths) should be collected and stored on a cycle-by-cycle basis for each day of the week for each signalized intersection listed above. Maximum back of queue/queue length measures should be collected during both the before and after deployment periods.

Throughput/Traffic Volumes

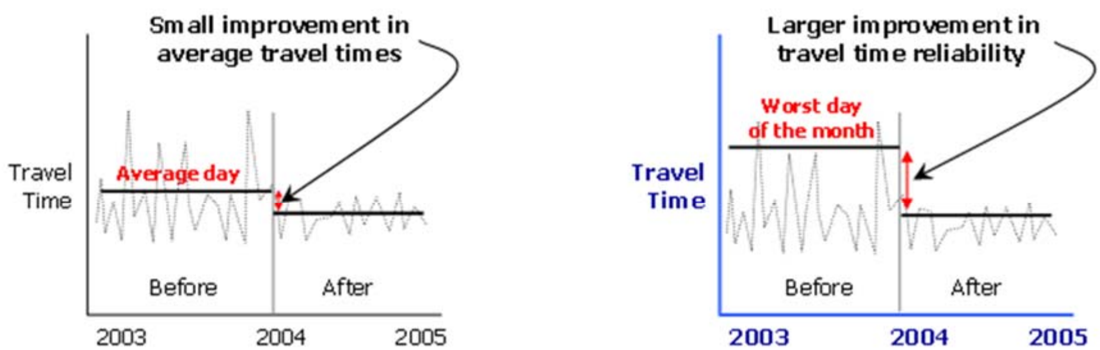
Throughput is a measure of the number of users served by the transportation system. Vehicle throughputs are needed to develop and calibrate the traffic simulation model and to assist in performing cluster analysis around different travel demand levels. Vehicle throughputs are also needed to help normalize safety and performance measures (e.g., collision rates). At a minimum, traffic volume/throughput data should be collected continuously in 5-minute intervals throughout the deployment period. Traffic volume data should include both equipped and unequipped vehicles and should be collected at strategic locations within each of the major deployment corridors. Sensors for collecting traffic volume/throughput data should be located in mid-block locations outside areas where queues form. Data should be collected and reported by direction of flow.

Reliability Measures

Reliability measures are intended to assess the consistency or variability in travel. The following describes the reliability measures the TTI CVPD Evaluation Team plans to use to assess the effectiveness of the CV deployment in Tampa.

Travel Time Reliability

In addition to travel time, travel time reliability measures will also be analyzed in the deployment area before and after activation of the CV technologies. Travel time reliability is “a measure of consistency or dependability in travel times, as measured from day-to-day and across/or different times of the day” (*10*). As illustrated in Figure 9, travel time reliability is often computed in before-and-after studies to capture reductions associated with the worst few days compared to the average day.



Source: USDOT/FHWA (*10*)

Figure 9. Travel Time Reliability

The TTI CVPD Evaluation Team plans to use two travel time reliability measures in assessing the overall impacts of deploying the CV technologies in the evaluation corridor: the 95th percentile travel time and the buffer time. The 95th percentile travel time is the travel time, reported in minutes and seconds, that 95 percent of vehicles experienced during the analysis period. Buffer time represents the time differential between the average and the 95th percentile travel times for the same analysis period (peak period, peak hour, etc.). Buffer time represents the extra time needed by travelers to ensure a high rate of on-time arrival.

Transit On-Time Performance

On-Time performance is also a measure of travel reliability for transit vehicles. On-time performance measures how closely an actual transit service ran to its schedule, usually within some allowable margin of error. The Hillsborough Area Rapid Transit (HART) operates a number of bus routes (both local and express) along the Marion Street Transitway, which runs from the Marion Transit Center to the intersection of Marion Street and Whiting St. The local routes using the Transitway throughout the day include the following: Routes 4, 8, 19, 30, and 46. The following Express routes also use the Marion Street Transitway during peak periods:

- Route 20X (SB – AM Drop-off/NB – PM Pickup).
- Route 21LX (NB – AM Drop-off/PM Pickup).
- Route 22X (NB – AM Drop-off/SB – PM Pickup).
- Route 27LX (NB – AM Drop-off/SB – PM Pickup).
- Route 28X (SB – AM Drop-off/NB – PM Pickup).
- Route 47X (NB – AM Drop-off/SB – PM Pickup).
- Route 51X (SB – AM Drop-off/NB – PM Pickup).
- Route 61LX (SB – AM Drop-off/NB – PM Pickup).
- Route 200X (SB – AM/PM Drop-off/NB – AM/PM Pickup).
- PSTA Route 100X (SB – AM/PM Pickup/NB – AM/PM Drop-off).
- PSTA Route 300X (NB – AM/PM Drop-off/Pickup).

For this analysis, the TTI CVPD Evaluation Team will depend upon on-time performance logs maintained by HART for buses using the Marion Street Transitway. These data need to be provided by bus route and specific run for service to and within the downtown area. The reports should show the scheduled and actual start times, waypoint times, and end times for each run on each route.

Arrivals on Green

Percent AOG is a common performance measure used to assess the quality of progression at a signalized intersection. It is a measure of the proportion of vehicles that arrive during green signal indications relative to the proportion of vehicles that arrive during red indications at a particular intersection over a given period. The TTI CVPD Evaluation Team plans to use AOG to assess several of the applications, particularly the I-SIG application on Meridian Drive (UC 5), and the TSP application on Marion St. (UC- 4). AOG performance measures are needed from the following intersections:

- The REL off-ramp exit/N. Meridian Ave. at E. Twiggs St. (UC 1/UC 5).
- N. Marion St. at E. Jackson St. (UC 4).
- N. Marion St. at E. Kennedy Blvd. (UC 4).
- N. Marion St. at E. Madison St. (UC 4).
- N. Marion St. at E. Twiggs St. (UC 4).
- N. Marion St. at E. Zack St. (UC 4).
- N. Marion St. at E. Polk St. (UC 4).
- N. Marion St. at E. Cass St. (UC 4).
- N. Meridian Ave. at E. Kennedy Blvd. (UC 6).
- N. Meridian Ave. at E. Jackson St. (UC 6).
- N. Meridian Ave. at E. Washington St. (UC 6).
- N. Meridian Ave. at E. Cumberland Ave. (UC 6).
- N. Meridian Ave. at E. Channelside Dr. (UC 6).

These data will be made available through the City of Tampa's traffic signal management system (Centracs). AOG data shall be available to the TTI CVPD Evaluation Team from every intersection in 5-minute intervals.

Agency Efficiency

The deployments of CV technologies are also expected to change the level of efficiency agencies manage on how well agencies manage operations of the transportation network. Agency efficiency is measured in terms of how well agencies can respond to changing conditions or unexpected events occurring on their networks. Agency efficiency can be measured in terms of the following:

- Changes in notification and/or response times to major incidents and crashes.
- Improved situational awareness of events occurring on the transportation network.
- Improved timeliness and quality of traveler information messages.
- Improved traffic management system responses to changing traffic conditions.

To assess agency efficiency, the TTI CVPD Evaluation Team will examine operations logs of agencies for events, both before and after the deployment of the CV technologies to assess how agency responses to these events changed. The impacts of the changes in performance measures such as changes in incident clearance times will be modeled to quantify their impacts on mobility.

Chapter 8. Simulation-Based Evaluation

Modeling and simulation is expected to play a significant role in the evaluation of the Tampa deployment. With the limited number of vehicles being equipped with CV technology, direct measurement of the extent to which the deployment of the CV technologies changes safety and mobility in the deployment area will mostly likely have to be estimated using modeling and simulation. This section provides a high-level overview of the analysis, modeling, and simulation (AMS) approach that will be used as part of the evaluation of the THEA CVPD. This section discusses the AMS activities needed to estimate performance measures while controlling for confounding factors and provides an overview of the methods to be used for estimating performance measures, and the hypotheses that will be tested using AMS.

The TTI CVPD Evaluation Team will use simulation and modeling to perform the following types of analysis:

- Estimating the potential mobility benefits associated with improvements in safety as a result of deploying the CV technologies.
- Examining how changes in market penetration levels may impact potential mobility benefits in the future.

Specific details related to the AMS will be provided in the Tampa AMS Evaluation Plan, scheduled for development in August 2017.

Modeling Approach

THEA has hired a consultant to develop a VISSIM model of the downtown Tampa area. The TTI CVPD Evaluation Team will use this model as the foundation for our modeling efforts. The TTI CVPD Evaluation Team expects the Tampa CVPD Team to provide a functioning model (i.e., runs error-free) that has been calibrated to some level. Once the common operational scenarios have been identified, the TTI CVPD Evaluation Team will calibrate the model for each operational condition. The TTI CVPD Team will use the calibrated simulation model to assess the mobility benefits associated with deploying the CV applications under different operational scenarios. A subvariant model will be created for each operational scenario to be tested. Test runs of each subvariant model will be run using different random seeds to assess the variability. Using the results of these test runs, the IE will determine the total number of runs (replications) necessary to provide statistically valid results.

In addition to using modeling and simulation for estimating the mobility benefits associated with reductions in collisions associated with the deployment, the TTI CVPD Evaluation Team will also use modeling to examine the extent to which different market penetration rates are likely to affect mobility in the deployment corridors. The TTI CVPD Evaluation Team will assess three different market penetration scenarios:

- No change in market penetration – this scenario assumes that the number of vehicles equipped with CV technologies remains at its current level of deployment and that no new vehicles will be equipped with the current suite of applications.
- Slight growth in market penetration – this scenario assumes that the number of vehicles equipped with CV technologies will reach 5 percent of the background traffic over the next seven years.
- Moderate growth in market penetration – this scenario assumes that the percentage of vehicles equipped with CV technologies will reach 25 percent of the background traffic over the next seven years.

All growth scenarios will use only the existing suite of applications being deployed, and no new applications will be added to the vehicles.

In addition to examining changes in performance with different penetration rates, changes in background traffic demands will also be projected. Over the course of the next five years, the Downtown Waterfront area is expected to experience substantial redevelopment. This is anticipated to change traffic demands and travel patterns significantly in the study area. Other redevelopment efforts are also expected to occur in the study area.

The TTI CVPD Evaluation Team will solicit the assistance of the Hillsborough Metropolitan Planning Organization, THEA, and the City of Tampa to develop realistic projections of traffic growth in the downtown area over the next 7 years. The Hillsborough Metropolitan Planning Organization just recently completed updates to their regional travel demand model. In the case that this model cannot be used, the TTI CVPD Evaluation Team will make straight line projections of traffic growth based off current growth trends. The TTI CVPD Evaluation Team will make three levels of traffic predictions:

- No change in background traffic demand – current demand levels will remain the same.
- Moderate change in background traffic demand -- background traffic demands will grow at current levels of growth.
- Large change in background traffic demands – background traffic demands will grow at twice the rate of current growth levels.

The modeling approach described below will capture both the direct mobility effects of CV deployment and the indirect mobility effects of safety improvements with CV deployment. The approach that the TTI CVPD Evaluation Team will use to estimate the mobility effects of CV deployment under controlled conditions and for different market penetration levels is as follows:

- Step 1. Assemble Data:
    - Use THEA/City of Tampa TMC operations log to estimate the frequency of collision events and the impacts (duration, # of lanes blocked, capacity reduction, etc.) they have on traffic operations when they occur.
    - Assemble volume (demand) data from deployer.
    - Review ATM logs and city calendar of special events for special events.

  - Review ATM logs for work zones.
  - Assemble weather data from ATM logs and NOAA data.
  - Assemble 511 travel times, Bluetooth data, I-SIG delays, and queues into estimates of total vehicle hours traveled for each observation day in the before and after data sets. Normalize for differences in demand by dividing by vehicle counts.
- Step 2. Identify Scenarios to be Simulated in Model:
  - Select travel time objective function for use in grouping observations into clusters.
  - Determine maximum number of distinct scenarios (with differing CV participation percentages) that can be modeled within the available evaluation budget.
  - Perform statistical tests to determine if cluster analysis can be performed on the pooled set of before and after days, or whether it needs to be limited to just the before days observations, or the after days observations.
  - Use a cluster analysis to group the days into the target number of clusters.
  - Examine each cluster and select a representative day (combining demand level, weather, incident type) to represent each cluster in the simulation model run. Ensure that weather, demand, and incident variations are adequately represented in the selected days for simulation.
  - Compute the probabilities for each cluster (to be used later when assembling the individual scenario results into a total year performance).
  - Select the number of levels of market penetration to be tested (e.g., 1 percent, 10 percent, 50 percent, 100 percent).
- Step 3. Calibrate Simulation Model (Before Deployment Runs):
  - Obtain calibrated simulation model from Deployment Team.
  - Calibrate model against Federal Highway Administration (FHWA) criteria for each scenario (demand, weather, event, incident). Validate against field data for the before condition. These runs will provide the before condition results.
- Step 4. Analyze Before Condition:
  - Use the microscopic simulation model to estimate the delay associated with typical events, incidents (crashes), weather, and demands when they occur in the deployment area for the after deployment condition. Apply probabilities of each scenario under the before condition to microsimulation model results to obtain estimate of total annual performance under the before condition.
- Step 5. Analyze the After Condition:
  - Re-run the before model scenarios but this time with CV deployed. This will get us the mobility effects of CV deployment without crash reductions.
  - To get the crash reduction mobility benefits of CV, do the following:
    - Identify those scenarios containing incidents of the type that Volpe has computed crash frequency reduction factors.
    - Convert Volpe crash frequency reduction estimates into estimates of reduced probabilities for the selected simulation model scenarios. These estimates would vary by market penetration level. Compute the after performance for each level of market penetration (taking into account the mobility effects of crash reductions) by recomputing the annual performance under the new probabilities.

Modeling Environmental Impacts

The purpose of the sustainability estimation is to assess the impact of CV technologies along two environmental dimensions: emissions and fuel consumption. CV technology will provide drivers with advanced information about traffic congestion and roadway conditions. Informed travelers may decide to avoid certain routes, smooth their speed profiles, or switch to alternative modes or departure times—all of which have the potential to reduce emissions, petroleum, and wildlife-vehicle collisions. The subsections below provide a high-level overview of the assumptions, constraints, needs, objectives, performance measures, and methodology for each environmental dimensions.

Emissions

Past research examines emissions impacts of various CV technologies. The most common methodology in these estimations uses output from a traffic simulation model as input to an emissions model, and then measures the change in emissions along a given segment of road before and after the technology is installed. For example, Stathopoulos and Noland estimated fuel consumption and emissions for an improved traffic flow scheme using the traffic simulation model, VISSIM, and the emissions model Comprehensive Modal Emissions Model (CMEM) (*14*). Similarly, Servin et al. integrated the traffic simulation model, Paramics, with CMEM to evaluate emissions for intelligent speed adaptation strategies under varying freeway congestion conditions (*15*). Chamberlin et al. integrated MOtor Vehicle Emission Simulation model (MOVES) and Paramics to evaluate intersection control strategies (*16*).

MOVES is a project-level simulator that uses a vehicle's operating characteristics—including idling, acceleration, deceleration, and cruise—to measure emissions and petroleum consumption. Zhao and Sadek provided a comparison of three methods of estimating emissions along a link using second-by-second vehicle speeds from traffic as an input to MOVES: a mean, mode, and probe vehicle approach (*17*). In the mean and mode approach, the mean or mode of the speed of all vehicles along a link are estimated for each second of the simulation. This second-by-second speed is used as the MOVES input. The probe approach involves randomly sampling a subset of vehicles along the link every second, and using their speeds as inputs to MOVES. The authors show that, along an arterial and freeway testbed, the probe approach provides much greater accuracy than the mean or mode approaches.

The TTI team plans to use Zhao and Sadek's probe approach to link the traffic simulation models, VISSIM4 and Aimsun, with the MOVES model. The team will use the second-by-second vehicle trajectory output from the simulation models as the input to MOVES. The main assumption is that the traffic simulation model accuracy of the traffic simulation model in capturing the changes in travel behavior in a world with and without the CV technology.

The performance measure used in the emissions analysis will be the total emissions and change in emissions along the link between the with and without CV technology cases. The TTI team will measure greenhouse gas emissions and certain criteria pollutant emissions, like nitrogen oxide (NO_x), particulate matter (PM), and carbon monoxide (CO).

The main constraints involved with measuring the impact on emissions using the methodology above are related to the secondary effects, such as changes in travel behavior that are not captured by the traffic simulation model. For example, if drivers with CV technology change their routes or departure times such that they are no longer captured in the traffic simulation model, then those emissions will also not be captured.

Fuel Consumption

Because fuel consumption and emissions are directly proportional and are both outputs from the MOVES model, the TTI team plans to use the same methodology as above for both emissions and fuel consumption. The performance metric will be quantity and percentage of petroleum increase or decrease between the with and without CV technology cases.

Chapter 9. Survey-Based Evaluation

This chapter includes the Stakeholder Acceptance/Satisfaction Plan and Survey/Interview Guides. It specifically discusses the survey and interview-based evaluations of pilot deployments, including surveys/interview guides that will be developed and conducted by the pilot deployers, as well as additional surveys/interviews that will need to be developed by Volpe/TTI CVPD Evaluation Team. The chapter also identifies the hypotheses that will be tested using surveys/interviews, including but not limited to the relevant hypotheses from Section 3, and the hypotheses from THEA.

The survey-based approach is relevant for measuring impacts on public agency efficiency, and end-user satisfaction, as well as for qualitative assessments of safety and mobility impacts. This approach is also relevant for gathering lessons learned that are transferable to prospective CV deployments. Lessons learned should at a minimum target the following areas:

- Application design, development, and test.
- Data management.
- Privacy and PII protection.
- Security management.
- Interoperability and standards.
- Device testing, licensing, and installation.
- System operations and maintenance.
- Performance management.
- Stakeholder outreach.

The approach should also be used to assess whether pilot deployers and transportation managers were able to develop solutions to technical challenges faced in implementing the CV pilot deployment. Specific elements that should be covered include:

- List of perceived technical challenges.
- Ability to develop solutions to technical challenges.
- Reasons why a challenge could not be overcome.
- Description of solutions developed to address challenges.
- Perceived success of solutions.

User Satisfaction Surveys

The THEA CVPD Team, with the support and direction of USDOT and The Volpe Center, will develop and implement the site-specific survey data collection plan to collect customer satisfaction data, defined as: end users' satisfaction with the CV technology (e.g., applications, devices), behavioral responses to applications, perceptions of impact of applications on safety, mobility, travel experience, attitudes toward the CV technologies, and preferences for achieving financial sustainability of the CV technologies.

For the Tampa site, the users fit into one of three categories:

1. Auto drivers: licensed auto drivers of any age who travel through the study area.
2. Pedestrians: persons 18 years or older who have been called for jury duty at the Hillsborough County Courthouse and opt to cross at mid-block crosswalk or outside the crosswalk, as well as those who use the intersections on Channelside Drive and have conflicts with vehicles turning right in front of streetcars and with traffic at Amalie Arena.
3. HART drivers: HART bus and streetcar drivers.

The statistical analysis of the survey responses will consist of tabulations of the responses and selected cross-tabulations relevant to understanding the acceptance of CV. Maximum, minimum, and mean responses will be reported for the multiple choice questions and those involving a numerical response.

Stakeholder Acceptance/Satisfaction Plan

This section describes how the TTI CVPD Evaluation Team will assess how well the pilot deployment program fulfills stakeholder goals related to the Tampa pilot. In developing this stakeholder acceptance/satisfaction plan, the TTI CVPD Evaluation Team has selected a manageable list of high-level goals, drawn from written documents of Tampa deployment leaders. Generally, stakeholder goals are related to MEP. In addition, the stakeholder acceptance/satisfaction plan also draws upon six capability maturity dimensions based on the American Association of State Highway and Transportation Officials transportation systems management and operations capability maturity model (*21*). The TTI CVPD Evaluation Team would develop interview questions that would solicit stakeholder input and lessons learned related to the following six dimensions listed in the management and operations capability maturity model:

- *Business Processes* – these questions would be related to the formal scoping, planning, programming, and budgeting associated with developing and implementing the CVPD.
- *Systems and Technologies* – these questions would be related to the use of the system engineering process, level of maturity of the system architecture standards, and procedures to ensure interoperability and standardization of CV technologies and applications.
- *Performance Measurement* – these questions would focus on the capability and maturity of performance measurement definitions, and data acquisition and use of performance measures to support and sustain the deployment.

- *Culture* – these questions would be related to the level of technical understanding, leadership, outreach, and legal authority needed to deploy and sustain a CV technology deployment.
- *Organization and Workforce* – these questions would be related to the organizational structure, staff development, and staff recruitment and retention processes needed to support and sustain a CV deployment.
- *Collaboration* – these questions would be related to the type and nature of the relationships that a deploying agency needs to have with public safety agencies, local governmental entities, and others to develop and sustain a CV deployment.

THEA's Goals and Evaluation Metrics

The THEA, the lead agency for the Tampa CVPD, has documented pilot goals. In general terms, the goals of the Tampa pilot are to transform the experience of automobile drivers, transit riders, and pedestrians in downtown Tampa by preventing crashes, enhancing traffic flow, improving transit trip times, and reducing greenhouse gas emissions. The specific high-level goals stated in the THEA ConOps document (March 2016) are listed below (*1*):

- Goal 1: Develop and Deploy CV Infrastructure to Support the Applications Identified during Phase 1.
- Goal 2: Improve Mobility in the CBD.
- Goal 3: Reduce the Number of Safety Incidents within the Pilot Area.
- Goal 4: Reduce Environmental Impacts within the Pilot Area.
- Goal 5: Improve Agency Efficiency.
- Goal 6: Develop Business Environment for Sustainability.

The ConOps document also specified objectives for each goal that help to define evaluation metrics to determine whether a particular goal has been achieved (see Table 7). While the metrics are in the form of yes/no answers, information gathered in the stakeholder assessments will include the nuances of challenges, facilitators, and lessons learned. In addition, six capability maturity dimensions will be used to determine whether critical institutional or business process improvements were influenced by the occurrence of the pilot. Prior to finalizing this plan, the TTI CVPD Evaluation Team will have some informal telephone conversations with FHWA and THEA to confirm the goals, objectives, and metrics to make sure the team is on the correct track.

Table 7. Tampa Stakeholder Goals, Objectives, Metrics.

Goal	Objective	Metric
1: Develop and Deploy CV Infrastructure	1: Deploy DSRC technologies to support V2V, V2I, and V2X applications.	Achieved: Yes, No
1: Develop and Deploy CV Infrastructure	2: Upgrade TMC software to ensure compatibility with CV applications.	Achieved: Yes, No
1: Develop and Deploy CV Infrastructure	3: Recruit a fleet of transit and private vehicle owners and individuals carrying V2X-enabled mobile devices to participate in the CV Pilot by installing and using CV technology offered in the pilot.	Achieved: Yes, No
2: Improve Mobility in the CBD	1: Replace existing traffic controllers and control systems at key intersections with I-SIG CV technology to improve traffic progression at identified problem areas.	Achieved: Yes, No
2: Improve Mobility in the CBD	2: Provide TSP applications to help HART buses stay on a predictable schedule.	Improvement in arrival on schedule: Yes, No
2: Improve Mobility in the CBD	3: Provide BRT applications to improve overall operation and encourage increased ridership.	Ridership increased: Yes, No
3: Reduce the Number of Safety Incidents within the Pilot Area	1: Provide detection of pedestrians and warnings to drivers of potential pedestrian conflicts.	Pedestrian conflicts decreased: Yes, No
3: Reduce the Number of Safety Incidents within the Pilot Area	2: Provide detection of potential vehicle conflicts and warnings to pedestrians.	Pedestrian conflicts decreased: Yes, No
3: Reduce the Number of Safety Incidents within the Pilot Area	3: Provide early detection of wrong-way drivers and issue warnings to wrong-way drivers and upstream motorists.	Wrong-way driving incidents decreased: Yes, No
3: Reduce the Number of Safety Incidents within the Pilot Area	4: Give drivers warnings of the REL exit curve and stopped vehicles ahead.	Queue length decreased: Yes, No
3: Reduce the Number of Safety Incidents within the Pilot Area	5: Provide detection and warning of potential conflicts between streetcar vehicles and autos, pedestrians/bicycles.	Streetcar conflicts decreased: Yes, No

Goal	Objective	Metric
4: Reduce Environmental Impacts within the Pilot Area	1: Provide CV Mobility and Safety applications to improve overall mobility and reduce stops and idle time within the CBD, reducing emissions.	Time spent in idle decreased: Yes, No
4: Reduce Environmental Impacts within the Pilot Area	2: Provide TSP applications to reduce idle time of HART buses.	Time spent by HART buses in idle decreased: Yes, No
5: Improve Agency Efficiency	1: Improve traffic data collection capability, reducing the costs of collecting data.	Real-time traffic data collection capability improved: Yes, No Cost of collection decreased: Yes, No
5: Improve Agency Efficiency	2: Reduce the number of incidents and police and rescue responses to incidents.	Police and rescue responses to incidents decreased: Yes, No
5: Improve Agency Efficiency	3: Reduce crashes and time agencies take to gather data.	Crash reduction: Yes, No
5: Improve Agency Efficiency	4: Improve technology for crash statistics gathering.	Efficiency gains in crash data gathering: Yes, No
5: Improve Agency Efficiency	5: Improve scheduling and dispatching of HART vehicles with improved trip times and vehicle information.	Improved scheduling and dispatching of HART vehicles: Yes, No
5: Improve Agency Efficiency	6: Reduce overhead of THEA responding to wrong-way entries and crashes on REL exit ramp.	Cost efficiencies in THEA responding to wrong-way entries and crashes: Yes, No
6: Develop Business Environment for Sustainability	1: Work with CAMP, OEMs, and third party developers to develop business cases for advancing CV-ready vehicles.	Achieved: Yes, No
6: Develop Business Environment for Sustainability	2: Work with industry sectors that will benefit from CV implementation (e.g., insurance carriers, fleet managers, safety organizations) to provide education on the benefits and seek support for advancement of the system.	Achieved: Yes, No
6: Develop Business Environment for Sustainability	3: Work with chambers of commerce and other business organizations to educate members on the return on investment from increased mobility.	Achieved: Yes, No
6: Develop Business Environment for Sustainability	4: Work with state and local government to encourage positive legislation and funding in support of CV technology.	Achieved: Yes, No

Tampa Pilot Stakeholders

The Tampa Pilot has multiple stakeholders in addition to THEA, the lead agency. The TTI CVPD Evaluation Team assumes that consultants or technology firms engaged in the pilot deployments would not be considered stakeholders, but that might be a point of discussion. Users also are not considered stakeholders.

For purposes of this stakeholder acceptance/satisfaction plan, the stakeholders of interest are those public or private sector entities that are directly affected by the Pilot Deployment (i.e., key agency partners) or those that may interact with the pilot (i.e., key stakeholder agencies). These agencies are listed below:

- Key Agency Partners:
  - THEA.
  - City of Tampa Traffic Engineering/Traffic Management Center.
  - HART and TECO Streetcar Line (a Division of HART).
- Key Stakeholder Agencies:
  - Hillsborough County.
  - Amalie Arena.
  - City of Tampa Police.
  - Florida Highway Patrol (Tampa Office).
  - Hillsborough County Sheriff's Office.
  - MacDill Air Force Base (Public Affairs Office).
  - Tampa Bay Port Authority (Cargo and Cruise).
  - Tampa Convention Center.
  - Tampa Downtown Partnership.
  - Tampa Bay Lightning Hockey Team.
  - Tampa Bay Lightning Hockey Club.
  - Florida Department of Transportation, District 7.

Pre-deployment telephone interviews will be conducted with these stakeholders to determine which goals and objectives (from Table 1) are relevant for the concerns of the various key stakeholders. The interviews that are then conducted as part of the stakeholder acceptance/satisfaction assessment will focus only.

Information Gathering Approach

The TTI CVPD Evaluation Team will conduct semi-structured interviews with key contacts at THEA, the agency partners, and the stakeholder agencies to gather necessary information. A key contact is defined as someone with direct knowledge about the goals, objectives, metrics, and outcomes of the pilot deployments. While many of the metrics will be answered by yes/no responses, significant information will be challenges, influencing factors, facilitators, and lessons learned, etc., that will be surfaced in conversations with key informants. In semi-structured interviewing, a guide is used with questions and topics that must be covered. An interviewer has some discretion about the order in which questions are asked, but the questions are standardized, and probes may be provided to ensure that the researcher covers the correct material. This kind of interview collects detailed information, which is needed for the stakeholder assessment, but in a way that is somewhat conversational. This will enable the TTI CVPD Evaluation Team to delve deeply into the topics and to understand thoroughly the answers provided.

The TTI CVPD Evaluation Team will design a semi-structured interview guide that follows best practice principles to achieve a balance between maximizing data quality while minimizing respondent burden and cost. The interview guide will be structured to capture three categories of information:

- Perceptions on whether goals/objectives were fulfilled, along with why or why not.
- Lessons learned from the pilot experience.
- Assessment of the agency/organizations changes in terms of capability maturity dimensions: business processes, systems and technology, performance measurement, culture, organization and staffing, and collaboration.

Interviews will be both in-person and by telephone, depending of the interview target. The TTI CVPD Evaluation Team expects to interview no less than two and no more than 10 informants per agency (depending on the nature and extent of the agencies involvement in the pilot). The TTI CVPD Evaluation Team expects that interviews will be recorded and transcribed. Interviewees will be able to review and approve/edit interview summaries.

Schedule

The TTI Evaluation Team will determine the interview schedule based on the anticipated progress of the pilot site. The informal conversions to confirm the accuracy and relevance of goals, objectives, and metrics would take place prior to deployment. The actual stakeholder assessment interviews will be conducted after the deployment has been ongoing for a minimum amount of time (to be determined together with FHWA) or recently concluded.

Data Analysis

Individual interview findings will be aggregated to describe the acceptance/satisfaction of each stakeholder agency. An analysis software called NVivo that supports qualitative research will be used to code and organize the unstructured textual information. A codebook will be developed that contains descriptive definitions of the codes. The analysis team will be prepared to use emergent codes, that is, codes that are developed in the course of analyzing data so that the team ensures that refinement of the coding scheme is done in a coordinated manner.

An outcomes and impacts profile will be generated for each stakeholder agency that describes:

- Perceptions on whether goals/objectives were fulfilled, along with why or why not.
- Lessons learned from the pilot experience.
- Assessment of the agency/organizations changes in terms of capability maturity dimensions: business processes, systems and technology, performance measurement, culture, organization and staffing, and collaboration.

To the extent possible, the TTI CVPD Evaluation Team will attempt to distinguish outputs from impacts in profiling the stakeholder agencies. Themes will be analyzed within individual interviews first, then findings on each theme will be aggregated across a stakeholder agency. Then, information derived from quantitative evaluations will be used to validate or credibility check the resulting qualitative results.

Chapter 10. Benefit Cost Evaluation

Benefits are generally derived from reductions in the cost of travel. However, if the project were to increase the cost of travel those results would also be entered as a benefit, but as a negative benefit. Typical benefit categories are discussed below.

For many transportation projects, the value of travel time savings is the largest benefit category. In this evaluation, the actual travel time (with the CV deployment projects) will be compared to travel times in a hypothetical base case where the CV deployment projects did not happen. Travel times can either be measured from field data or modeled depending on data availability and model accuracy. The travel times should include all travelers, with those in automobiles, transit vehicles, and pedestrians potentially deriving specific travel time benefits from these CV deployment projects. Values of time will be derived from the *Tiger Benefit-Cost Analysis (BCA) Resource Guide* (*18*) or, when appropriate, local values of time can be used. The values of time often differ by mode so the time savings and number of travelers by mode will all be needed for this calculation.

Changes in the number of crashes will also be an important part of these CV deployment projects. The TTI lead evaluation team will not be estimating the change in crashes but Volpe will be making that estimate. Preferably the estimated changes will be on the AIS scale (from AIS1 being a minor injury to AIS6 where there was a fatality) plus property damage only crashes. Using Volpe's estimate the TTI team will determine the monetary value of the changes in crashes based on federal guidance (*18*).

The CV deployment projects are also likely to impact vehicle emissions. The change in emissions between the actual case (with the CV demonstration projects) and a base case (as if those projects had not occurred) will be estimated for a 7-year timeframe. These changes will then be monetized using the same federal guidance as noted above. Pollutants that will be examined in the BCA include CO_2, VOC, NO_X, PM, SOX, and CO.

Similarly, the total change in fuel used will be monetized. Current and predicted costs for fuel can be found at the U.S. Energy Information Administration website (*19*). Note that the portion of the cost of fuel that is tax will be removed prior to calculations since that is a transfer and not a change in societal benefits.

The final category of benefits will be vehicle operating costs. Vehicle operating costs will based on the American Automobile Association (AAA) values that are published annually (*20*). Any reduction/increase in vehicle miles traveled will result in reduced/increased maintenance, tires, and depreciation based on average per mile vehicle operating costs as calculated by AAA. The costs will not include ownership costs, as it is assumed that those costs remain.

References

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