Connected Vehicle Pilot Deployment Program Phase 1, Performance Measurement and Evaluation Support Plan – Tampa (THEA)

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16. Abstract

The Performance Measurement and Evaluation Support Plan for the Connected Vehicle Pilot Deployment Program Phase 1, Tampa Hillsborough Expressway Authority, outlines the goals and objectives for the Pilot as well as the proposed performance metrics. The document addresses the issues, operational needs, and the targeted improvements for the Pilot focus areas. Goal-related performance measures are presented for each of the six Use Cases, followed by confounding factors assessment and system deployment impact evaluation design to account for and control for observed and unobserved confounding factors. A detailed approach to participant selection and to the treatment of confounding factors is presented as evidence of a scientifically sound approach to the design of the entire CV Pilot evaluation. The six Use Cases are considered individually for experimental design, participant selection, and measurements of performance. Finally, the report outlines the methods and procedures for data collection, methods for estimating each identified performance measures, performance measure reporting, and the interface between THEA and its core agency partners with the Independent Evaluation effort.

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CV Pilot Deployment, Performance Measures, Confounding Factors, Experimental Design, Data Reporting			
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List of Acronyms

AADT	Average Annual Daily Traffic
AET	All-electronic Toll
API	Automated Protocol Interface
ATE	Average Treatment Effect
BAA	Broad Agency Announcement
BRT	Bus Rapid Transit
BSM	Basic Safety Message
CAMP	Crash Avoidance Metrics Partners, LLC
CBD	Central Business District
ConOps	Concept of Operations
CV	Connected Vehicle
DiD	Difference-in-Difference
DSRC	Dedicated Short Range Communication
EEBL	Emergency Electronic Brake Light Warning
FCW	Forward Collision Warning
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FLHSMV	Florida Highway Safety and Motor Vehicles
GIS	Geographical Information System
HART	Hillsborough Area Regional Transit
HCM	Highway Capacity Manual
IE	Independent Evaluator
IMA	Intersection Movement Assist
I-SIG	Intelligent Traffic Signal System
JSON	Java Script Object Notification
LEHD	U.S. Census Bureau Longitudinal Employer-Household Dynamics
LOS	Level of Service
MAFB	MacDill Air Force Base
MOVES	Motor Vehicle Emission Simulator
NOAA	National Oceanic and Atmospheric Administration
O&M	Operations and Maintenance
OBU	On Board Unit
ODE	Operational Data Environment
OEM	Original Equipment Manufacturer
PeDM	Probe-enabled Data Monitoring
PED-SIG	Mobile Accessible Pedestrian Signal
PED-X	Pedestrian in Signalized Crosswalk
PII	Personally Identifiable Information

PSM	Propensity Score Matching
RDE	Research Data Exchange
REL	Reversible Express Lanes
RSU	Roadside Unit
RLVW	Red Light Violation Warning
SPF	Safety Performance Function
SRM	Signal Request Message
SSM	Signal Status Message
STOL	Saxton Transportation Operations Laboratory
TDP	Tampa Downtown Partnership
TECO	Tampa Electric Company
THEA	Tampa Hillsborough Expressway Authority
TIP	Transportation Incentive Program
TMC	Traffic Management Center
TSP	Transit Signal Priority
UC	Use Case
USDOT	United States Department of Transportation
USF	University of South Florida
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VAD	Vehicle Awareness Device
VIN	Vehicle Identification Number
XML	Extensible Markup Language

1 Introduction

The Tampa Hillsborough Expressway Authority (THEA) CV Pilot Deployment (Pilot) is one of the three connected vehicle (CV) deployment projects selected by Federal Highway Administration (FHWA) September of 2015 as a part of a U.S. Department of Transportation funded program. This program consists of three phases: Concept of Operations (ConOps), Design-Build, and Operations and Maintenance (O&M). The Pilot identifies areas of traffic management in Tampa, Florida which may be improved by CV applications, develops a system concept for deploying these CV applications and after approval from US DOT designs, deploys and operates the system.

Ultimately the Pilot examines performance measures and contributes to a national data repository on CV for use by global research partners in furthering the development, deployment and standardization of Connected Vehicle Technology. The deployment is slated for downtown Tampa, Florida and will include several CV applications, deployed across the highway, transit, and pedestrian modes of transportation on a variety of facility and vehicle types. This Pilot "aims to create a connected urban environment to measure the effect and impact of CVs in Tampa's vibrant downtown."

This Pilot Project, as envisioned, will deploy CV applications on an urban expressway, urban arterials, in Tampa's Central Business District (CBD) and involve vehicle to vehicle (V2V), vehicle to infrastructure (V2I) and vehicle to "everything" (V2X) technologies.

As the evaluation of the impacts of the Pilot deployment is central to the overall purpose of the project and is a prime motivation for US DOT funding, the Performance Measurement and Evaluation Support Plan represents another critical portion of the development the Pilot. The Broad Agency Announcement (BAA) and subsequent FHWA direction specify that the evaluation "pillars" of Mobility, Safety, Environment, and Agency Efficiency be measured. This report serves to detail THEA's proposed approach to accomplishing the evaluation of the pilot deployment for these four areas.

1.1 Purpose of the Report

This report will describe the performance measurement and evaluation support plan and detail the approaches being planned for providing understandable results of the deployment of CV technologies to FHWA, stakeholders, other users of the system, and research entities.

For each of the six Use Cases that have been presented in the ConOps [1], the data needs, measurement criteria, and experiment type are detailed. Discussions of confounding factors and methods that will be used to adjust for them are included in this document. The plans for collecting data and sharing that data are also presented. Central to this Performance Measurement and Evaluation Support is the description of the linkages between the goals and objectives of the CV Pilot and the manner in which achievement of these benefits will be measured and reported.

1.2 Organization of the Report

The remainder of the report is organized into the following sections:
Section 2 – CV Pilot Needs
The problems and operational needs of the Pilot focus areas are outlined as are the current operational situation and potential improvements resulting from the deployment.

Section 3 -CV Pilot Goals and Objectives
This section defines the CV Pilot goals, and objectives from a user perspective to enable users, stakeholders, system owners, agency partners and system developers to achieve consensus and understanding of how the new system will operate and benefit their interests, as delineated in Section 5 of the ConOps.

Section 4 - Performance Measures and Targets
The goal-related performance measures are detailed for each of the six Use Cases that are both quantitative and qualitative, depending on the case.

Section 5 – Confounding Factors
Confounding factors for the Pilot target area are presented, and those that are identifiable and measurable beforehand (a-priori) are discussed.

Section 6 -System Deployment Impact Evaluation Design
System deployment impact evaluation designs are outlined for each of the Use Cases.

Section 7 – Data Collection Plan
This section outlines the methods of data collection, protocols for participant action logs, plans for data scrubbing, and procedures for the archiving of the data.

Section 8 -System Impact Evaluation Plan
Detailed methods for estimating each identified performance measure for each of the Use Cases are presented.

Section 9 – Performance Reporting
The manner in which performance will be reported to FHWA, stakeholders, and other users of the system is proposed in this section along with the anticipated frequency of reporting.

Section 10- Support to Independent Evaluation (IE) Effort
The interface between THEA and its core agency partners with the Independent Evaluation effort is addressed.

Section 11 – Data Sharing Network
Data sharing plans, including providing information to the Research Data Exchange (RED), are discussed.

Section 12 – Conclusion

References

2 CV Pilot Needs

The THEA CV Pilot aims to meet the purposes set forth in the US DOT's BAA to advance and enable safe, interoperable, networked wireless communications among vehicles, the infrastructure, and travelers' personal communications devices and to make surface transportation safer, smarter, and greener. The THEA CV Pilot aims to demonstrate the kinds of improvements that can be made in an urban environment, with Tampa's CBD as the example site. THEA is deploying site-tailored collections of applications that address specific local needs while laying a foundation for additional local/regional deployment, and providing transferable lessons learned for other prospective deployers across the nation.

2.1 Pilot Focus Area System Description

Downtown Tampa is bordered by Ybor Channel (Cruise Ship and Commercial Port Channel) to the east, Garrison Channel (local waterway) to the south, Florida Avenue to the west, and Scott Street to the north. A virtually flat topography near sea level helps to simplify the evaluation of traffic flow parameters. The Focused Pilot Area is depicted in Figure 2-1.

In terms of transportation features of the TAMPA CBD, THEA owns and operates the Selmon Expressway and the Reversible Express Lanes (REL), a reversible elevated express lane, an all-electronic toll (AET) 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). Figure 2-2 illustrates the Selmon Expressway and Environs.

REL traffic exits at the intersection of Twiggs Street and Meridian Avenue in downtown. The Selmon Expressway, also an AET facility, runs parallel to the REL. Exits 7 and 8 provide ingress and egress for downtown traffic as well. The final exit is at Dale Mabry Highway, which is the location of MAFB's main gate. Since the spring of 2010, all vehicles on the expressway are tolled electronically as they pass under toll gantries. Payment is made through SunPass or license plate-based accounts.

The area targeted for the Pilot Deployment is multi-modal in nature. Meridian Avenue is a major gateway to downtown Tampa and will be the focal point for several of this pilot's applications.

Channelside Drive, on the east and south borders of the test area, connects to Amalie Arena. Hillsborough Area Regional Transit (HART) bus lines route through this area, and express routes utilize the REL for commuters from the Brandon area. The Marion Transit Center is in the northwest section of the Pilot focus area on Marion Street at Laurel Street near I-275. The Tampa Electric Company (TECO) Line Streetcar Trolley extends through the project area servicing local businesses and the Amalie Arena, special event traffic generators.

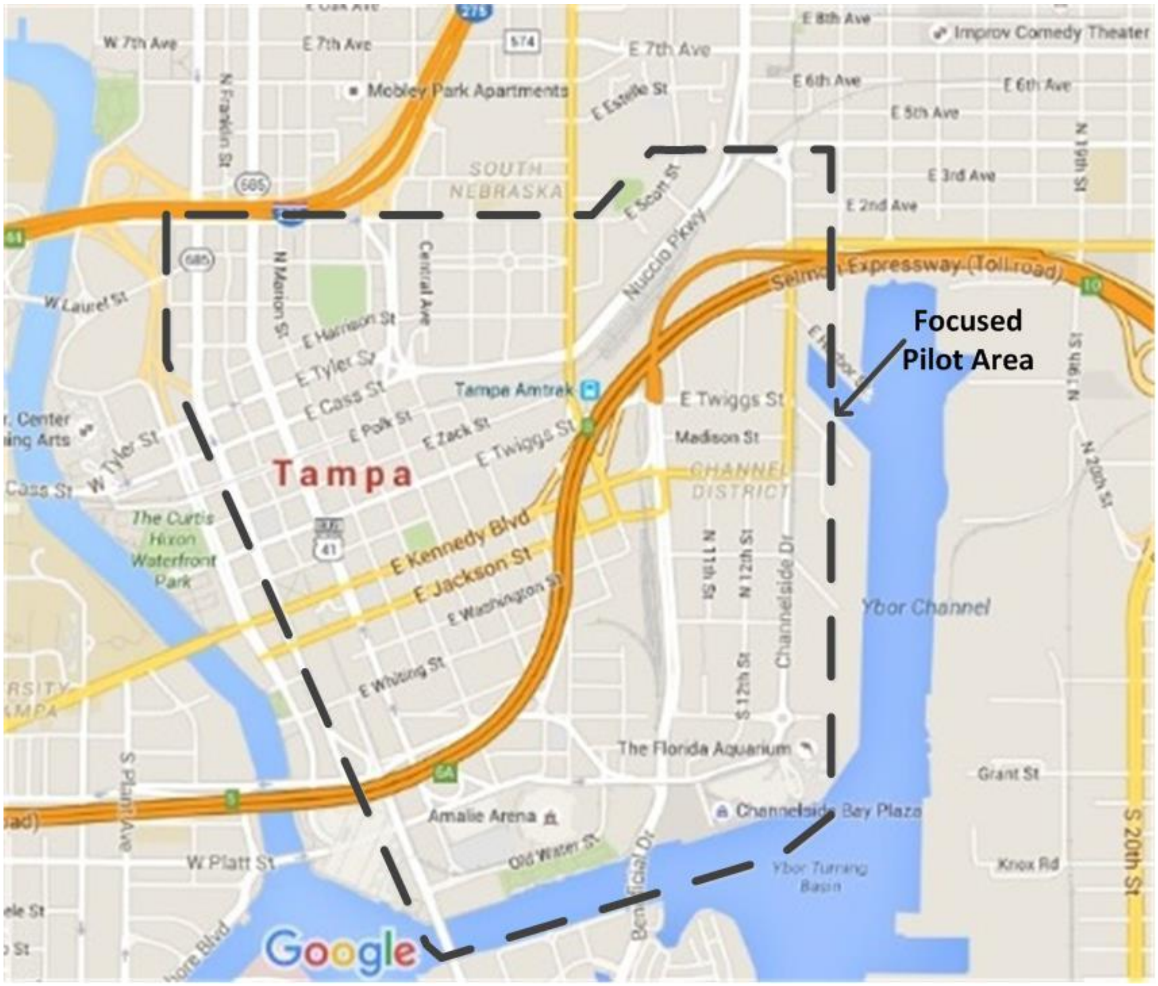

Figure 2-1 THEA Focused Pilot Area
Source: Googlemaps.com, HNTB

Tampa Port Authority operates three International Cruise Ship terminals as well as cargo facilities located in the Pilot focus area. The Tampa CBD has a high volume of pedestrian activity and an active bike share program. MAFB is located eight miles south of downtown Tampa adjacent to the western terminus of the Selmon Expressway. The base has a Transportation Incentive Program (TIP) in which about 1,450 base personnel use express bus or vanpools, and the program provides monthly express HART 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.

Figure 2-2 Selmon Expressway and Environs
Source: THEA, HNTB

2.2 Transportation Related Issues – Mobility, Safety and Environmental

The Pilot deployment area experiences several different mobility and safety issues on a daily basis. It is anticipated that several of these issues can be mitigated using connected vehicle applications. The following are examples of the current conditions that effect safety and mobility in the Pilot focus area and contribute to increased vehicle-related emissions.

The Selmon's REL toll lanes' morning commute endpoint is at the 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 CBD. 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. Figure 3 illustrates the crash experience from January 2010 to December 2013 for the intersection at the terminus of the REL at E. Twiggs Street. Accidents clustered in the vicinity of the terminus of the REL at Meridian Avenue and Twiggs Street lie within the two red ovals shown in Figure 2-3.

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.

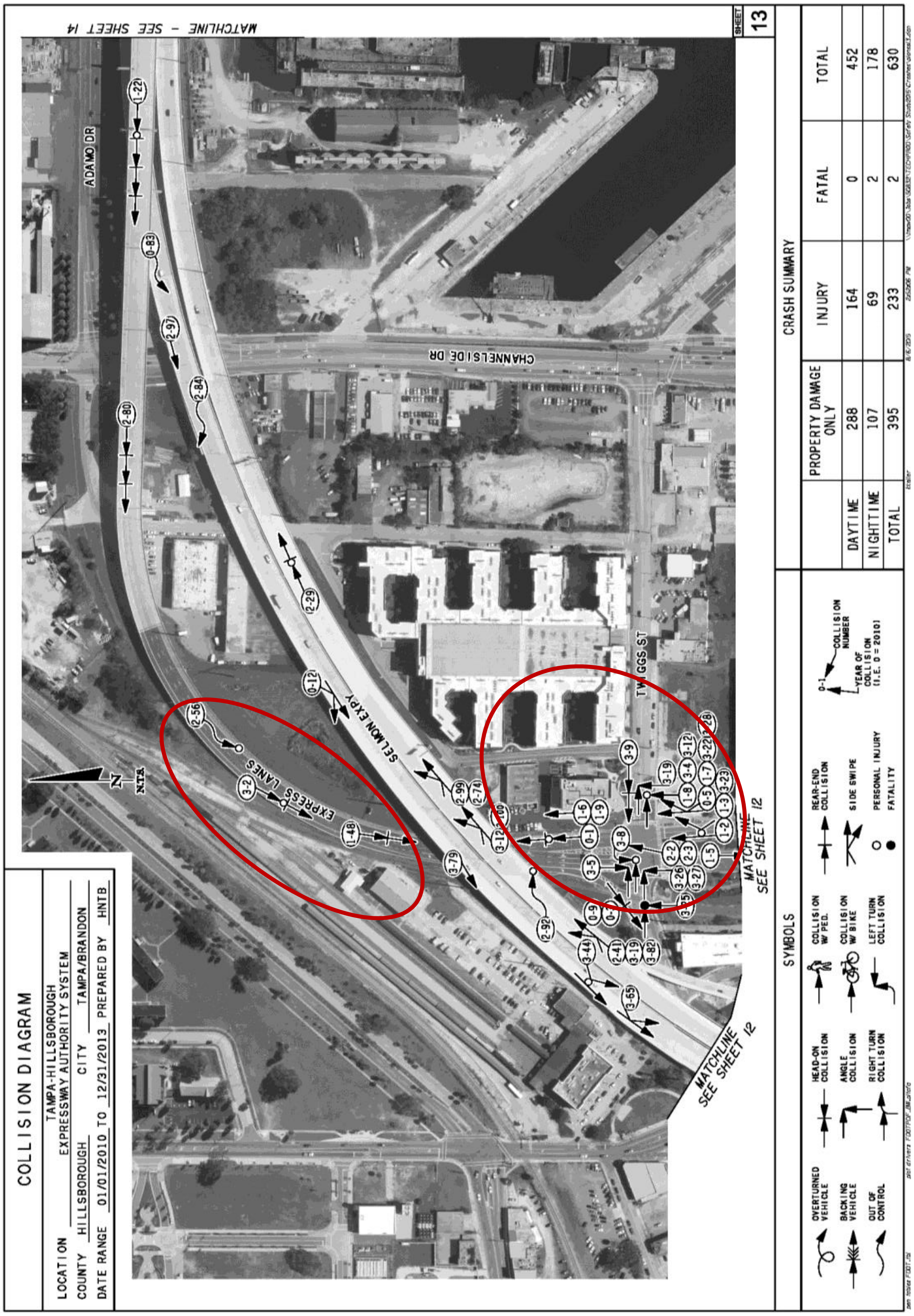

Figure 2-3 Collisions REL at E. Twiggs Street

Source: HNTB Arterial Safety Analysis, April 2015

Vehicles and pedestrians conflict with The TECO Line Streetcar Trolley (Figure 2-4) at crossing locations throughout the project area, particularly along Channelside Drive. On the east portion of the project area along Channelside Drive corridor, visitors experience delays and path-finding difficulties associated with arrivals and departures at the International Cruise Ship terminals and the Amalie Arena.

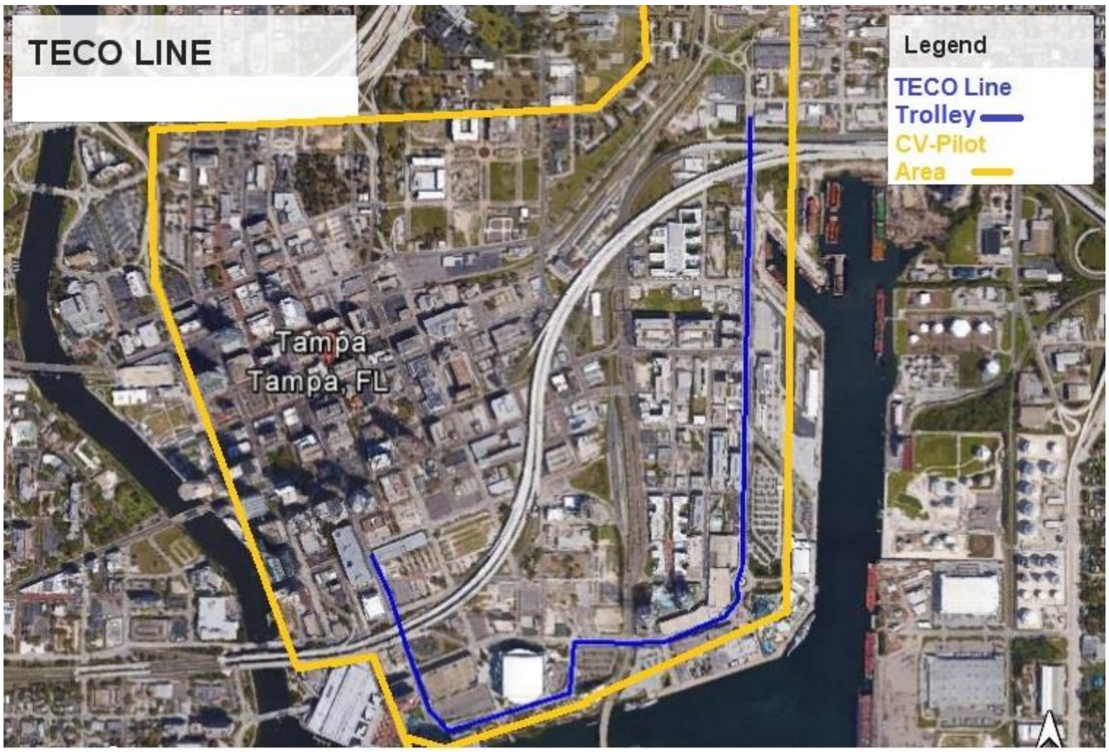

Figure 2-4 TECO Line Trolley
Source: Googlemap.com, HNTB

MacDill AFB experiences long queue times at controlled access points during the peak morning arrival time. A project is currently underway to provide real time motorist information via a smart phone application to facilitate the dissemination of queue time and alternative entry point information. MAFB presents an opportunity to create a fleet of vehicle probes for data collection. This is possible through its commuter vehicle population and TIP, which utilizes vanpool vehicles in addition to HART buses.

In order to improve mobility, enhance safety, mitigate the environmental impacts of queuing, and enhance agency efficiency, a set of six Use Cases that will deploy site-specific CV applications had been developed. These Use Cases are presented in the following section and are consistent with those detailed in the ConOps for the THEA Pilot previously submitted to FHWA.

2.3 Stakeholder Interaction

THEA has partnerships with various stakeholders that have a vested interest in the study area to integrate transportation, mobility, environmental, and safety solutions for the benefit of Tampa citizens, businesses, and visitors. THEA's approach to stakeholder interaction is to continue to build off the past relationships that have worked throughout the years.

2.3.1 City of Tampa

The City of Tampa and THEA have mutual concerns. The City's Traffic Management Center (TMC) is co-located with THEA's TMC. The two agencies have forged a strong partnership that started years before at the opening of the Selmon Expressway Reversible Express Lanes and the building of their new TMC. The jointly-operated TMC is a testament to the dedication of THEA and the City of Tampa to this approach. THEA meets daily with the City of Tampa Traffic Management staff, and the City of Tampa has multiple avenues to give input on the CV Pilot Deployment.

2.3.2 HART

HART has been involved in several meetings in the ConOps development and has played an active role in the project, representing not only fixed route transit but also the TECO Streetcar Trolley, which is operated by HART. THEA's Executive Director has a standing meeting with the HART CEO on a monthly basis and staff is included on a project by project basis. For the CV Pilot Deployment, HART staff have been engaged on a weekly basis.

2.3.3 MacDill Air Force Base

MacDill's role in the project has been twofold, not only from the CV Pilot Deployment, but also from an existing project that provides MacDill airmen and Department of Defense employees with a cellular application that communicates the amount of wait time at each gate. This application is an initial step toward the CV Pilot Deployment. MacDill staff has been involved in the ConOps development and general project development. Numerous meetings have occurred between THEA staff and MAFB.

2.3.4 Amalie Arena

As several of the THEA CV Pilot Deployment applications will impact Amalie Arena clientele, their Director of Customer Experience was included in the initial Stakeholder meeting on December 3, 2015.

2.3.5 Tampa Downtown Partnership (TDP)

The TDP is a non-profit organization that is an advocacy group for Tampa's Downtown and the development of a pedestrian/bicycle friendly urban lifestyle. A member of the TDP staff is a part of the THEA CV Pilot Deployment Stakeholder Review Panel. THEA has worked with the TDP on a regular basis and communication occurs weekly. TDP attended the initial Stakeholder meeting on December 3, 2015.

2.3.6 Other

Other agencies that are included on the Stakeholder Review Panel include, Florida Highway Patrol, City of Tampa Police, Florida Department of Transportation – District 7 Traffic Operations, and the

Hillsborough County Sheriff's Office. These agencies are engaged as the project dictates, and all took part in initial Stakeholder meeting on December 3, 2015.

The next steps during the Systems Requirements Task will specifically develop a Requirements Traceability and Verification Matrix, tracing requirements back to needs defined in the ConOps and providing a documentation process for verification. This matrix will be expanded during Phase 2 to provide forward traceability to design specifications, verification/test plans, operations, and evaluation support activities.

For the final Task that will address Stakeholder involvement, the THEA team will prepare a high level plan for the recruitment and training of all stakeholders, travelers, test vehicle drivers, and other personnel participating in the pilot. In order to fully capture the impact of the pilot on all stakeholders including the traveling public, the training and education plan will include a process to identify, engage, educate and solicit feedback from a relevant cross section of participants early in the process.

3 CV Pilot Goals and Objectives

This section defines the CV Pilot goals, and objectives from a user perspective to enable users, stakeholders, system owners, agency partners and system developers to achieve consensus and understanding of how the new system will operate and benefit their interests, as detailed in Section 5 of the ConOps.

THEA has developed partnerships of multiple stakeholders to deploy applications using data captured from multiple sources (e.g., vehicles, mobile devices, and infrastructure) across multiple elements of the surface transportation system (i.e., transit, arterial, and electronically tolled roadways) to support improved system performance.

The goals and objectives for the CV Pilot are:

3.1.1 Goal 1: Develop and Deploy CV Infrastructure to Support the Applications Identified During Phase 1

Objective 1: Deploy Dedicated Short Range Communication (DSRC) technologies to support V2V, V2I and V2X applications.

Objective 2: Upgrade TMC software to ensure compatibility with CV Applications.

Objective 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, and recruit a group of smart phone owners to participate in the CV Pilot by installing and using the pedestrian (including bicyclists) app offered in the pilot.

It should be noted that measurement of the accomplishment of Goal 1 will not be measured in the same fashion as this plan details for the remaining goals. Demonstration of progress towards the achievement of Goal 1 is assumed to be an on-going process of progress meetings, reports, and deliverables to the Sponsoring Agency, and successful progression through the “gates” to Phases 2 and 3.

3.1.2 Goal 2: Improve Mobility in the CBD

Objective 1: Replace existing traffic controllers and control systems at key intersections with Intelligent Traffic Signal System (I-SIG) CV technology to improve traffic progression at identified problem areas.

Objective 2: Provide Transit Signal Priority (TSP) applications to help HART buses stay on a predictable schedule.

Objective 3: Provide Bus Rapid Transit (BRT) applications to improve overall operation and encourage increased ridership.

3.1.3 Goal 3: Reduce the Number of Safety Incidents within the Pilot Area

Objective 1: Provide detection of pedestrians and warnings to drivers of potential pedestrian conflicts.

Objective 2: Provide detection of potential vehicle conflicts and warnings to pedestrians.

Objective 3: Provide early detection of wrong-way drivers and issue warnings to wrong-way drivers and upstream motorists.

Objective 4: Give drivers warnings of the REL exit curve speed and stopped vehicles ahead.

Objective 5: Provide detection and warning of potential conflicts between trolleys, vehicles, and pedestrians.

3.1.4 Goal 4: Reduce Environmental Impacts within the Pilot Area

Objective 1: Provide CV Mobility and Safety applications to improve overall mobility and reduce stops and idle time within the CBD, thus reducing emissions.

Objective 2: Provide TSP applications to reduce idle time of HART buses.

Objective 3: Provide BRT applications to improve overall operation and encourage increased ridership.

3.1.5 Goal 5: Improve Agency Efficiency

Objective 1: Improve traffic data collection capability, reducing the costs of collecting data.

Objective 2: Reduce the number of incidents and police and rescue responses to incidents.

Objective 3: Reduce crashes and time agencies take to gather data.

Objective 4: Improve technology for crash statistics gathering.

Objective 5: Improve scheduling and dispatching of HART vehicles with improved trip times and vehicle information.

Objective 6: Reduce overhead of THEA responding to wrong-way entries and crashes on REL exit ramp.

3.1.6 Goal 6: Develop Business Environment for Sustainability

Objective 1: Work with Crash Avoidance Metrics Partners, LLC (CAMP), Original Equipment Manufacturers (OEMs), and third party developers to develop business cases for advancing CV-ready vehicles.

Objective 2: Work with industry sectors that will benefit from CV implementation, i.e., insurance carriers, fleet managers, safety organizations, etc., to provide education on the benefits and seek support for advancement of the system.

Objective 3: Work with Chambers of Commerce and other business organizations to educate members on the return on investment from increased mobility.

Objective 4: Work with state and local Government to encourage positive legislation and funding in support of CV technology.

Table 3-1 illustrates the relationships between goals and objectives from the ConOps to the use cases detailed later in this plan.

Table 3-1 THEA CV Pilot Deployment Goals and Objectives Summary

Goal	Objectives	Use Case
Goal 1: Develop and Deploy CV Infrastructure to Support Applications Identified in Phase 1	Objective 1: Deploy Dedicated Short-Range Communication (DSCR) technologies to support V2V, V2I, and V2X applications Objective 2: Upgrade TMC software to ensure compatibility with CV applications Objective 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	Objective 1: Replace existing traffic controllers and control systems at key intersections with I-SIG CV technology to improve traffic progression Objective 2: Help HART buses stay on predictable schedule through TSP applications Objective 3: Improve 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	Objective 1: Detect pedestrians and provide warnings to drivers of potential pedestrian conflicts Objective 2: Detect potential vehicle conflicts and provide warnings to pedestrians Objective 3: Provide early detection of wrong way drivers and issue warnings to wrong-way drivers and upstream motorists Objective 4: Warn drivers of REL exit curve speed and stopped vehicles ahead Objective 5: Detect and warn of potential conflicts between trolleys, 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	Objective 1: Provide CV mobility and safety applications to improve overall mobility and reduce stops and idle time within the CBD, thus reducing emissions Objective 2: Provide TSP applications to reduce HART buses idle time Objective 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	Objective 1: Improve data collection capability, reducing the costs of collecting data Objective 2: Reduce the number of incidents and police and rescue responses to incidents Objective 3: Reduce crashes and time agencies take to gather data Objective 4: Improve technology for crash statistics gathering Objective 5: Improve scheduling and dispatching of HART vehicles with improved trip times and vehicle information Objective 6: Reduce THEA's overhead in responding to wrong-way entries and crashes on REL exit ramp	To be determined
Goal 6: Develop Business Environment for Sustainability	Objective 1: Work with CAMP, OEMs, and third party developers to develop business cases for advancing CV-ready vehicles Objective 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 Objective 3: Work with Chambers of Commerce and other business organizations to educate members on the return on investment from increased mobility Objective 4: Work with state and local government to encourage positive legislation and funding in support of CV technology	To be addressed in Task 10

If gains are found in the Use Cases, inferences will be made regarding impacts on the entire study area.

3.2 Use Cases

The THEA Connected Vehicle Pilot has developed six Use Cases (UCs) to describe the issues that the project will address. They are summarized in Table 3-2 and are mapped on Figure 3-1:

Table 3-2 THEA CV Pilot Deployment Use Case Summary[1]

Use Case	Condition	Location
UC1	Morning Peak Hour Queues	REL at E. Twiggs Street
UC2	Wrong-Way Entries	REL at E. Twiggs Street and Meridian Street
UC3	Pedestrian Safety	E. Twiggs Street at George E. Edgecomb Courthouse
UC4	Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety	BRT-REL to Marion Street Transit Station
UC5	TECO Line Streetcar Trolley Conflicts	Channelside Drive
UC6	Enhanced Signal Coordination and Traffic Progression	Meridian Street to serve MacDill Air Force Base traffic

[1]These are the preliminary locations and the document will be updated in Phases 2 and 3.

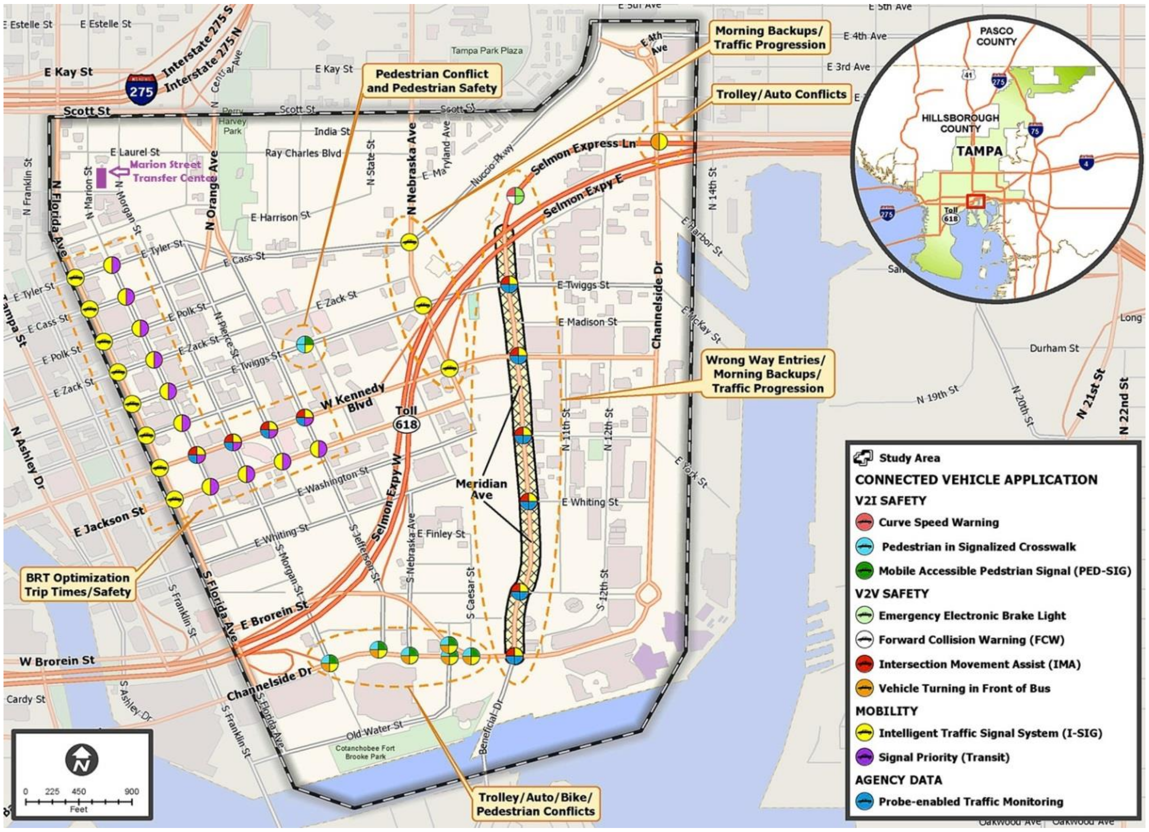

Figure 3-1 THEA CV Pilot Deployment Locations
Source: Googlemaps.com, HNTB

3.2.1 Use Case 1: Morning Peak Hour Queues

As vehicles exit the REL onto Meridian Street to make a right turn onto East Twiggs Street, the right turn lane backs up due to local congestion. An additional issue is that many of these vehicles then want to make a right turn onto Nebraska Avenue, which is almost an immediate right turn after turning onto East Twiggs Street. The combination of these issues causes the queue to back up onto the REL. This backup causes exiting vehicles wanting to turn right to use the shoulder as part of the right turn lane. 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 or attempt a rapid lane change. Applications to be deployed at this location are:

- V2I – Curve Speed Warning
- V2V – Emergency Electronic Brake Light Warning (EEBL)
- V2V – Forward Collision Warning (FCW)

3.2.2 Use Case 2: Wrong Way Entries

At the exit of the REL on East Twiggs Street, there is a relatively easy opportunity for a driver to become confused and attempt to enter the REL going the wrong way. There are no gates or barriers at the REL exit to prevent drivers from entering the REL going the wrong way. Drivers traveling on

East Twiggs Street approaching the intersection where the REL ends and Meridian Street begins can mistakenly enter the REL going the wrong way. Drivers approaching this intersection coming from downtown can inadvertently make a left turn onto the REL exit. Conversely, drivers on East Twiggs Street approaching this intersection going towards downtown can inadvertently make a right turn onto the REL exit. Finally, drivers approaching the intersection on Meridian can potentially veer slightly to the left onto the REL exit. Each of these possibilities is a safety concern. The CV applications to be used in this Use Case are:

- Intersection Movement Assist (IMA)
- Red Light Violation Warning (RLVW)
- Intelligent Signal Control (I-SIG)
- Probe Enabled Data Monitoring (PeDM)

3.2.3 Use Case 3: Pedestrian Safety

At the George E. Edgecomb Hillsborough County Courthouse, there is one primary crosswalk for pedestrian access to the main parking garage. The crosswalk is marked and has a yellow flashing beacon light to warn drivers that they are approaching a crosswalk. This crosswalk is the primary route for jurors, lawyers, and other people to get to/from the courthouse. During morning rush hour, there is significant pedestrian traffic as potential jurors unfamiliar with the area are attempting to arrive on time. This is compounded on Mondays and Tuesdays when new juror pools of up to 400 persons are required to report during rush hour. Lack of attention by drivers causes a safety concern for pedestrians trying to reach the courthouse. Some pedestrians elect to take a shortcut by crossing East Twiggs Street mid-block and outside the crosswalk. Planned CV deployment at this location includes:

- V2I – Mobile Accessible Pedestrian Signal (PED-SIG)
- V2I – Pedestrian in Signalized Crosswalk (PED-X)

3.2.4 Use Case 4: Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety

Marion Street is a two-lane urban arterial in the heart of the Tampa CBD that serves as a primary bus route, which on the north end terminates at the Marion Transit Center. HART operates several routes that converge onto Marion Street all headed to the Marion Street Transit Station. Along these routes, many of the bus stops are on the approach to an intersection. When there is congestion, buses are unable to reach their stops causing them to potentially fall behind schedule; thus, causing a mobility concern. CV Technology will be used to address the mobility concerns. Buses and traffic signals will communicate, and if a bus is behind schedule, the traffic signal system will either give the bus priority or flush the queue allowing the bus to reach its stop, assuming there are no other higher priorities. CV applications planned for deployment of this UC include:

- I-SIG
- Transit Signal Priority (TSP)
- PeDM
- IMA

3.2.5 Use Case 5: TECO Line Streetcar Trolley Conflicts

The TECO Streetcar Trolley runs along Channelside Drive from the Amalie Arena area up Channelside Drive, North, past the Selmon Expressway. The trolley is a steel wheel on steel rail fixed-guideway system in a dedicated right-of-way. It is powered by an overhead catenary and crosses intersections at grade. As a result, at various stops along the trolley route, vehicles may have to turn right in front of a stopped trolley. As the pedestrians disembark from the trolley and the trolley prepares to depart, it is possible a vehicle may turn right in front of the streetcar. Pedestrians may be crossing the intersection where the vehicle is turning right as well. The potential of a trolley and vehicle crash and a pedestrian incident are safety concerns. CV Technology will be used to provide information to trolley operators, drivers, and pedestrians to improve safety around these locations. The CV applications to be used in this Use Case are:

- I-SIG
- Vehicle Turning in Front of Bus (VTRFTV)
- V2I – PED-X
- V2I – PED-SIG

3.2.6 Use Case 6: Enhanced Signal Coordination and Traffic Progression

There is significant congestion and delay along Meridian Avenue during morning peak travel periods. Adding to this issues are a large number of MAFB commuters traveling through downtown on the Selmon Expressway or arterial routes, trying to reach one of four MAFB entrance gates without knowledge of the travel times for their route versus other routes or the length of the queue at each gate. As some of these commuters are using surface roads through downtown, they interact with other traffic and pedestrians. With this increase in traffic, the potential for pedestrian incidents increases, creating a safety concern. The CV technologies that will be used to improve the mobility and safety through the downtown area for this UC are:

- I-SIG
- PeDM

Figure 3-2 is taken from the ConOps for the THEA project and illustrates the combinations of CV applications that are being planned to address the problems that have been identified for each of the Use Cases.

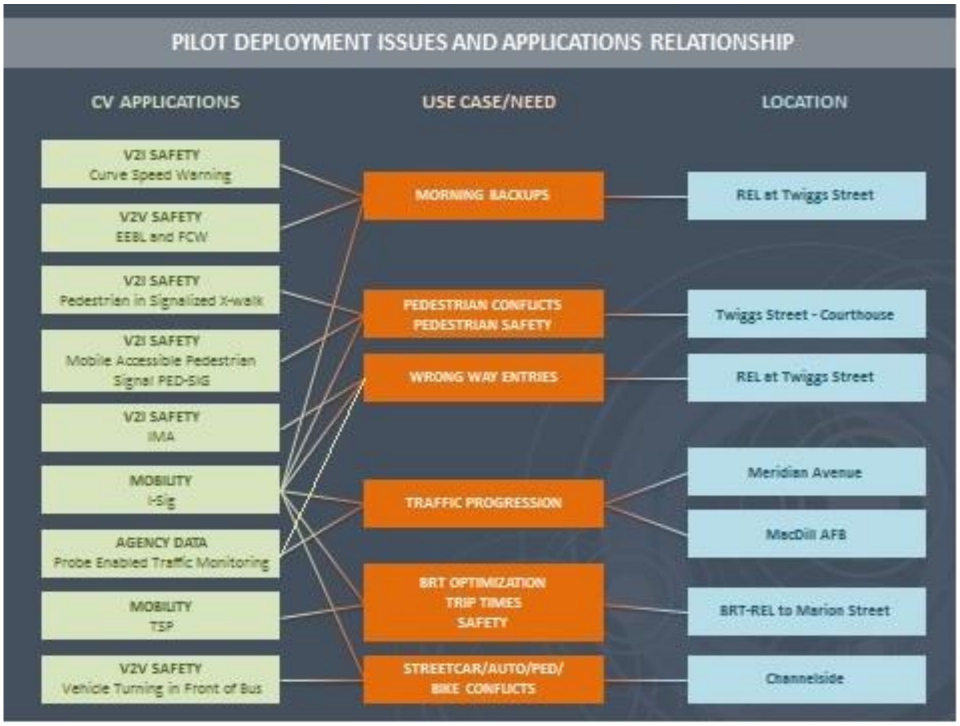

Figure 3-2 THEA CV Pilot Deployment "Spider Diagram" of CV Applications, Use Cases and Locations

Source: THEA Connected Vehicle Pilot, User Oriented Concept of Operations, January, 2016 [1]

4 Performance Measures and Targets

4.1 Introduction

Performance Measures for the THEA CV Pilot will ascertain the effectiveness of the use cases regarding the four “pillars” of mobility, safety, environment, and agency efficiency. This section identifies performance measures for each use case scenario that were determined to be tied to the goals of this deployment. The measures are intended to be credible and based on data availability. Further, the identified performance measures are intended to be clear, reliable, and responsive to change and are tied to the target values discussed in the approved ConOps document. The performance measures will be computed for each participant and then averaged over the sample size that corresponds to the same time period. Note that this section only lists the performance measures that will be used for performance measurement analysis. Detailed explanations of the experimental design and how these performance measures will be obtained and analyzed will be discussed in sections 6 and 8 of this report.

4.2 Use Case 1 (UC1) – Morning Peak Hour Queues

As vehicles exit the REL onto Meridian Street to make a right turn onto East Twiggs Street, the right turn lane backs up due to local congestion. Additional congestion is produced by vehicles turning onto Nebraska Avenue, which is almost an immediate right turn after turning onto East Twiggs Street. This causes the queue to backup up onto the REL. For the analysis of UC1, all four pillars, including mobility, safety, environment, and agency efficiency, are addressed.

4.2.1 Mobility

To determine the mobility benefits for UC1, the following measures will be analyzed for the before and after CV deployment:

- Travel time (using segment level travel time analysis for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the Highway Capacity Manual (HCM), to the REL signalized intersection of E. Twiggs St.)
- Travel time reliability (using segment level travel time reliability analysis for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St.)
- Queue length (maximum queue length measured lane by lane from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St.)
- Delay (average delay for auto mode: compared to the average delay data obtained during *before implementation*, as explained under Section 6)
- Throughput (for auto mode, from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St.)
- Percent (%) arrival on green (at REL off-ramp exit and E. Twiggs St.)

4.2.2 Safety

In order to determine the safety benefits for UC1, the following performance measures are considered for the REL/Twiggs/Meridian Intersection only:

- Crash reduction / crash rate
- Type of conflicts / near misses
- Severity of conflicts / near misses
- Approaching speed on REL

Changes in safety for the REL segment will be analyzed through a collection of vehicle crash rates by type and severity and by assessing changes in vehicular conflicts and near misses for the before and after CV deployment scenarios. In addition, the approaching vehicle speed on the REL will also be taken into account for the safety performance measurement analysis, since this approach speed will be a good indication of whether the equipped vehicles receive and react to the CV advanced warning of a queue forming on the REL.

4.2.3 Emissions

To determine environmental benefits for UC1, the following performance measures will be considered:

- Changes in idle speed emissions
- Changes in running emissions

Changes in vehicle emission will based on changes in vehicle travel (i.e., changes in speed, idle time) and applied to customized emission rates obtained through the Environmental Protection Agency Motor Vehicle Emission Simulator (MOVES) modeling system [2]. Section 8 discusses the approach to MOVES customization to reflect the CV pilot study area baseline environmental and travel conditions.

4.2.4 Agency Efficiency

In order to determine the agency efficiency benefits for UC1, the research team will be required to analyze the following performance measures:

- Mobility improvements observed from mobility performance measures described above
- Safety improvements observed from safety performance measures described above
- Customer satisfaction through opinion survey and/or CV app feedback

4.3 Use Case 2 (UC2) – Wrong-Way Entries

At the exit of the REL on East Twiggs Street, drivers can become confused and attempt to enter the REL going the wrong way. At present, there are no gates or barriers at the REL exit to prevent drivers from entering the REL going the wrong way. To effectively measure the mobility, safety, environmental and agency efficiency benefits that can be obtained through the CV deployment, the following performance measures will be considered.

4.3.1 Mobility

For the analysis of UC2, two mobility-specific performance measures will be used: vehicle travel time delay on REL (measured in seconds/minutes), and travel time delay on the adjacent arterial (measured in seconds/minutes), and will be analyzed for the before and after CV deployment scenarios. Mobility benefits for UC2 will be measured by analyzing:

- Travel time delay on REL (average delay for auto mode: measured from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St., and compared to the average delay data obtained during *before implementation*, as explained under Section 6)
- Travel time delay on adjacent arterial (average delay for auto mode: from N. Nebraska Avenue to N. 12th Street intersections on E. Twiggs St. This delay is compared to the average delay data obtained during *before implementation*, as explained under Section 6)

4.3.2 Safety

Crash reduction for the East Twiggs Street at REL segment will be analyzed through vehicle crash rates along with the type of vehicular conflicts and near misses for the before and after CV deployment. In addition, the approaching vehicle speed on East Twiggs Street will be measured to assess safety performance, since the approach speed will be a good indication of whether the equipped vehicles receive and react to the CV warning.

To determine the safety benefits for UC2, the research team will be required to analyze the following performance measures:

- Crash reduction / crash rate on East Twiggs Street
- Type of conflicts / near misses East Twiggs Street
- Number of wrong way entries and frequency

4.3.3 Environment

To determine environmental benefits for UC2, the following performance measures will be considered:

- Changes in idle speed emissions
- Changes in running emissions

Additionally, the agency efficiency performance measurement will be a combination of analysis derived from the mobility and safety measures, along with the customer satisfaction analysis through opinion survey and/or CV app feedback.

4.3.4 Agency Efficiency

To assess agency efficiency gains, the following performance measures will be considered:

- Mobility improvements observed from mobility performance measures described above
- Safety improvements observed from safety performance measures described above
- Customer satisfaction through opinion survey and/or CV app feedback

4.4 Use Case 3 (UC3) – Pedestrian Safety

There is one primary crosswalk for pedestrians to traverse the distance between the parking garage and the courthouse. The crosswalk is marked and has only a yellow flashing light to warn drivers that they are approaching a crosswalk. This crosswalk is the primary route for jurors, lawyers, and other people to get to/from the courthouse. During morning rush hour, potential jurors and courthouse employees try to find parking to reach the courthouse on time. Increased congestion is encountered on Mondays and Tuesdays when new juror pools of up to 400 persons are required to report during rush hour. Many are not familiar with the area and may not be paying attention to the crosswalk. Lack of attention by drivers and pedestrians causes a safety concern for pedestrians trying to reach the courthouse.

For the analysis of UC3, addressing all four pillars of performance measurement, including mobility, safety, environment, and agency efficiency, is necessary.

4.4.1 Mobility

Under the mobility pillar, mobility specific performance measures, such as vehicle travel time and vehicle travel time reliability on the segment of roadway in which the crosswalk is located will be analyzed before and after CV deployment. In addition, the determination of maximum vehicle queue length in feet and average vehicular delay in seconds/minutes will be measured. The deceleration rate of vehicles will be taken into account for this UC, since it could be inferred that if there is a sudden deceleration (sudden application of brakes and/or vehicle deceleration rates of 11 ft/s^2), it is likely that the slowdown was to prevent an accident. To determine the mobility benefits, the following performance measures will be considered:

- Travel time (using segment level travel time analysis for auto mode: from REL exit at E. Twiggs St. to N E St.)
- Travel time reliability (using segment level travel time analysis for auto mode: from REL exit at E. Twiggs St. to N E St.)
- Queue length (maximum queue length measured lane by lane from REL exit at E. Twiggs St. to N E St. The queue lengths are projected to be higher in the after CV implementation case compared to the before scenario, because drivers will get warnings and are projected to react to the warnings by stopping more often for pedestrians than in the before CV implementation case. However, the safety aspect is projected to be better. We anticipate there will be some compromise between mobility and safety.)
- Vehicle Delay (average delay for auto mode: compared to the average delay data obtained during *before implementation*, as explained under Section 6)
- Throughput (for auto mode: from REL Exit at E. Twiggs St. to N E St.)

4.4.2 Safety

For safety, crash reduction for the segment that includes the crosswalk will be analyzed using vehicle crash rates with other vehicles and pedestrians, along with the type and severity of vehicular conflicts and near misses for the before and after CV deployment scenarios. In addition, the approaching vehicle speed towards the crosswalk will also be taken into account for the safety performance measurement analysis, since this approach speed will be a good indication of whether the equipped vehicles receive and react to the CV advanced warning of a pedestrian ready to step into the crosswalk. To assess the safety benefits, the following performance measures will be measured:

- Crash reduction / crash rates between vehicles and between vehicles and pedestrians
- Type of conflicts / near misses between vehicles and between vehicles and pedestrians
- Severity of conflicts / near misses between vehicles and between vehicles and pedestrians
- Reduction in approach vehicle speed towards crosswalk

4.4.3 Environment

In order to determine the environmental benefits for UC3, the research team will analyze the following performance measures:

- Changes in idle speed emissions
- Changes in running emissions

4.4.4 Agency Efficiency

In order to determine the agency efficiency benefits for UC3, the research team will analyze the following performance measures:

- Mobility improvements observed from mobility performance measures described above
- Safety improvements observed from safety performance measures described above
- Customer satisfaction through opinion survey and/or CV app feedback

4.5 Use Case 4 (UC4) – Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety

Marion Street, a two-lane street, is a primary bus route, which on the north end terminates at the Marion Transit Center. HART operates several routes that converge onto Marion Street, all headed to the Marion Street Transit Station. Along these routes, many of the bus stops are on the approach to an intersection. When there is congestion, buses are unable to reach their stops, causing them to potentially fall behind schedule. CV technology will be used to address the mobility concerns from scheduling delays. For the analysis of UC4, three sets of performance measurement will be considered: mobility, environment; and, agency efficiency.

4.5.1 Mobility

Under the mobility pillar, a set of mobility specific performance measures, such as bus travel time and bus route travel time reliability of its route, will be analyzed for the before and after CV deployment scenarios along with the determination of percent bus arrivals on schedule, and percent bus arrivals on green for the before and after CV implementation cases. To assess mobility benefits, the following performance measures will be addressed:

- Bus travel time (average using segment level analysis for transit/bus mode: along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
- Bus route travel time reliability (average using segment level analysis for transit/bus mode: along the travel segments of Marion Street, staring from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
- Percent (%) arrival on schedule (at bus stops along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
- Percent (%) arrival on green (at signalized intersections along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
- Signal Priority: (at signalized intersections along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Street Transit Center)
    - Number of times priority is requested and granted
    - Number of times priority is requested and denied
    - Number of times priority is requested, granted and then denied due to a higher priority

4.5.2 Safety

UC4 is specific to mobility, environment, and agency efficiency. Safety is neither a primary concern nor motivation for deployment in this UC, therefore, no safety metrics were identified for analysis.

4.5.3 Environment

The environmental performance measurement for UC4 will be based on the reduction in transit vehicle emissions on the route before and after CV implementation. Additionally, the agency efficiency performance measurement will result from a combination of analysis from the mobility pillar along with the customer satisfaction analysis through an opinion survey and/or CV app feedback. To determine the environmental benefits, the following performance measures will be considered:

- Changes in idle speed emissions
- Changes in running emissions

4.5.4 Agency Efficiency

To determine the agency efficiency benefits, the following performance measures will be tracked:

- Mobility improvements observed from mobility performance measures described above
- Customer satisfaction through opinion survey and/or CV app feedback

4.6 Use Case 5 (UC5) – TECO Line Streetcar Trolley Conflicts

The TECO Streetcar runs along Channelside Drive from the Amalie Arena area up Channelside Drive, North, past the Selmon Expressway. The streetcar rides on rails, is electrically powered, and is in a dedicated lane. As a result, at various stops along the streetcar route, vehicles may have to turn right in front of a stopped streetcar. As the pedestrians disembark from the streetcar, and the streetcar prepares to startup, it is possible a vehicle may turn right in front of the streetcar. Pedestrians may be crossing the intersection where the vehicle is turning right as well. The potential of a streetcar and vehicle crash and a pedestrian incident are safety concerns. CV Technology will be used to provide information to streetcar operators, drivers, and pedestrians to improve safety around these locations. For the analysis of UC5, two pillars of performance measurement, safety and agency efficiency, will be considered.

4.6.1 Mobility

No mobility measurements were identified for this use case.

4.6.2 Safety

UC5 is specific to safety and agency efficiency. Safety in the area surrounding the Amelie Arena area north on Channelside Drive, and along the Selmon Expressway segment will be analyzed by measuring changes in vehicle/pedestrian vs. TECO Streetcar crash rates along with the type of the conflicts and near misses these modes had for the before and after CV deployment scenarios. The following safety performance measures will be considered:

- Crash reduction / crash rate
- Type of conflicts / near misses
- Severity of conflicts / near misses

4.6.3 Environment

UC5 is specific to safety and agency efficiency. No environmental measurements were identified for this use case.

4.6.4 Agency Efficiency

The agency efficiency performance measurement will be based on a combination of analysis from the safety data and metrics along with customer satisfaction analysis through a survey and/or CV app feedback. To assess agency efficiency benefits for UC5, the following performance measures will be considered:

- Safety improvements observed from safety performance measures described above
- Customer satisfaction through opinion survey and/or CV app feedback

4.7 Use Case 6 (UC6) – Enhanced Signal Coordination and Traffic Progression

There is significant congestion and delay along Meridian Avenue during morning peak travel periods. Adding to this issue is a large number of MAFB commuters traveling through downtown on the Selmon Expressway or arterial routes, trying to reach one of four MAFB entrance gates without knowledge of the travel times for their route versus other routes or the length of the queue at each gate. As some of these commuters are using surface roads through downtown, they interact with other traffic and pedestrians. With this increase in traffic, the potential for pedestrian incidents increases, creating a safety concern. CV technology will be used to improve the mobility and safety through the downtown area. For the analysis of UC6, all four pillars of performance measurement, namely mobility, safety, environment, and agency efficiency, will be addressed.

4.7.1 Mobility

Under the mobility pillar, mobility specific performance measures, such as vehicle travel time and vehicle travel time reliability of the Meridian Avenue will be analyzed for the before and after CV deployment scenarios along with the determination of vehicle queue length in feet and vehicular delay in seconds/minutes. Additionally, the vehicle percent arrivals on green will be determined and analyzed for the before and after conditions. To determine the mobility benefits, the following performance measures will be considered:

- Travel time (using segment level travel time analysis for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the Channelside Dr. signalized intersection on Meridian Avenue)
- Travel time reliability (using segment level travel time reliability analysis for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the Channelside Dr. signalized intersection on Meridian Avenue)
- Queue length (maximum queue length measured lane by lane from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per HCM, to the Channelside Dr. signalized intersection on Meridian Avenue)
- Delay (average delay for auto mode: compared to the average delay data obtained during *before implementation*, as explained under Section 6)
- Throughput (for auto mode, from the beginning of the REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the Channelside Dr. signalized intersection on Meridian Avenue
- Percent (%) arrival on green (at all signalized intersections from the beginning of REL off-ramp exit to the Channelside Dr. signalized intersection on Meridian Avenue)

4.7.2 Safety

For safety, crash reduction for the REL segment will be analyzed through vehicle crash rates along with the type and severity of vehicular conflicts and near misses for the before and after CV deployment scenarios in order to perform the safety performance measurement. In addition, the approaching vehicle speed on REL will be taken into account for the safety performance measurement analysis, since this approach speed will be a good indication of whether the equipped vehicles receive and react to the CV advanced warning of a queue forming on the REL.

To assess the safety benefits, the following performance measures will be considered:

- Crash reduction / crash rate
- Type of conflicts / near misses
- Severity of conflicts / near misses
- Vehicle speed on Meridian Ave through all intersections in study area

4.7.3 Environment

To determine the environmental benefits, the following performance measures will be considered:

- Changes in idle speed emissions
- Changes in running emissions

4.7.4 Agency Efficiency

To determine the agency efficiency, the following performance measures will be addressed:

- Mobility improvements observed from mobility performance measures described above
- Safety improvements observed from safety performance measures described above
- Customer satisfaction through opinion survey and/or CV app feedback

Table 4-1 provides a snapshot of the performance measures to be addressed.

4.8 Performance Measure Targets

As detailed in the approved ConOps, it will be challenging to set performance targets. This is because the CV Pilot project is without precedent. For example, the degree of improvement due to mobility apps deployment will depend on the efficiency conditions of the current or baseline the traffic network conditions. For users, with traffic signal preemption, improvements in trip time over the signalized network might be as high as 15 percent, though some loss of efficiency on the side streets may occur. Signal system improvements of 10 percent would be considered quite effective in carefully managed traffic signal systems like Tampa's. The study will assess the current baseline and determine the project improvements. Generic mobility improvements in the neighborhood of 10 percent will be considered acceptable. Though no prescribed precise goal is definitive at this stage, improvements are expected.

It is unlikely that safety will be directly measureable from the small numbers of incidents that will occur within the study limits. The relatively small samples of reported incidents and confounding factors (e.g., weather) will make statistically significant safety performance measures a challenge. Therefore, for this type of experimental setting, targets might not be achieved or meaningful. For instance, accident avoidance, measured by the number of alerts, may be more important than the number of incidents. This is expected to occur with processing the BSM data. Other surrogate parameters, such as the frequency of alerts, user experience and satisfaction with the app, ratings of distraction or helpfulness, and how an app might be improved will be measured by user surveys.

Table 4-1 Summary of Performance Measures

Performance Pillars	*Performance Measures*	*UC1 Morning Peak Hour Queues*	*UC2 Wrong Way Entries*	*UC3 Pedestrian Safety*	*UC4 Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety*	*UC5 TECO Line Streetcar Trolley Conflicts*	*UC6 Enhanced Signal Coordination and Traffic Progression*
Mobility	Travel time	✓	✓	✓			✓
	Travel time reliability	✓		✓			✓
	Queue length	✓		✓			✓
	Vehicle delay	✓	✓	✓			✓
	Throughput	✓		✓			✓
	Percent (%) arrival on green	✓			✓		✓
	Bus travel time				✓		
	Bus route travel time reliability				✓		
	Percent (%) arrival on schedule				✓		
	Signal priority: - Number of times priority is requested and granted - Number of times priority is requested and denied - Number of times priority is requested, granted and then denied due to a higher priority (i.e. EMS vehicle)				✓		
Environmental	Emissions reductions in idle	✓	✓	✓	✓		✓
	Emissions reductions in running	✓	✓	✓	✓		✓
Safety	Crash reduction	✓	✓	✓		✓	✓
	Crash rate	✓	✓	✓		✓	✓
	Type of conflicts / near misses	✓	✓	✓		✓	✓
	Severity of conflicts / near misses	✓		✓		✓	✓
	Percent (%) red light violation/running		✓				
	Approaching vehicle speed	✓	✓	✓			✓
	Number of wrong way entries and frequency		✓				
Agency Efficiency	Mobility improvements through the mobility pillar analysis	✓	✓	✓	✓		✓
	Safety improvements through the safety pillar analysis	✓	✓	✓		✓	✓
	Customer satisfaction through opinion survey and/or CV app feedback	✓	✓	✓	✓	✓	✓

5 Confounding Factors

5.1 Introduction

This section identifies confounding factors that are likely to affect the performance measurement plan.

5.2 Identification of Confounding Factors

The accuracy and effectiveness of performance measurement depends on the presence of concurrent confounding factors [3]. Confounding factors are any events that might arise during the pilot implementation, which can be associated with having an apparent effect on some dependent variables of interest (i.e., performance measures). In a design experiment, confounding factors that are not accounted for during design could either understate or overstate the relevance of treatment effects upon treated units. In extreme cases, confounding factors can lead to spurious relationships between explanatory and dependent variables, with the variables having no direct causal connection, while it may be wrongly inferred that they do.

Two types of confounding factors are likely to arise from the pilot implementation:

1. Study-area specific factors (e.g., climate, special events)
2. Deployment-specific factors (e.g., participant specific, technology-specific)

Factors that can a-priori (i.e., before pilot implementation) be identified, recorded and measured are defined as observed factors. Factors that cannot be directly observed or measured are defined as unobserved factors. During performance measurement and statistical modeling, observed factors can be accounted for by their proper inclusion as explanatory variables and modeling method, while unobserved factors can be accounted for by utilizing appropriate statistical techniques to reduce omitted-variable bias.

5.3 Study Area-Specific Factors

Given the longitudinal aspect of the pilot deployment, several time-variant factors and events that are specific to the area will be accounted for, spanning from seasonal weather to planned events in the study area main points of attraction, to planned construction development plans, and seasonal cruise line tourism. These factors have the potential to generate confounding information across all Use Cases by influencing individual travel behavior.

5.3.1 Weather

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 thunderstorms may last for only a few moments to several hours or even for an entire day. During the summer, average monthly rainfall increases to about 7.5 inches from the winter average of 2.5 inches. In addition, rain precipitation can be above average even during the winter months. For example, in January 2016, rain precipitation was 6.2 inches, compared to the historical 2.2-inch average. Precipitation is not homogenous in the Tampa Bay Area, and tends to be higher near bodies of water. Localized weather conditions can have spatially heterogeneous effects on travel behavior. For example, thunderstorms 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. Figure 5-1 presents average daily rain precipitation for January 2016 and shows that precipitation in the Brandon Area, where most of the THEA morning peak traffic originates, was higher than in the CV pilot area of Tampa CBD.

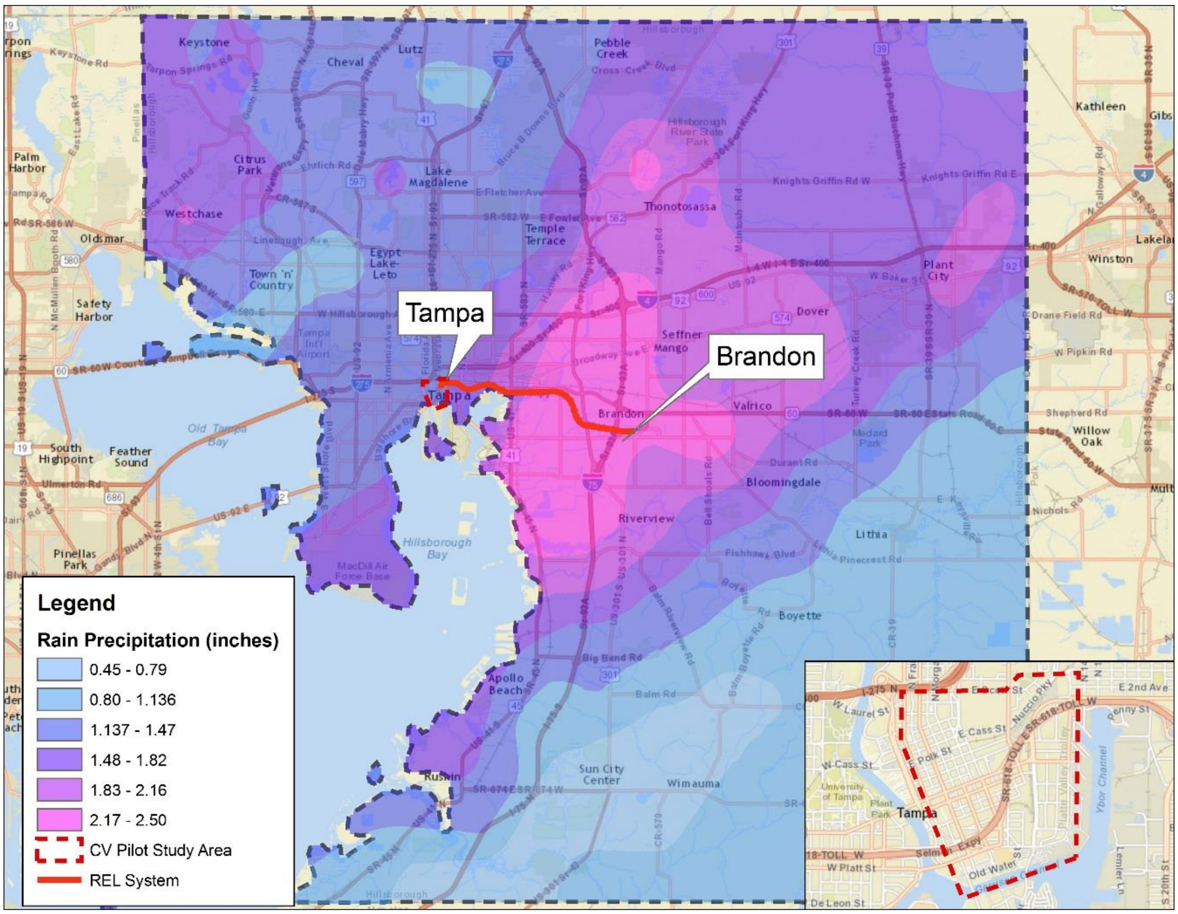

Figure 5-1 Average Daily Precipitation – January 2016

Source: NOAA Advanced Hydrologic Precipitation Service[4]; CUTR

To control for weather-related factors at the aggregate level, a daily data log recording temperature, observed precipitation, and other weather related occurrences will be maintained throughout the study period. Data will come from the National Oceanic and Atmospheric Administration (NOAA) Advanced Hydrologic Precipitation Service. Observed daily precipitation data will be obtained using NOAA data series, which rely on a multisensory approach to measure hourly precipitation. NOAA precipitation data will be complemented by additional weather information to provide a more detailed picture of overall road weather.

In addition to NOOA precipitation, data from online sources, which provide information via Automated Protocol Interface (API), will be gathered. Several online weather forecasting sites provide tiered API subscription services. The following information can be queried using geographic coordinates identifying the location of the use case:

- Current conditions
- Hourly 1-day forecast
- Satellite thumbnail
- Dynamic Radar image
- Severe alerts
- Webcams thumbnails
- Dynamic animated Radar image
- Dynamic animated Satellite image
- Current Tropical Storms

Current condition data provide time-stamped information on current temperature, weather condition, humidity, wind, 'feels like' temperature, barometric pressure, and visibility. The API output can be either in Extensible Markup Language (XML)l or Java Script Object Notification (JSON) format, which can be redacted into database format to comprise the weather log dataset. The dataset will be then used to merge weather information with the travel datasets.

At the disaggregate level, vehicle BSM windshield wiper data may be used if available to ascertain the presence and severity of rainfall. Finally, weather data will be linked to the person/vehicle data in preparation of performance measurement and reporting.

5.3.2 Special Events

The CV Pilot Study Area is site to several attractions, which 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. Figure 5-2 shows the location of these points of interest.

Figure 5-2 City of Tampa Attraction Sites

Source: CUTR

The Tampa Convention Center is a 600,000-square foot facility with a 200,000-square foot exhibit hall. It is located south of the CV Pilot area, along Channelside Drive and is served by the THEA Selmon Expressway and by the TECO Streetcar. There are major planned events for 2016-2017, including:

- 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)

These are recurring events that are likely to be planned in 2018.

The Straz Center, located at the edges of the western study area, is a 335,000-square foot venue providing a variety of cultural events and educational programs. In 2014, the Center attracted about 74,000 participants in educational activities and held about 1,200 events. The Amalie Arena (formerly known as the Tampa Bay Times Forum) is an event facility used for sporting and concert events.

The Cruise Pier, part of the Port of Tampa, is the homeport of five vessels from four cruise lines attracting more than 600,000 passengers annually (average 67,000 monthly) to travel on a variety of 4, 5, 7, and 14-day cruise itineraries.

In addition, each year at the end of January, the City of Tampa hosts the Gasparilla Pirate Festival, an annual historical celebration that attracts on average about 300,000 visitors, with attendance increasing in the last few years due to increased marketing efforts.

5.3.3 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 in a walkable, multimodal, and wellness centered city. Construction is scheduled to break ground in 2016 with its first phase completed within five years. As a result, traffic patterns might be affected by construction mitigation plans, changing commuters' habitual travel patterns.

All of the above study area-specific factors will be accounted for by recording the time and date of the event, and recording any quantitative traffic information relating the planned and unplanned event to change in traffic patterns/levels.

5.4 Deployment-specific factors

Deployment-specific confounding factors include all those factors or events that can be potentially triggered by the Pilot implementations. These include equipment malfunction instances as identified by the ConOps Failure/Anomaly/Exception Conditions and Safety Plan, and induced errors by linking data across platforms. Other confounding factors are likely to be introduced by participant identification and selection, their personal use of installed vehicle equipment, and improper use of downloaded applications.

5.4.1 ConOps Failure and Anomaly Conditions

ConOps Failure/Anomaly/Exception Conditions, which are specific to each use case activation conditions, are expected to arise when CV technologies, system, or devices are operational and in use during the activation phases, as described in the ConOps.

5.4.2 ConOps Maintenance Conditions

During the Pilot deployment, maintenance conditions are expected to arise, which will require temporarily "turning off" the CV technology/system/device(s) during the time period where activation conditions will be present. Two types of maintenance situations are likely to occur: 1) Maintenance due to device failure (unexpected); and, 2) Planned system maintenance (expected). Unexpected maintenance conditions will require communication to the affected user(s) and prompt action to minimize the confounding effect. Scheduled maintenance will be conducted during expected normal conditions. When designing and planning maintenance capabilities, consideration for potential impacts to safety-related functionality will be included to eliminate or minimize potential safety risks.

5.4.3 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 will be identified during the data recording and cleaning process prior to performance measurement.

5.5 Experimental Design-Induced Confounding Factors

Participants in the CV Pilot deployment will include drivers, pedestrians, and bus and trolley operators. Although the primary objective of experimental design is to minimize the presence and influence of confounding factors, the experimental design approach, under use case-specific constraints, is likely to introduce some form of error in the form of:

- Participant self-selection
- Participant attrition
- Participant moral hazard

5.5.1 Participant Self-Selection

Participant recruitment identifies a treatment and control group following the suggested experimental design as discussed in Section 6 of this document. The recruitment goal is to select a pool of participants where treatment and control groups are randomly selected from a sample of participants that is representative of the users of a particular system. In reality, when sending out requests to participate in the Pilot study, some individuals, due to their specific socio-economic, residential location, and travel behavior characteristics, will tend to self-select to either participate or exclude themselves from the study. Though the experimental design approach will minimize the difference between treatment and control units, self-selection will still be an issue, as it will also depend upon the adopted recruitment approach (e.g., phone, internet, snail mail, shopping center boot, etc.)

5.5.2 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) will be employed to reduce the impact of ensuing confounding factors.

5.5.3 Participant Moral Hazard

Other confounding factors are likely to arise due to participant moral hazard that might be induced by CV equipment or application. Moral hazard is a situation where an individual might undertake a riskier behavior, knowing that it is protected against a risky situation. For example, pedestrians might push into the crosswalk to assess the Pedestrian Mobility alert’s sensitivity in order to gain some advantage in crossing the street, thus increasing the risk exposure. Car drivers may similarly push the limits of their apps and take unnecessary risks.

Participant recruitment can reduce the impact of confounding factors due to moral hazard. In addition, selected participants will be advised of the limits of the technology and will be required to sign an Informed Consent Form to participate that will explain the limits of the technology and their liability in using the app not as prescribed.

6 System Deployment Impact Evaluation Design

6.1 Introduction

This section details the proposed system deployment impact evaluation design to account and control for the confounding factors identified in Section 5. It discusses the applicable methods and modeling techniques that will be employed to evaluate performance of each of the six use cases. As discussed in Section 5, the presence of confounding factors is likely to pose a challenge in the assessment of the quantitative performance measures and targets identified in Section 4.

The CV pilot deployment provides a unique opportunity to implement a scientific experimental design approach to optimize the level of control upon observed and unobserved confounding factors. An *experiment* is a test or series of tests in which ad-hoc changes are made to the input variables of a process to purposefully observe and identify the reason for changes that may be observed in the output response [5].

Following the literature, the event for which we want to estimate and quantify the causal effect is defined as the *treatment*. It follows that a *treatment group* is a group that receives the treatment or the intervention. In the CV pilot deployment, the treatment group is the group that is exposed to the application(s) being tested. The *outcome* indicates the variable(s) that is used to measure the effect of the treatment. In the CV pilot, the outcome denotes the quantifiable performance measure(s) (i.e., travel time delay, accident reduction).

A well-designed experiment is important because the results and conclusions that can be drawn depend to a large extent on the manner in which the experiment is laid out and the data were collected. A statistical design of experiments is a process of planning the experiment so that appropriate data can be analyzed by appropriately choosing statistical methods, resulting in valid and objective conclusions. AADT

Furthermore, the pilot will be implemented over time, likely to span over two years. This means that time will be an important variable used to distinguish group participation and to gauge the impact on performance measures. The passage of time, on the other hand, can introduce additional confounding factors, such as the presence of time-variant unobservable events that could mask the true performance of CV technologies.

6.2 Experimental Strategies

In an ideal context, confounding factors can be controlled for by conducting counterfactual analysis via random experiment design. Counterfactual modeling measures the potential outcome in the absence of an intervention, such as the implementation of the CV connected technology. Empirically, there are different options for assessing the counterfactual, ranging from a simple before vs. after comparison of outcomes to measuring responses in the context of a random experiment design. The applicability of each approach is contingent upon the baseline characteristics of each use case defined in the ConOps.

This plan identifies three approaches to control and minimize the impact of study-area specific and deployment-specific confounding factors:

1. Random Design
2. Quasi-Experimental Design
3. Before and After Comparison (Time Series Analysis)

6.2.1 Random Design

In a completely randomized design, study participants are randomly drawn from a representative sample of users and randomly assigned to a treatment group and a control group. The treatment group comprises those individuals who are assigned to the intervention (i.e., the treatment) and the control group consists of those individuals who are assigned to be excluded from the intervention. Random assignment to the treatment and control groups ensures the two groups are similar and have the same probability of being assigned to either one of the groups. Each unit has one outcome that would manifest if the unit were exposed to the treatment and another outcome that would manifest if the unit were exposed to the control. The *treatment effect* is the difference between these two potential outcomes. However, the individual-level treatment effect is unobservable because individual units can only receive the treatment or the control, but not both. Random assignment to treatment ensures that units assigned to the treatment and units assigned to the control are identical (over a large number of iterations of the experiment). Indeed, units in both groups have identical distributions of covariates (i.e., explanatory variables) and potential outcomes. Thus, the average outcome among the treatment units serves as a counterfactual for the average outcome among the control units. The differences between these two averages is the average treatment effect (ATE), which is an estimate of the central tendency of the distribution of unobservable individual-level treatment effects. If a sample is randomly drawn from a population, the ATE from the sample is also an estimate of the population ATE. In a fully randomized experiment for the CV Pilot, the ATE would then be:

$$ATE = (T_1^A - T_0^N) - (C^A - C^N)$$

where T_1^A is treatment at CV technology activation (A); T_0 is treatment at normal conditions; C^A is control at CV activation; C^N is control at normal conditions. In the ConOps, normal conditions (N) are those conditions characterized by *a "no problem" or "no issue" perspective, without any initiation of the proposed CV technologies, which is as the system operates today*. Activation conditions (A), are those "*conditions that activate or trigger the CV application*." Note that in the context of this experimental design, those participants selected as controls will have CV applications installed, but the equipment will not be activated to send out warnings. Section 6.3.2 provides details in discussing the preferred experimental design to assess UC1.

While an experiment ensures, in expectation, that potential outcomes (and all covariates) are equivalently distributed in the treatment and control groups, this is not the case in an observational study. In an observational study, units are not assigned to treatment and control randomly, so their assignment to treatment may depend on unobserved or unobservable factors. Observed factors can be statistically controlled (e.g., through regression or matching), but any estimate of the ATE could be confounded by unobservable factors that influenced which units received the treatment versus the control.

During the CV Pilot deployment, full random assignment of participants might be very hard to achieve due to several constraints. For example, in some use cases where users will be adopting an app, it will be difficult if not impractical to determine which individual can be assigned to receive information from the app at any given time. In other use cases where individual recruitment is necessary in order to proceed to CV technology installation within the vehicle, implementation of a randomized design may be feasible. When a fully randomized experimental design cannot be implemented, performance measurement will be based on a quasi-experimental approach.

6.2.2 Quasi-Experimental Design

Whenever random assignment to treatment and control group cannot be achieved, bias in the selection arises. For example, this situation could arise when sampling participants to UC1 (morning backups), as discussed in the next section. Furthermore, self-selection can also occur, which could result in a pool of participants where random assignment to treatment and control might not be achievable. Self-selection leads to bias. If this bias is not controlled for, then statistical inference and estimation of performance measures can either underestimate or overestimate the relevance of a given deployed CV technology.

In this event, quasi-experimental design approaches will be adopted to minimize the bias introduced by not randomly matching treatment and control groups. Quasi-experimental methods share many characteristics of randomized experiments, with the exception that they do not use random assignment. Quasi-experiments can be more representative of real world conditions, such as when only participants who are willing to be randomly assigned to treatment are available and might form an unrepresentative subset of all participants. However, one of the major disadvantages of quasi-experiments is that the estimates of treatment effects that they produce may not be unbiased. This is because the nonrandom selection process can result in difference between groups that can be mistakenly ascribed to treatment effects (e.g., the efficacy of CV technology in improving mobility, when mobility improvements might not be realized).

In the empirical literature, several approaches have been developed to reduce this selection bias. The most widely used methods fall within propensity score matching (PSM). PSM is a non-experimental method employed to select comparable units of observation for estimating intervention impacts using comparison group data. Since first introduced by Rosenbaum and Rubin [6], PSM techniques have been applied in several fields of research, such as to study the impact of training on labor wage differentials and to estimate the impact of welfare programs [7]. It has also been used to evaluate the impact of transportation investments on land-use [8], employment [9], and population growth [9, 10]. For example, Funderburg et al. [10] used PSM to select a set of comparable census tracts to use as controls in evaluating the impact of transportation infrastructure investments on employment and population growth.

Quasi-experimental approaches have been increasingly used to reduce estimation bias and to economize on behavioral specification complexity and data requirements. For example, Rephann and Isserman [11] devised methods to match control to treatment counties for policy evaluation of infrastructure investments on county development. At a less aggregate level, Concas [8] used propensity score matching to analyze the impact of transportation infrastructure improvements on residential and commercial property prices.

The proposed approach is to use propensity score matching to match controls to treatment. To identify suitable controls, the first step is to estimate the propensity score for each treatment and potential control by running a logistic regression with the dependent variable set to Y=1 if the individual is selected as part of the treatment group and Y=0 if otherwise (i.e., the rest of the participants), and using a set of controls as explanatory variables. The controls or explanatory variables would include socio-demographic factors, variables describing the individual current travel behavior, vehicle stock information. In a parametric model, the propensity score is the predicted probability:

$$\hat{p} = \frac{e^{(\hat{\alpha}+\hat{\beta}'x)}}{1-e^{(\hat{\alpha}+\hat{\beta}'x)}} \quad (1)$$

where $\hat{\alpha}$indicates the intercept parameter estimate, $\hat{\beta}$ represents the vector of parameter estimates, and *x* is the vector of explanatory variables (e.g., the socio-demographic variables).

To ensure the best selection of controls, the performance plan will also employ a data-driven approach, to derive a non-parametric propensity score. This study will use the nonparametric conditional density estimation method discussed in Li and Racine [12] and implemented by the R *np* package [13]. The use of nonparametric generated propensity score in addition to the logistic regression generated propensity score is intended to ensure a robust selection of matched controls.

6.2.2.1 Choice of Matching Algorithms

The logistic regression and the nonparametric regression scores are used to in this step to find the matching controls by applying a set of matching algorithms. Using the estimated propensity scores (from the logistic and from the nonparametric regressions), three different matching algorithms will be applied: 1) a nearest neighbor matching (one-to-one without replacement); 2) the global minimization algorithm based on Ming and Rosenbaum [14]; and, 3) the genetic matching method of Abadie and Imbens [15]. Matching is conducted using the *R MatchIt* package [16].

The nearest neighbor employs a “greedy” algorithm to cycle through each treatment unit (T) one at a time, selecting the control unit (C) with the smallest distance to the treatment unit (T). The global minimization algorithm treats the distance between treatment and potential controls as a cost from going from one node to another over a network. The problem requires assigning distances to each node and finding the path that minimizes the total distance. Rosenbaum and Rubin [6] argued that the collection of matches found using optimal matching can have substantially better balance than matches found using greedy matching, without much loss in computational speed. Genetic matching automates the process of finding by implementing matching with replacement using the method of Abadie and Imbens [15] where balance is determined by a set of two univariate tests, paired t-test for dichotomous variables and a Kolmogorov-Smirnov test for multinomial and continuous variables.

The accuracy of the matching process will be ensured by comparing the differences in means of before vs. after matching and summaries based on quantile-quantile plots that compare the empirical distributions of each explanatory variable.

Finally, the analysis will rank the matched controls based on the number of matching algorithms. This allows further selecting a subset of matched control groups based on the number of matched algorithms.

Non-parametric regression produces a second propensity score upon which the matching algorithms are applied to select the matched controls. Finally, the matched controls identified with the logistic regression score are compared to those identified using the non-parametric regression score. The matched controls will then be selected for quasi-experimental analysis using the Difference-in-Difference approach, as discussed below.

6.2.2.2 Difference-in-Difference (DiD) Approach

Given the longitudinal context of the study, evaluation under randomized design and quasi-experimental will be conducted within a DiD design. DiD is a research design for estimating causal effects from randomized and quasi-experimental designs. It follows from the definition of average treatment effect defined earlier in this document. DiD is widely used in empirical economics, for example, to estimate the effects of policy interventions and policy changes that do not affect everybody at the same time and in the same way.

To analyze the impact on performance measures prices, the proposed general functional specification will be adopted:[1]

$$y_i = \alpha_0 + \alpha_1 T + \alpha_2 YR + \alpha_3 TPH + \beta_k x_k + u_i \qquad (1)$$

where y_i is the mobility performance measure tracked for individual (*i*); *T* is a categorical variable indicating that the individual belongs to the treatment group (*T=1*) or to the control group (*T=0*); *PH* is a time period categorical variable indicating treatment phase (*PH=1* treatment phase, *0*= base or reference); and, x_{ik} is a vector of controls measuring changes study area-specific factors (e.g., changes in weather conditions). The parameter of interest (α_3), the difference-in-differences estimator (DID), measures the difference in housing price over treatment phases and is equal to:

$$\hat{\alpha}_3 = \left(\bar{y}_{PH=1,T=1} - \bar{y}_{PH=1,T=0}\right) - \left(\bar{y}_{PH=0,T=1} - \bar{y}_{PH=0,T=0}\right) \qquad (2)$$

The parameter $\hat{\alpha}_3$ measures the difference in average performance measure (e.g., travel time savings, travel time reliability) between treatment and control groups as a result of CV technology deployment, after controlling for observed and unobserved confounding factors. Essentially, by estimating $\hat{\alpha}_3$, the question we will seek to answer is: What would have happened to the treated units' performance measures had they not been treated with the adopted CV technology?

6.2.3 Before and After Comparison (Time Series Analysis)

This is the least-preferred approach, because it relies only on a comparison of time trends in performance measures (e.g., travel times, risk avoidance), without resorting to a direct identification of treatment and control groups. The goal is to assess if the treatment (i.e., the CV technology deployment) has caused a change in pattern upon the baseline conditions using a pretest-posttest approach. The empirical analysis lends itself to comparing changes in the experimental subjects over time using an interrupted time series approach where the series are broken into intervals representing interventions [17, 18].

[1] For notational convenience the time subscript is omitted

Whenever adopted, the approach will utilize the performance measures data collected over the course of the pilot implementation, with a design strategy focused on the timing of the treatment. In this instance, a first period of data collection will take place, which defines the baseline. In a subsequent period, the treatment (i.e., the CV technology) will be applied as data collection and performance measurement continue. Study-area specific confounding factors are recorded concurrently to serve as explanatory variables in time series statistical analysis.

6.3 Use Case 1 (UC1): Morning Peak Hour Queues

The focus of this use case is on drivers exiting the Selmon Expressway REL at the intersection of Meridian Avenue and Twiggs Street during the morning peak period causing morning backups in the system. As detailed in Section 4, applicable quantitative measures for this use case require data collection and analysis of travel patterns and behavior of drivers and patrons of the Selmon Expressway REL.

6.3.1 Background on Baseline Commuting Patterns

Historical traffic data on the REL section leading to Twiggs Street amount to 11,000 vehicle average annual daily traffic (AADT) in 2014 [19]. AADT on the last section should approximate the number of vehicles coming to the end of the REL. Looking at AADT only, it would be impractical to proceed to the identification of the population of individuals from which to sample treatment and control groups. Although information exists about the current patrons of the THEA Expressway REL, the population of users of the system who travel during those normal conditions described in the ConOps is not known. Secondary, publicly-available data provide some insight about the REL patrons and identify the user population from which to randomly draw a sample.

The U.S. Census Bureau Longitudinal Employer-Household Dynamics (LEHD) program allows conducting spatial analysis of workers' commuting patterns by combining federal, state, and Census Bureau data on employers and employees [20]. Through the *OnTheMap* program, a user can import Geographic Information Systems (GIS)-produced shapefiles identifying specific study areas (i.e., CV Pilot study area) and analyze worker/job commuting patterns. The most recent data is for 2013, which provide a baseline picture of workers' travel patterns to and from the CV Pilot study area. LEHD data can be used to gather information on the potential pool of participants to the Use Case 1 (Morning Backups), Use Case 2 (Wrong Way Entry), and Use Case 6 (Traffic Progression).

According to LEHD, there are a total of 51,770 workers employed in the CV Pilot study area, the vast majority living in surrounding areas, as detailed in Table 6-1. The majority of workers employed in the study area (87.9%) commute to work and travel a distance less than 24 miles. About 15.3 percent commute to the nearby bedroom community of Brandon and surrounding cities of Riverview and Valrico.

Table 6-1 LEHD OnTheMap - Workers Employed in the CV Pilot Study Area

CV Pilot Area Workers	***Count/Freq.***
Working in the CV Pilot Area	51,770
Age 29 or younger	13.7%

Age 30 to 54	61.5%
Age 55 or older	24.8%
Working in the CV Pilot Area but living elsewhere	51,582
Male	39.9%
Female	60.1%
White	78.3%
Black or African American	18.1%
Hispanic or Latino	17.6%
Earning $1,250 per month or less	12.4%
Earning $1,251 to $3,333 per month	28.2%
Earning more than $3,333 per month	59.4%
Living in Brandon, Riverview, Valrico	15.3%
Traveling less than 10 miles	41.0%
Traveling 10 to 24 miles	46.9%

Figure 6-1 is generated using LEHD data to geographically locate where workers employed in the CV Pilot study area reside.

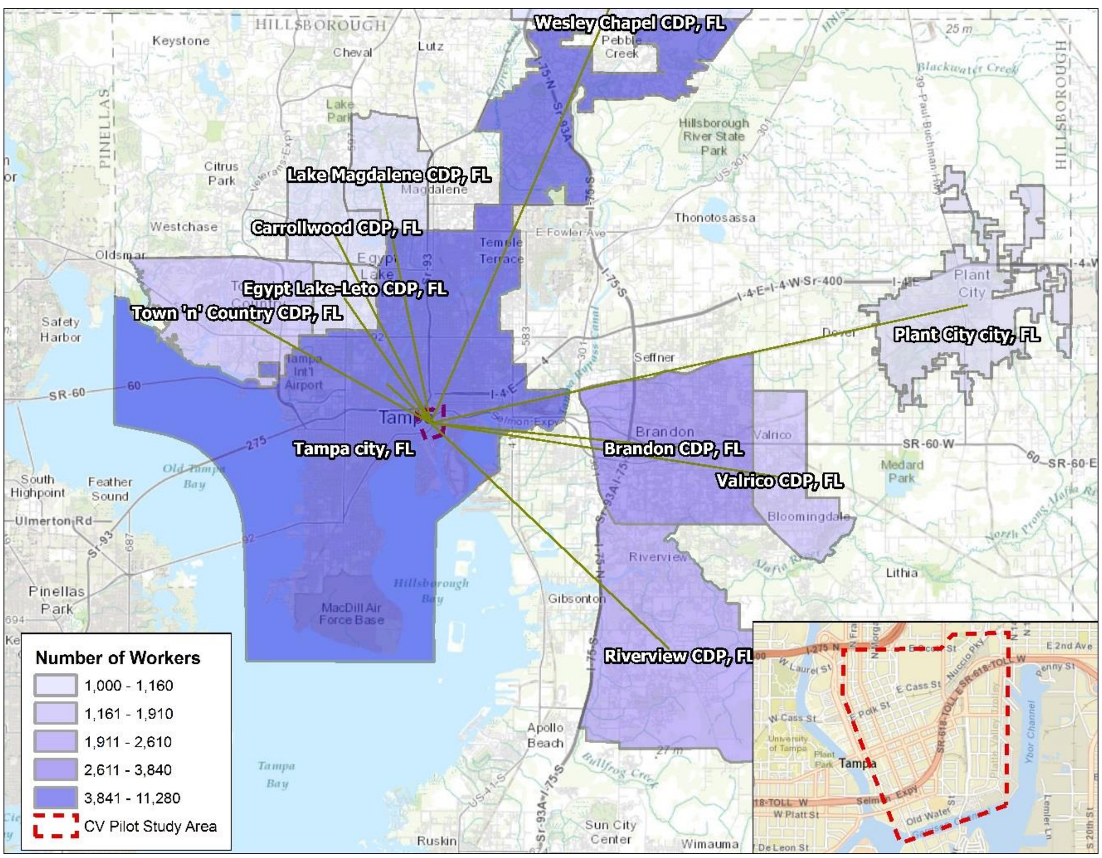

Figure 6-1 CV Pilot Study Area – Workers' Place of Residence

Source: LEHD, CUTR

6.3.2 Recommended Experimental Design

UC1 presents characteristics that can lead, at a minimum, to a quasi-experimental approach, and, in a best-case scenario, to a randomized design experiment (the preferred approach). This is because there is some form of identifying and selecting treatment control participants using the information gathered above. It is recognized that participant recruitment is likely to encounter constraints leading to sample selection from which a fully random sample of controls might not be obtainable. In this case, the second-best approach is the quasi-experiment, leading first to the identification of the treatment group, and, subsequently, to the assembling of a control group that will be matched to the treatment based on propensity score matching methods discussed above.

Given the longitudinal nature of the study, the approach to experimental design will consist of two stages.

6.3.2.1 Stage I

Upon identification of the target population and required sample size (minimum sample size, plus additional buffer due to participant entry/exit), individual participation will be implemented. The experimental design approach will follow these steps:

1. Participant assignment (stratification) to treatment (T) and control (C), where both T and C have vehicles equipped with CSW, EEBL, and FCW
2. Baseline Establishment→ CV Pilot Scenarios:
   I. Normal Conditions ($T_0^N$and C^N), where
      - T_0^N are the treated participants equipped with CSW, EEBL, and FCW but not receiving warnings;
      - C^N are the control the participants equipped with CSW, EEBL, and FCW but not receiving warnings;

   II. Activation Conditions ($T_0^A$and C^A), where
      - T_0^A are the treated participants equipped with CSW, EEBL, and FCW but not receiving warnings;
      - C^A are the control participant equipped with CSW, EEBL, and FCW but not receiving warnings;
3. Data recording and analysis to establish optimal timing of Phase II
   I. Concurrent recording of observable confounding factors

In the ConOps, normal conditions (N) are those conditions characterized by *a "no problem" or "no issue" perspective, without any initiation of the proposed CV technologies, which is as the system operates today*. Activation conditions (A), are those "*conditions that activate or trigger the CV application*."

The goal of Stage I is to establish a baseline where the response in travel behavior of the treatment group during normal and activation conditions can be measured and assessed, before entering Stage II, where the CV technologies will be "turned on" and warnings will be issued during activation conditions. In addition, this baseline stage will provide information as the CV technologies go through the first installation in the participants' vehicles to identify relevant issues at the onset of the Pilot implementation.

6.3.2.2 Stage II

After performance measurement data collection and measurement of Stage I, Stage II will be initiated and timed to mimic Stage I baseline travel behavior conditions. This stage will consist of the following steps:

1. CV Normal Conditions
   I. T_1^N are the treated participants equipped with CSW, EEBL, and FCW and <u>receiving</u> warnings;
   II. C^N are control participant equipped with CSW, EEBL, and FCW but <u>not receiving</u> warnings;
2. CV Activation Conditions where:
   I. T_1^A are treated participants equipped with CSW, EEBL, and FCW and <u>receiving</u> warnings;
   II. C^A are control participant equipped with CSW, EEBL, and FCW but <u>not receiving</u> warnings;

6.3.3 Performance Measurement (Statistical Modeling)

Stage I will allow gathering and measuring performance during CV normal and activation conditions. At the disaggregate level, it will permit measuring individual travel behavior responses of the treated group during normal and activation condition (T_0^A and T_0^N) without receiving warning. This information will be key in order to establish a baseline when comparing the same treatment during normal and activation conditions while receiving treatment (i.e., warnings). It will also allow assessing the control group responses. At a mesoscopic level, Stage I will allow measuring performance along the Selmon Expressway REL and the intersection of Meridian Avenue and Twiggs Street during the relevant peak periods. The measurement of performance at this level will constitute the baseline normal and activation conditions of the use case.

Stage II will allow measuring treatment response to CV pilot implementation during normal and activation conditions. At the disaggregate level, it will allow measuring individual travel behavior responses of the treated group during normal T_1^N and activation condition T_1^A, and the responses of the control group during condition during normal C^N and activation condition C^A. At a mesoscopic level, Stage II will allow measuring performance along the Selmon Expressway REL and the intersection of Meridian Avenue and Twiggs during the relevant peak periods and ascertain improvements (if any) upon the baseline performance measures of Stage I.

To the extent that treatment and control participants are correctly identified, then the following can be estimated for each of the performance measure pillars (Mobility, Safety, and Environment):

A. Average treatment effect on the treated (ATET) = $(T_1^A - T_1^N)$
B. Average treatment effect (ATE) = $[(T_1^A - T_0^N) - (C^A - C^N)]$

While (A) allows measuring individual performance for those treated with CV technologies, it is (B) that will provide the unbiased magnitude of the performance improvements.

Furthermore, (B) can only be achieved by setting up the experiment in two stages, where Stage I has the CV technologies installed but “turned-off” on the treatment group (T_0^N and T_0^A). In Stage II, the CV technologies will be turned-on on the treatment group for the duration of the Pilot implementation (T_1^N

and T_1^A).This process is irreversible, because the ad-hoc turning on and off of any warnings on the treated group would create disruptive behavioral responses leading to an uncontrollable experimental design.

6.4 Use Case 2 (UC2): Wrong-Way Entries

The objective of this use case study is to employ CV technologies to reduce the number or likelihood of wrong-way entries into the Selmon Expressway REL during the period between 6:00 AM and 1:30 PM, when vehicles from the REL transfer to Meridian Avenue in order to enter downtown. Wrong-way drivers have become a significant problem in the Tampa Bay area and are a major safety concern at the State level as well. Potential CV technologies proposed for this location are V2I, V2V and V2X.

6.4.1 Background on Baseline Driver Patterns

According to the activation conditions described in the ConOps, the same drivers identified in UC1 (morning backups) exiting the Selmon Expressway REL at the intersection of Meridian Avenue and Twiggs Street might experience a situation where a driver might be induced to wrongly access the REL in an outbound direction from Twiggs Street towards Brandon.

While information is available for the driver as per UC1, there is no knowledge about the population of drivers that might engage in wrong-way driving. Additionally, UC2 is not intended to test if the wrong-way driving warning message is working when a wrong-way driving driver is detected on the REL off-ramp and the vehicles approaching the REL off-ramp in this segment receive this warning message to take action. What can be observed, as detailed in Section 4, is the driver behavior for the wrong-way driving vehicle and the vehicles on the adjacent street during normal and activation conditions using video surveillance and vehicle detection at entry.

In addition, since the wrong-way entry is a random occurrence, having data from the vehicles used for UC1 might not be sufficient for analysis, so observation has to be deployed in order to access the driver behavior in response to CV applications. On the other hand, it will be possible to quantify the number of instances a vehicle might engage into a wrong-way entry and then abort when realizing travel is occurring in the wrong direction.

6.4.2 Recommended Experimental Design

UC2 presents characteristics that make a before vs. after assessment preferable to a quasi-experiment design. In a best-case scenario, quasi-experimental design can be adopted to measure the response of those drivers identified in UC1 during UC2 activation condition. In practical terms, there might be very few instances (or none at all) where a driver that is also a participant in UC1 and UC2 might be faced with a wrong entry state of activation.

A phased approach might be considered to first collect baseline data to establish the level of wrong-way entries, in order to compare with the after the treatment period where the CV technologies will alert the drivers when they are entering the wrong-way on the REL.

6.4.3 Performance Measurement (Statistical Modeling)

To the extent that treatment and control participants are correctly identified, then the following can be estimated for each of the performance measure pillars (Mobility and Safety):

A. Average treatment effect on the treated (ATET) = $(T_1^A - T_1^N)$
B. Average treatment effect (ATE) = $[(T_1^A - T_0^N) - (C^A - C^N)]$

6.5 Use Case 3 (UC3): Pedestrian Safety

The objective of this use case study is to employ CV technologies to improve pedestrian and driver safety at the Hillsborough County Courthouse on Twiggs Street. As described in the ConOps, this area is characterized by significant competing vehicular and pedestrian traffic during the morning peak hour (7:00 AM – 10:00 AM).

6.5.1 Background on Baseline Pedestrian and Driver Patterns

Given that vehicle traffic is related to Twiggs Street, some of the traffic will consist of drivers coming off the Selmon Expressway REL as described in UC1.

It is expected that the vehicles passing on this segment and, therefore, traversing the crosswalk, are primarily commuters; however, some visitors might be expected to come to the courthouse to serve for jury duty (especially on Monday mornings). The difference between these two groups is the familiarity of the area. The crosswalk on this segment is the primary way for pedestrians to legally and safely cross the street between the parking garage and the courthouse. The crosswalk is marked and has only a yellow flashing beacon in order to warn drivers that a pedestrian is approaching the crosswalk. This crosswalk is the primary route for jurors, lawyers, and other people to get to/from the courthouse. During morning rush hour, there are many pedestrians trying to enter the courthouse on time. This is compounded on Mondays and Tuesdays when new juror pools of up to 400 persons are required to report during rush hour. Many of these people are not familiar with the area and may not notice the crosswalk. Lack of attention by drivers and pedestrians causes a safety concern for pedestrians trying to reach the courthouse. To complicate the issue, pedestrians running late may not pay attention to vehicles as they rush into the crosswalk trying to get to the courthouse on time. Finally, some pedestrians may elect to take a shortcut by crossing East Twiggs Street outside the crosswalk.

Figure 6-2 shows the location of the parking garage, the crosswalk and the incoming traffic direction. It is expected that only visitors (jurors) might be eligible participants. Because employees park in a parking garage adjacent to the courthouse building, they do not need to use the crosswalk.

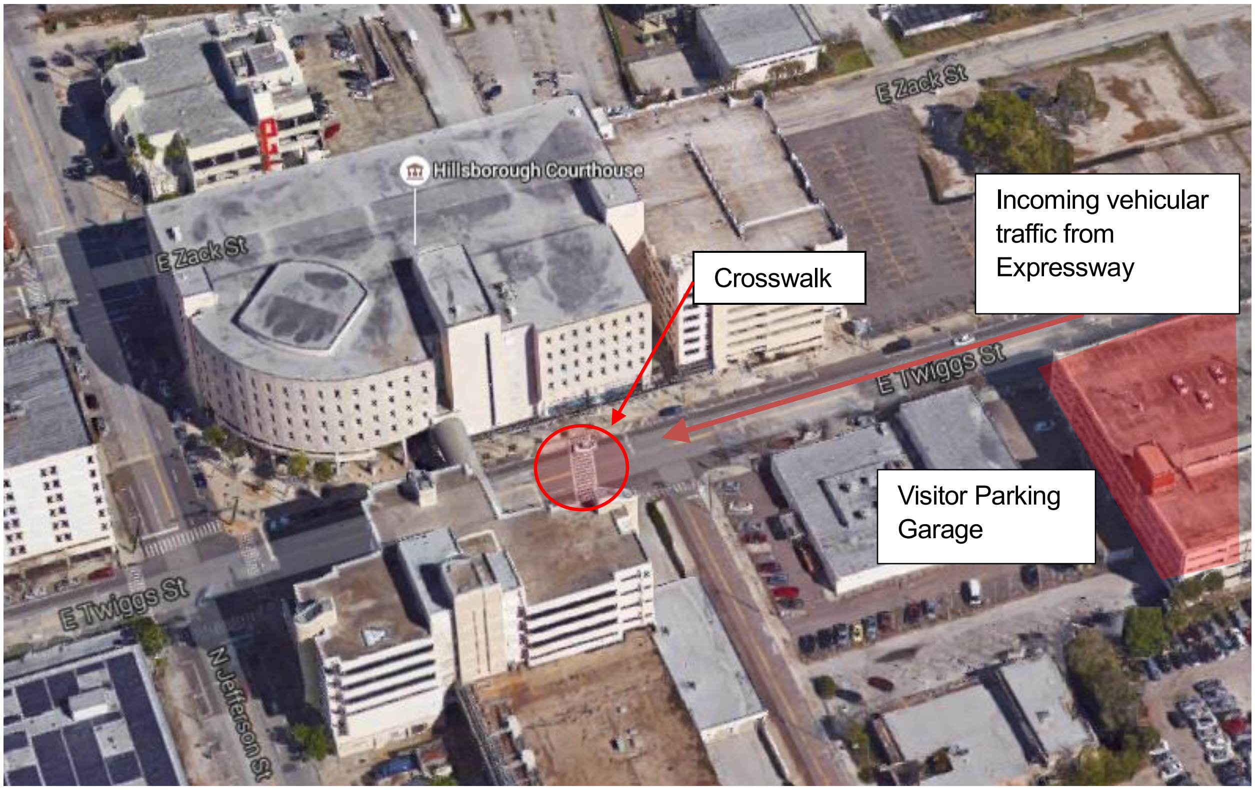

Figure 6-2 UC3 Location and Features
Source: Google Maps; CUTR

6.5.2 Recommended Experimental Design

UC3 presents characteristics that can lead at a minimum to a quasi-experimental approach, and, in a worse-case scenario, to interrupted time-series. This is because there is some form of identifying and selecting treatment control participants using the information gathered above. Two types of pedestrians who cross the crosswalk can be expected: the frequent visitors to the courthouse (employees, lawyers, etc.), and the one-time visitors, such as jurors who report for jury duty and are dismissed. The CV application for pedestrian safety is expected to be a smartphone application, informing the pedestrians of an encroaching vehicle. This will only exist for participants in the experiment and not all crossing pedestrians. However, roadside technologies can provide messages or warnings to all users; therefore, all pedestrians can be used in the experiment. This approach will be implemented if the number of pedestrians with CV equipped smartphones is not adequate. The roadside technologies can receive notification from the vehicle for approaching vehicle and warn all pedestrians (potentially) with an audio or visual message (DMS or flashing light). The same applies to the passing drivers. Some will be participating in the study in conjunction with UC1, but not all. To accommodate as many users as possible, video detection technologies might be used to detect and warn all pedestrians and drivers via flashing lights, audio warning at the crosswalk, and DMS signs. This has not been tested and is proposed only as a backup.

In order for the preferred experimental design to work, both pedestrians and drivers conflicting at the crosswalk have to be part of the study before they arrive, and the vehicle (for drivers) and smartphone app (for pedestrians) loaded onto the perspective technologies. However, the likelihood of this occurring without the pilot team's intervention is very low. It is, therefore, acknowledged that in this particular case, a controlled experiment will have to take place where a predetermined number of pedestrians and vehicles equipped with the CV technologies will meet at the crosswalk with interactions recorded under controlled conditions. This method is used when none of the previous methods work, since there is no control on when either pedestrians or drivers will arrive at the crosswalk for a CV technology to be implemented.

6.5.3 Performance Measurement

If a phase approach is applicable as per UC1, then UC1 performance measurement approach will be adopted. The before/after evaluation can be achieved with the activation conditions being similar to the control conditions with the difference being the deployment of the CV application. The measurement will occur with surrogate measures of crashes, such as conflicts or near misses, percentage of pedestrians who cross at the crosswalk, and traffic and pedestrian delays. A pedestrian crash index or safety index can be calculated providing the relative likelihood of a pedestrian being struck. This will be compared to pedestrians using CV applications and pedestrians who do not to establish the benefits of the CV technologies.

6.6 Use Case 4 (UC4): BRT Signal Priority Optimization, Trip Times and Safety

The objective of this use case study is to employ CV technologies to reduce transit signal delay, pedestrian conflicts, and signal coordination issues inbound along Kennedy Boulevard and northbound on Marion Street to the Marion Street transit station.

6.6.1 Background on Baseline Bus Conditions

Marion Street, a two-lane street, is a primary bus route, which on the north end terminates at the Marion Transit Center. HART operates several routes that converge onto Marion Street at the Kennedy Boulevard intersection, all headed north to the Marion Street Transit Station.

Along the above mentioned routes, many of the bus stops are on the approach to an intersection. When there is congestion, buses are unable to reach their stops causing them to potentially fall behind schedule; thus, causing a mobility concern. CV Technology will be used to address the mobility concerns. Buses and traffic signals will communicate, and, if a bus is behind schedule, the traffic signal system will either give the bus priority or flush the queue allowing the bus to reach its stop assuming there are no other higher priorities.

Figure 6-3 depicts the HART downtown network of service, whereas Figure 6-4 is a zoomed in version, which depicts the routes that run from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center. These routes are HART Route 4, Route 8, Route 19, Route 30, and Route 46.

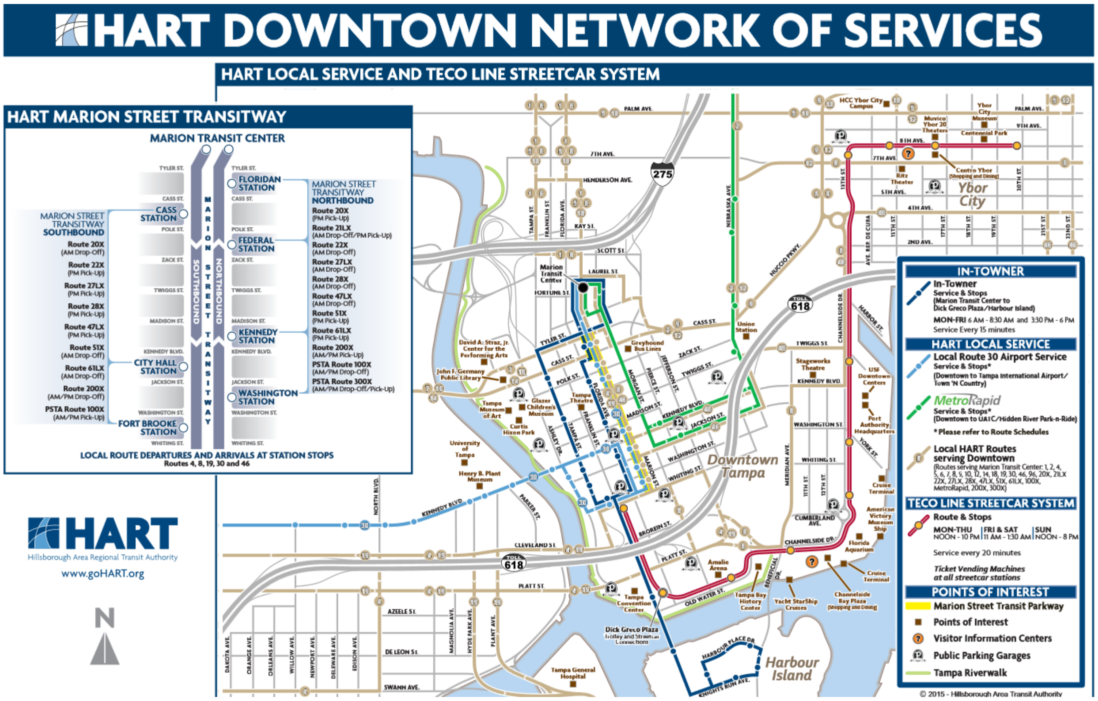

Figure 6-3 HART Downtown Network of Services

Source: HART, CUTR

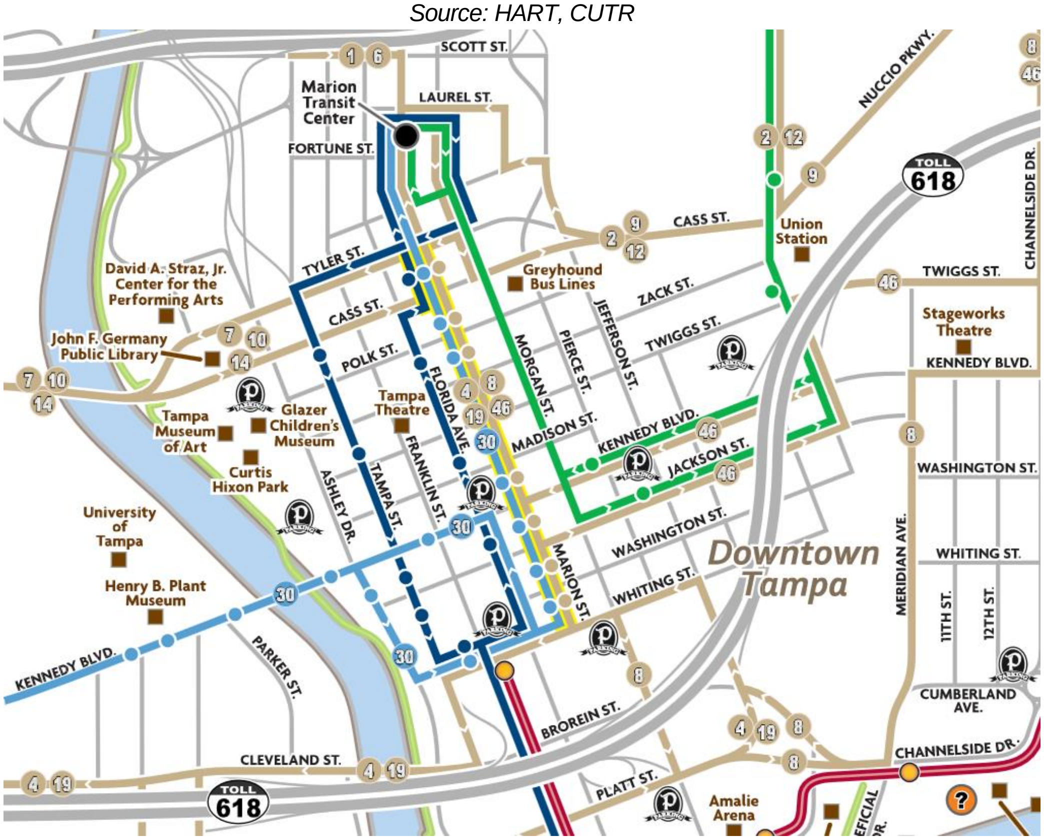

Figure 6-4 UC5 Study Area from Kennedy Blvd. and Marion St. to Marion Transit Center

Source: HART, CUTR

6.6.2 Recommended Experimental Design

The participants of this use case will include the bus operators, pedestrians, and drivers in the CV pilot area. Bus operators cannot be randomly selected due to HART operating parameters. The recommended experimental design is before/after or interrupted time series approach.

For UC4, only the transit vehicles/buses that operate in the aforementioned segment will have a CV app on board. Therefore, this will be an interrupted time series experimental design and will call for a before and after CV analysis approach.

The sample size will be affected by the number of buses that will be equipped with the CV app, however, by calculating the weekday departures for the 5 main bus routes involved in this UC, it can be observed that there are approximately 140 independent daily bus trips that will pass through this segment. This correlates to an ample amount of data over a given amount of time to analyze the CV application performance measurement.

6.6.3 Performance Measurement (Statistical Modeling)

The before and after CV application data will allow gathering and measuring the baseline and the after CV implementation performance measures. The results will be analyzed statistically on overall percentage increase or decrease for each measure of interest and is discussed in detail on Section 8 of this report.

6.7 Use Case 5 (UC5): TECO Line Streetcar Trolley Conflicts

The objective of this use case study is to employ CV technologies to reduce vehicle and pedestrian conflicts with the TECO Streetcar Line at crossing locations throughout the project area, particularly along Channelside Drive.

6.7.1 Background on Baseline Trolley Conditions

The streetcar passes several intersections where vehicles cross the streetcar tracks. As the pedestrians disembark from the streetcar and the streetcar prepares to startup, it is possible that a vehicle may turn right in front of the streetcar. Pedestrians may be crossing the intersection where the vehicle is turning right as well. The potential of a streetcar and vehicle crash and a pedestrian incident are safety concerns. CV technologies will be used to provide warnings to pedestrians, vehicles and the trolley operators for potential conflicts. The trolley operators are the same, and the pedestrians and drivers are random users of the area. Employees of the venues at Channelside Drive are potential participants that are repeat users of the area and potential participants.

6.7.2 Recommended Experimental Design

The participants of this use case will include the trolley operators, pedestrians, and drivers in the CV pilot area. Trolley operators cannot be randomly selected. The recommended experimental design is before/after or interrupted time series approach.

6.7.3 Performance Measurement

In the context of a before vs. after evaluation, performance measurement will take the form of a baseline vs. deployment evaluation in terms of percent changes upon baseline conditions.

6.8 Use Case 6 (UC6): Enhanced Signal Coordination and Traffic Progression

The objective of this use case study is to employ CV technologies to improve travel times on Meridian Avenue through downtown to MAFB in concurrence with increased queue times at controlled access points during the peak morning arrival time at MAFB.

6.8.1 Background on Baseline Driver Patterns

According to the MAFB fact sheet, the base has about 12,000 military and 1,300 civil personnel assigned. Of the active duty personnel, about 11,000 live off base.

The U.S. Census *OnTheMap* program only reports information about the civilian workforce employed at the base and surroundings, thus, providing only an indication of the location and travel information of the overall population of civil and active duty personnel. Figure 6-5 shows the location patterns of MAFB workers. About 27 percent of the workers lives within the City of Tampa limits, and about 10 percent lives in the Brandon area (Brandon, Valrico, Riverview, and Ruskin).

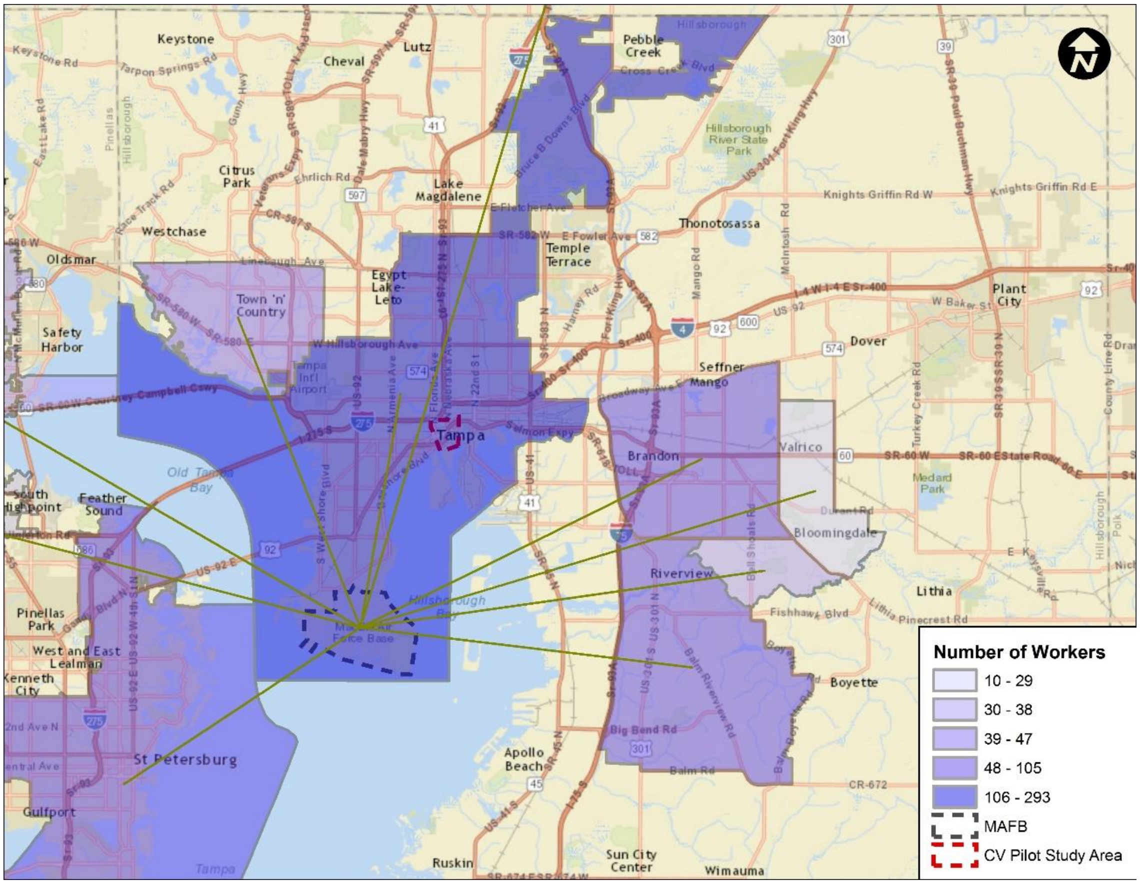

Figure 6-5 MAFB Workers' Place of Residence

Source: LEHD; CUTR

6.8.2 Recommended Experimental Design

This use case presents the same characteristics of UC1. For this reason, the use case can lead, at a minimum, to a quasi-experimental approach, and, in a best-case scenario, to randomized design experiment (preferred approach). In this case, the pool of potential participants can be drawn from UC1 and augmented to be representative of the MAFB workers commuting from the Brandon area. The split/stratification of treatment and control will have to be determined by this sample augmentation.

In the presence of individual self-selection, the second-best approach will be the quasi-experimental design, with the implementation of PSM methods to match treatment and control groups and minimize bias during performance measurement.

6.8.3 Performance Measurement (Statistical Modeling)

To the extent that treatment and control participants are correctly identified, then the following can be estimated for each of the performance measure pillars (Mobility, Safety, and Environment):

A. Average treatment effect on the treated (ATET) = $(T_1^A - T_1^N)$
B. Average treatment effect (ATE) = $[(T_1^A - T_0^N) - (C^A - C^N)]$

While (A) allows measuring individual performance for those treated with CV technologies, it is (B) that will provide the unbiased magnitude of the performance improvements.

As in UC1, Stage II will allow measuring treatment response to CV pilot implementation during normal and activation conditions. At the disaggregate level, it will allow measuring individual travel behavior responses of the treated group during normal T_1^N and activation condition T_1^A, and the responses of the control group during normal C^N and activation condition C^A. At a mesoscopic level, Stage II will allow measuring performance along the corridor during the relevant peak periods and ascertain improvements (if any) upon the baseline performance measures of Stage I.

6.9 Summary of Recommended Experimental Design Methods by Use Case

Table 6-2 summarizes the recommended experimental method(s) for each of the six use cases. Recommendations are based on the likelihood of selecting participants and the CV technologies being considered. In the next sections, each use case performance measurement approach is discussed, along with the rationale behind the choice of experimental method.

Table 6-2 Recommended Experimental Design

Experimental Design	*UC1 Morning Peak Hour Queues*	*UC2 Wrong Way Entries*	*UC3 Pedestrian Conflicts at Courthouse*	*UC4 Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety*	*UC5 TECO Line Streetcar Trolley Conflicts*	*UC6 Enhanced Signal Coordination and Traffic Progression*
Interrupted time series	✓	✓	✓	✓	✓	✓
Quasi-Experiment	✓	✓	✓		✓	✓
Random Design	✓					✓
Participant Recruitment	YES	Partially from UC1/UC4	YES, courthouse employees; jurors could adopt apps	NO	Only App adopters	YES, from UC1

6.9.1 Sample Size Determination

Statistically meaningful difference and effect size represent the magnitude of an effect of interest, such as the performance metrics outlined in Chapter 4. Changes in travel times, travel time reliability, and safety between treated and untreated units represent the magnitude of the effect of interest to be detected by a test with a specified power.

For those use cases where the experimental and quasi-experimental design approach are considered, a power and sample size (PSS) approach will be adopted to identify a minimum required sample size [21, 22]. To identify the minimum required sample size, PSS analysis will be conducted using the commercial statistical software package Stata (Stata PSS).[2]

It is expected that minimum sample size requirements are a function of: 1) selected power of the test; 2) significance level; and, 3) expected difference in the effect size of each adopted performance measure (e.g. travel time savings, safety, emission rates) between treatment and control units.

[2] www.stata.com

The power of the test is a measure of the probability of correctly rejecting the null hypothesis when the null hypothesis is false. Power (π) is inversely related to the probability of a type II error (β or fail to reject null when the null is false) and is computed as $\pi = 1 - \beta$. Typical values for power are 0.8 or 0.9, depending on the study objectives.

The significance level (α) identifies the type-I error probability of rejecting the null when the null is true. Typical set up is α =0.05

The examples below provide some information on the sample size selection process that will be adopted in the next phase of the pilot deployment. The purpose is to convey an idea of how sample size requirement depend on the performance measure being considered, underlying baseline characteristics, and expected CV improvement targets.

Example 1. UC1 Mobility Performance Measure Assessment (Table 6-3)
Unit of measure: changes in travel time (using segment level travel time analysis: from the beginning of REL off-ramp to the REL signalized intersection of E. Twiggs St.)

Assume that after initial baseline assessment, average travel time along the segment is 450 seconds per vehicle with a standard deviation of 100 (sec/veh). After CV implementation, the control group will retain the baseline average travel times, while the treatment group will show an average travel time improvement of about 11 percent and unchanged standard deviation.

Table 6-3 UC1 Baseline Travel Times and Expected CV Improvements – Example 1

Metric	*Baseline*	*CV Implementation*	*Change*
Mean Travel Time (sec/veh)	225	200	-11.1%
Standard Deviation (sec/veh)	100	100	0.0%

The objective is to compare the two means and test:
Null hypothesis: H_0: $|200 - 225| = 0$
Alternative hypothesis: H_a: $|200 - 225| \neq 0$

The formula to compute the required minimum sample *n* size for a two sample mean comparison with α=0.05 and π=0.90 is

$$n = \frac{2\left(Z_a + Z_{1-\beta}\right)^2 \sigma^2}{\Delta^2}$$

Where
Z_a depends on level of significance; for α=0.05 this is 1.96
$Z_{1-\beta}$ depends on power, for π=0.90 this is 1.282
σ is the standard deviation
Δ is the expected effect size (difference in means)
Substituting the numbers in the above formula:

$$n = \frac{2(1.96 + 1.282)^2 100^2}{25^2} \cong 337$$

That is, the minimum sample size for each group is 337, which corresponds to a required total sample size for treatment and control to 674. Furthermore, the sample needs to be adjusted to account for sample drop out (i.e., participants dropping out without replacement). The standard approach is to adjust the sample size using the formula

$$n_d = \frac{n}{(1 - R_d)}$$

Where n_d is the inflated sample size; and, $R_d$is the dropout rate.

Assuming a 10 percent dropout rate, the adjusted sample size is

$$n_d = \frac{337}{(1 - 0.1)} \cong 374$$

Therefore, the minimum required sample size for treatment and control group, after accounting for drop-outs is 748.

The required sample size can be calculated for different scenarios accounting for differences in required power. This would allow matching the minimum required sample size with constraints dictated by other factors, such as budget allocated to participant recruitment and CV installation. The figure below, produced using Stata PSS, shows the simulated minimum sample size based on different power levels.

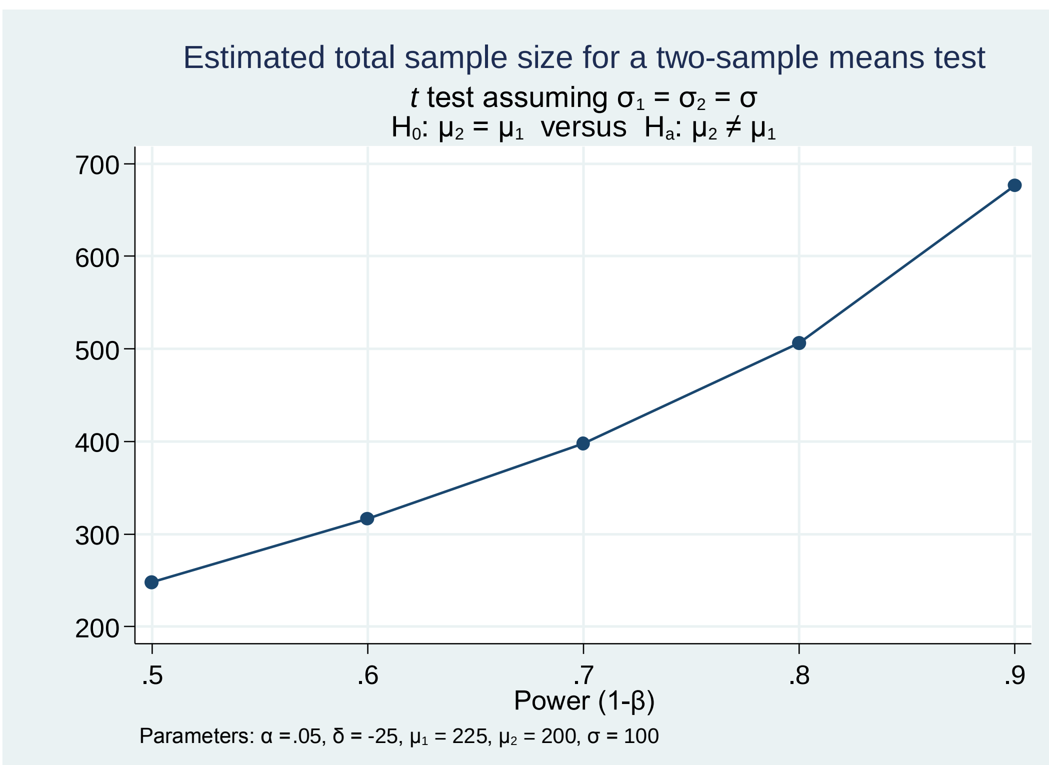

Figure 6-6: Required Sample Size and Power

Example 2: UC1 Mobility Performance Measure Assessment

Unit of measure: travel time reliability (using segment level travel time reliability analysis: from the beginning of REL off-ramp to the REL signalized intersection of E. Twiggs St.)

This example considers measuring the effectiveness of CV applications in increasing the travel time reliability of vehicles traveling along UC1's segment. As in Example 1, CV implementation will improve travel times and at the same time reduce the variability of travel times. Table 6-4 shows a 6.7 percent reduction in mean travel time and a 15-percent reduction in the standard deviation.

Table 6-4 UC1 Baseline Travel Times and Expected CV Improvements – Example 2

Metric	*Baseline (control)*	*CV Implementation (treatment)*	*Change*
Mean Travel Time (sec/veh)	225	210	-6.7%
Standard Deviation (sec/veh)	100	85	-15.0%

Using the same power and confidence level, the minimum required sample size (computed in Stata PSS) is *N*=1,204 (602 for treatment and 602 for control). After accounting for 10 percent drop out, the total sample size is N=1,338.

Alternatively, the power of the test can be identified by specifying an upper sample size boundary. This could be the case if, say, budget constraints limit the actual sample size to N=1,000. In this case, the power of the test would be $\pi=0.72$.

In summary, during Phase 2 of the Pilot Deployment, PSS analysis will be performed to define a minimum requirement sample size for those use cases where the experimental design approach will be applicable. The analysis will take into account additional factors related to the scalability of performance measurement so that the participant pool is large enough to be able to detect measurable changes in performance.

7 Data Collection Plan

7.1 Data Collection Plan

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 Basic Safety Messages (BSMs). Signal Request Messages (SRMs) and Signal Status Messages (SSMs) 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. Vehicle Awareness Devices (VADs) will exclusively broadcast BSMs. RSUs will store data generated (e.g., speed), received (e.g., BSMs), and broadcasted (e.g. BSMs). OBUs will utilize installed applications to inform the driver of potential conflicts/issues. VADs will be used exclusively as a probe, whose output (BSMs) is used as input to the CV applications. It is expected that there will be over a thousand VADs and over a thousand OBUs. VADs are limited to vehicles only. RSUs will periodically connect to the master server to archive their stored data.

During Phase I, the initial design for data collection will be defined. For the CV Pilot, there were six use cases defined. Within each use case, two or more applications were identified to address the issues associated with that use case. The six use cases and their associated applications are listed below:

- Morning Peak Hour Queues
    - Curve Speed Warning (CSW)
    - Emergency Electronic Brake Light (EEBL)
    - Forward Collision Warning (FCW)
- Wrong Way Entries
    - Red Light Violation Warning (RLVW)
    - I-SIG
    - Probe-enabled Data Monitoring (PeDM)
    - Intersection Movement Assist (IMA)
- Pedestrian Safety
    - Pedestrian in Signalized Crosswalk Warning (PED-X)
    - Mobile Accessible Pedestrian Signal (PED-SIG)
- Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety
    - IMA
    - I-SIG
    - Transit Signal Priority (TSP)
    - PeDM
- TECO Line Streetcar Trolley Conflicts
    - I-SIG
    - Vehicle Turning Right in Front of Transit Vehicle(VTRFTV)
    - PED-X
    - PED-SIG
- Enhanced Signal Coordination and Traffic Progression
    - I-SIG

- PeDM

7.1.1 Morning Peak Hour Queues

The Morning Peak Hour Queues use case consists of three applications: CSW, EEBL, and FCW.

For the CSW applications, the application will broadcast a normalized speed that will be received by OBU equipped vehicles. A normalized speed is determined by using the end of the queue, the curve geometry, and Florida statutes on speed to determine the normalized speed. The OBUs receive the normalized speed and adapt the speed to the vehicle type. The OBUs will store these speeds and BSMs (ones it generates and ones it receives) to a local storage device connected to the OBU. Initially, vehicles will be brought in to download the data to the master server every other month. The OBUs will store changes to the normalized speed. Each of these records will have timestamps when the speed was initially broadcast by the RSU. This historic speed data will be sent to the master server.

For the EEBL application, OBU equipped vehicles will both broadcast and receive BSMs. The EEBL application will use the BMSs and EEBL braking effort to determine if there is a vehicle braking in front and generate a warning to the driver. The OBU will store timestamped BSMs and EEBL warnings it generates.

For the FCW application, OBU equipped vehicles will both broadcast and receive BSMs. The FCW application will use these BSMs to determine if the vehicle is in danger of crashing into the rear of another vehicle and generate a warning to the driver. The OBU will store timestamped BSMs and FCW warning messages it generates.

7.1.2 Wrong Way Entries

The Wrong Way Entries use case consists of four applications: I-SIG, PeDM, IMA and RLVW.

For the I-SIG application, the intersection will be setup to detect red light running violations. Using the existing red light running application, a vehicle will be determined to potentially run a red light based on the vehicle’s speed and acceleration profile, along with the signal timing and geometry information to determine if a vehicle is going to run a red light. Red light running violations are used to determine a vehicle that has entered going the wrong way. When the RSU receives a red light running violation, it will timestamp and store the information indicating a vehicle entered in the wrong direction. The RSU broadcasts an alert that there is a wrong way driver entering the REL. Vehicles on the REL approaching the exit receive the alert. It is possible that vehicles not on the REL could receive the alert. These vehicles will ignore the alert based on their current location. Law enforcement may receive the alert if their vehicle is OBU equipped or a message is sent to them from the TMC operator.

For the PeDM application, the RSU will store any BSMs it receives either from OBUs (planned for over 1,000) or VADs (planned for over 1,000). This BSM data can be compared to the location of the red light violation area to determine if the vehicle entering the wrong way is equipped and what, if any, actions other equipped vehicles in the area did in reaction to the wrong way vehicle.

For the IMA application, if the wrong way vehicle is equipped, the OBU will warn the driver of driving the wrong way. The OBU will record the warning and timestamp. Other OBU equipped vehicles that may be in area will receive a wrong way driver warning. The OBUs will timestamp and store the warning.

7.1.3 Pedestrian Safety

The Pedestrian Safety use case consists of three applications: Pedestrian in Signalized Crosswalk Warning (PED-X), and Mobile Accessible Pedestrian Signal (PED-SIG).

For the Pedestrian in Signalized Crosswalk (PED-X) Warning application, the RSU will receive pedestrian locations entering or in the crosswalk from a smart phone and potentially a detection warning that a pedestrian is entering the crosswalk. The RSU will receive the location, direction, and speed from the smart phone and create a pedestrian BSM (standard BSM) and broadcast it to vehicles. If the RSU determines a pedestrian and vehicle may crash, the RSU will send a warning to the vehicle and smart phone of a potential crash. The RSU will store the vehicle BSMs, the pedestrian locations, the pedestrian BSMs, and pedestrian/vehicle crash warnings.

For the Mobile Accessible Pedestrian Signal (PED-SIG) application, the RSU will receive an indication from a pedestrian detect of a pedestrian entering the crosswalk. The RSU will compare the data with all BSMs to determine if it is already aware of the pedestrian; essentially, determining if the pedestrian is carrying a PID and using the application. When the RSU identifies a non-equipped pedestrian, a pedestrian BSM is created and broadcast for approaching OBU equipped vehicles to receive. A similar approach is used for unequipped vehicles entering the crosswalk. In this case, the RSU creates a vehicle BSM and broadcast for approaching PID equipped pedestrians to receive. The RSU will store the vehicle BSMs, the pedestrian locations, the pedestrian BSMs, and pedestrian/vehicle crash warnings.

An application will be installed on a smart phone. The application will broadcast its location and store received warnings of a potential crash with a vehicle. At this time, the storage of the data is to be determined because these devices will be owned by volunteers and the amount of storage the application may have access will vary. The project must also be sensitive to using any storage on volunteers' personal devices.

7.1.4 Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety

The Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety use cases have two applications: I-SIG, IMA, PeDM and TSP.

For the I-SIG application, the RSU will receive location and movement data from equipped transit vehicles and emergency vehicles. The RSU will store the transit data received and share the data with the TSP application. The data will be archived to the master server only when it changes (i.e., new schedule times).

For the TSP application, the RSU will receive the bus vehicle identification number (VIN) and location as fields in the SRM and send that information and a priority request to transit central. Transit central determines if the bus is behind schedule. If the bus is on or ahead of schedule or an emergency vehicle has requested priority, transit central ignores the priority request and no action is taken. If transit central determines the bus is behind schedule, the priority request is granted. The RSU receives the priority request and sends it to the signal controller and to the bus OBU. The RSU stores the initial priority request, timestamp, and bus information, including VIN, position, and speed data. If the RSU receives s priority granted message from transit central, the RSU stores the timestamp and the SSM (priority granted message). These data are sent to the master server for archiving.

7.1.5 TECO Line Streetcar Trolley Conflicts

The TECO Line Streetcar Trolley Conflicts use case consists of four applications: I-SIG, Vehicle Turning Right in Front of Transit Vehicle Warning (VTRFTV) PED-SIG and PED-X.

For the I-SIG application, the RSU will receive BSMs from equipped vehicles (non-transit in this case) and shared with the VTRFTV application. These BSMs will be stored by the RSU.

For the VTRFTV application, the trolley OBU will transmit BSMs and receive vehicle turning right warnings. The trolley OBU will store BSMs it transmits and any vehicle turning right warnings it receives. The RSU will receive trolley and other vehicle BSMs, determine if a vehicle is turning right in front of starting up or moving trolley, and send a vehicle turning right warning. The RSU will store the trolley BSMs, the other vehicle BSMs, and any warning the RSU sends.

For the PED-X, the RSU will receive BSMs from trolleys, other vehicles nearing the intersection, and pedestrian locations from smart phones. The RSU will create a pedestrian BSM and broadcast it to vehicles. If the RSU determines a pedestrian and trolley or a pedestrian and a vehicle may crash, the RSU will send a warning to the trolley/other vehicle and smart phone of a potential crash. The RSU will store the trolley BSMs, other vehicle BSMs, the pedestrian locations, the pedestrian BSMs, and pedestrian-trolley/other vehicle crash warnings.

The PED-SIG application portion will be installed on a smart phone. The application will broadcast its location and received warnings of a potential crash with a trolley/ other vehicle. At this time, the storage of the data is to be determined because these devices will be owned by volunteers and the amount of storage the application may have access will vary. The project must also be sensitive to using any storage on volunteers' personal devices.

7.1.6 Enhanced Signal Coordination and Traffic Progression

The Enhanced Signal Coordination and Traffic Progression use case consists of two applications: I-SIG and PeDM.

For the I-SIG application, the RSU will use BSMs shared from the Probe Enabled Data Monitoring application (described below) to determine the congestion at an intersection. These BSMs and intersection congestion level will be stored by the RSU.

For the PeDM application, the RSU will store any BSMs it receives either from OBUs or VADs. These data are shared with the I-SIG application.

7.2 Participant Action Log Protocols

The primary focus of the CV Pilot is to measure improvement in safety and mobility. As such, the performance measures will be focused on safety and mobility measures. In order to assist evaluators in their evaluation, knowing the protocols followed by people who interact with the system can be used to determine whether the use cases/application(s) improved performance. The following users have been identified:

- Passenger vehicle drivers
- Bus operators
- Trolley operators
- Smart Phone application users (including bicyclists per local laws)
- TMC operators

7.2.1 Passenger vehicle drivers

Passenger vehicle drivers who have VADs installed in their vehicles will not take actions because of the CV Pilot applications. Their only requirement will be to periodically have the stored data downloaded so that it can be archived on the master server.

Passenger vehicle drivers who have OBUs installed in their vehicles may receive in-vehicle warnings. These participants will be trained on how the warnings are presented and potentially how to respond to these warnings. When the participants bring their vehicle to have the data downloaded, they will be asked to fill out an anonymous survey of their experience including their perception of any warnings they received, how they reacted to them, and whether the warning had any impact on their safety and/or mobility.

7.2.2 Bus Operators

Bus operators will be trained to use the OBUs installed on their buses. These OBUs will provide an indication to the driver that they have been granted priority or their priority has been overridden. In terms of operating the bus, the operator has no additional action to take. Periodically, the operators will be anonymously surveyed to determine their perception of any messages they received, how they reacted to them, and whether the message had any impact on their safety and/or mobility.

7.2.3 Trolley Operators

Trolley operators will be trained to use the OBUs installed on their trolleys. These OBUs will provide a warning to the operator that a vehicle is turning right in front of the trolley. This warning may cause the driver to take some immediate action and provide a warning to smart phone application-equipped pedestrians crossing in front of the trolley when the pedestrian and trolley may crash. The OBUs will not have the capability to determine what action the operator took; although, the trolley BSMs may show a sudden decrease in speed, for example. If an operator experiences an event during their shift, they will be asked to fill out an anonymous survey on their experience, including their perception of any warnings they received, how they reacted to them, and whether the warning had any impact on their safety and/or mobility.

7.2.4 Smart Phone Application Users

Smart Phone Application Users will be people who have voluntarily downloaded the CV Pilot application on their smart phone. The application will broadcast its location and warn the person that they may be on a collision course with a vehicle or trolley. The application will not have the ability to determine what, if any, action the person takes when they receive a warning. The application will prompt the person to fill out an anonymous survey after a warning has been issued. The survey request will occur in the evening of the day the warning was issued. The person will be surveyed to determine their perception of any warnings they received, how they reacted to them, and whether the warning had any impact on their safety and/or mobility.

7.2.5 TMC Operators

TMC operators oversee the City of Tampa traffic signal system and the reversal of the REL. The operators will be trained to handle alerts that they may receive, such as a wrong way driver. TMC operators' procedures will be modified to include the steps needed to handle the event. For a wrong way driver, the TMC Operator may perform the following actions:

- Acknowledge the warning
- Inform Tampa Police Department, Hillsborough County Sheriff, and Florida Highway Patrol providing last know location and heading
- Use available CCTV to view the event if possible and monitor until the event has been neutralized

At the end of each shift when an event occurred, the operator will be asked to respond to an anonymous survey for that event. The operator will be surveyed to determine their perception of the event, how well the procedures worked to neutralize the event as soon as possible, and whether the use of the procedures had any impact on safety and/or mobility.

Evaluators may examine the procedures as well to gain insight to how events were handled and the effect they had on the performance measures.

7.3 Document procedures for data quality verification, data cleaning, PII removal, and fusion of CV data with data from other sources

This phase of the data collection plan outlines the procedures for quality checking, cleaning, removal of Personally Identifiable Information (PII), and fusion of CV data with data from other sources. This phase is labor intensive, but completion of procedures in this step will yield data that are appropriately aggregated, logically structured, and sufficiently documented to enable independent and successful interaction with the data after upload to the Research Data Exchange (RDE). Future users and subscribers to the fused data from multiple sources will be able to utilize it to provide benefits through applications. The steps in this phase utilize a framework called the Operational Data Environment (ODE), which is outlined below.

The ODE framework is a proposed mechanism for data cleaning, structuring, fusion and streaming. This framework was built and tested in Southeast Michigan in 2016 as part of a FHWA sponsored project titled "Southeast Michigan Test Bed Advanced Data Capture Field Testing." It is recommended that the THEA site leverage this framework to carry out the data handling and distribution. ODE can act as a real-time smart data router, brokering processed data from various sources, including Connected Vehicles and Infrastructure, to a variety of data users. Figure 7-1 shows the generalized ODE represented in the CVRIA format. The ODE is designed to be a part of the Agency architecture that acts as a smart data router. Figure 7-2 is a conceptual representation of the ODE for the THEA site.

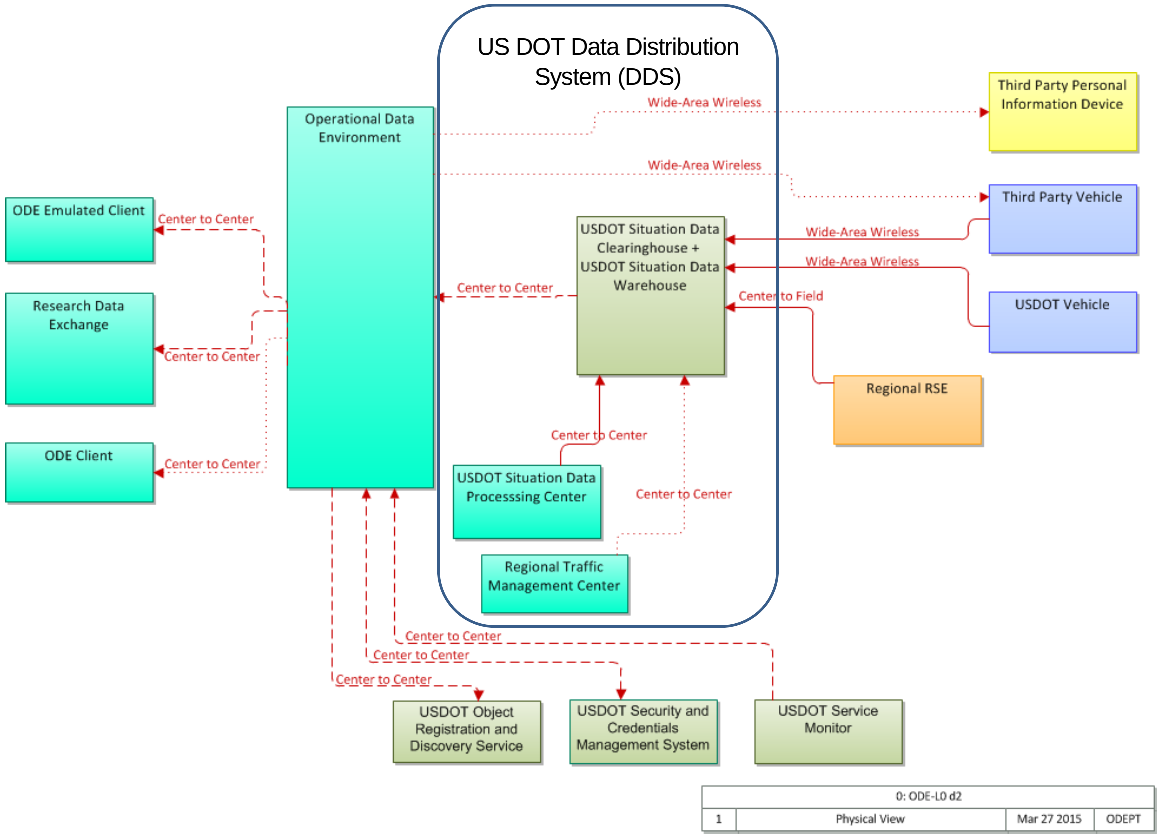

Figure 7-1 ODE as Represented in the CVRIA Architecture

Source: Booz Allen Hamilton, April 2016

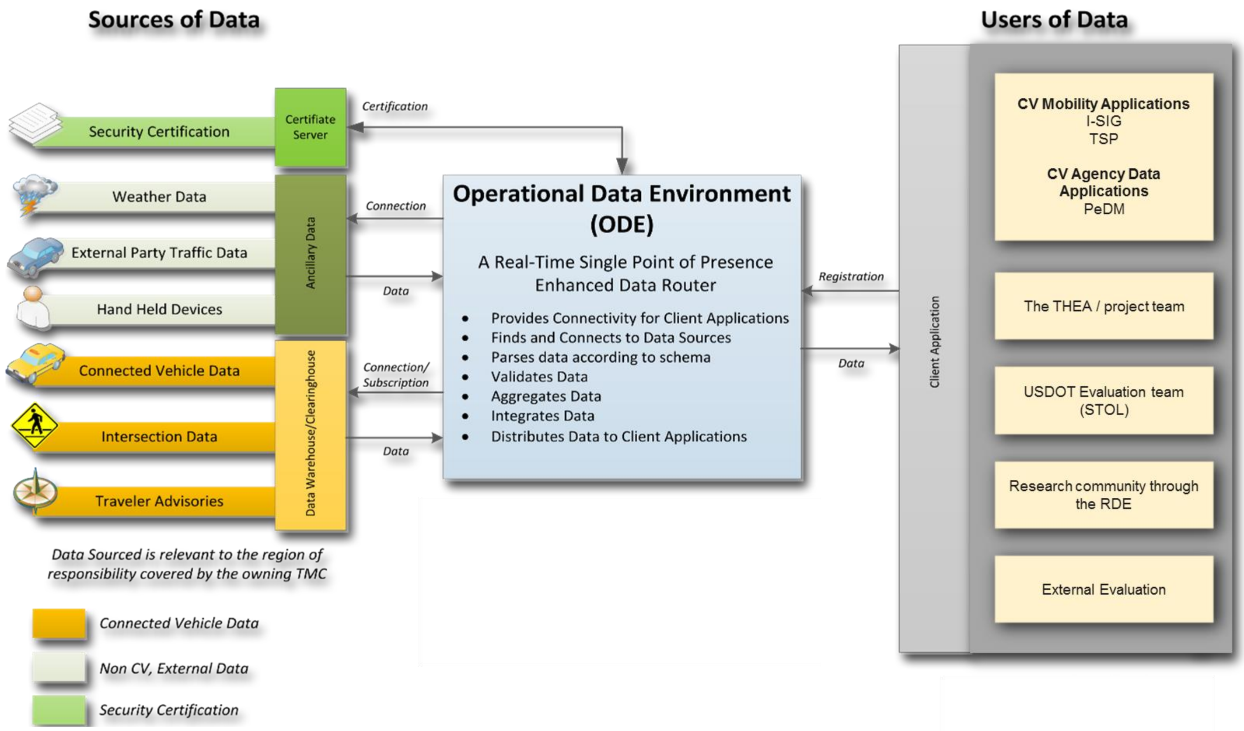

Figure 7-2 Concept Diagram for the ODE for the THEA Site

Reference: Southeast Michigan Test Bed Advanced Data Capture Field Testing, Task 4: Operational Data Environment - Concept of Operations, April 2015.

An environment such as the ODE can carry out functions like data valuation or checking, data aggregation, data integration from multiple sources, and propagate the data as necessary to storage mechanisms for archiving in real-time, or propagate the data to other subscription services like CV applications, which can use the streamlined and cleaned data to generate alerts or guidance to the users of the network. The V2V Safety and V2I Safety applications will not be subscribers to data from the ODE. However, the data from them are sent to the ODE for archiving purposes. The reason that the Safety applications are not served by the ODE is that the latency required by the Safety applications is very low for them to be useful, which cannot be achieved when the data is sent for processing to the TMC or the ODE and then returned to the Safety applications as alerts or warnings.

The steps within this phase, which utilize the ODE framework, are detailed in Figure 7-3 below.

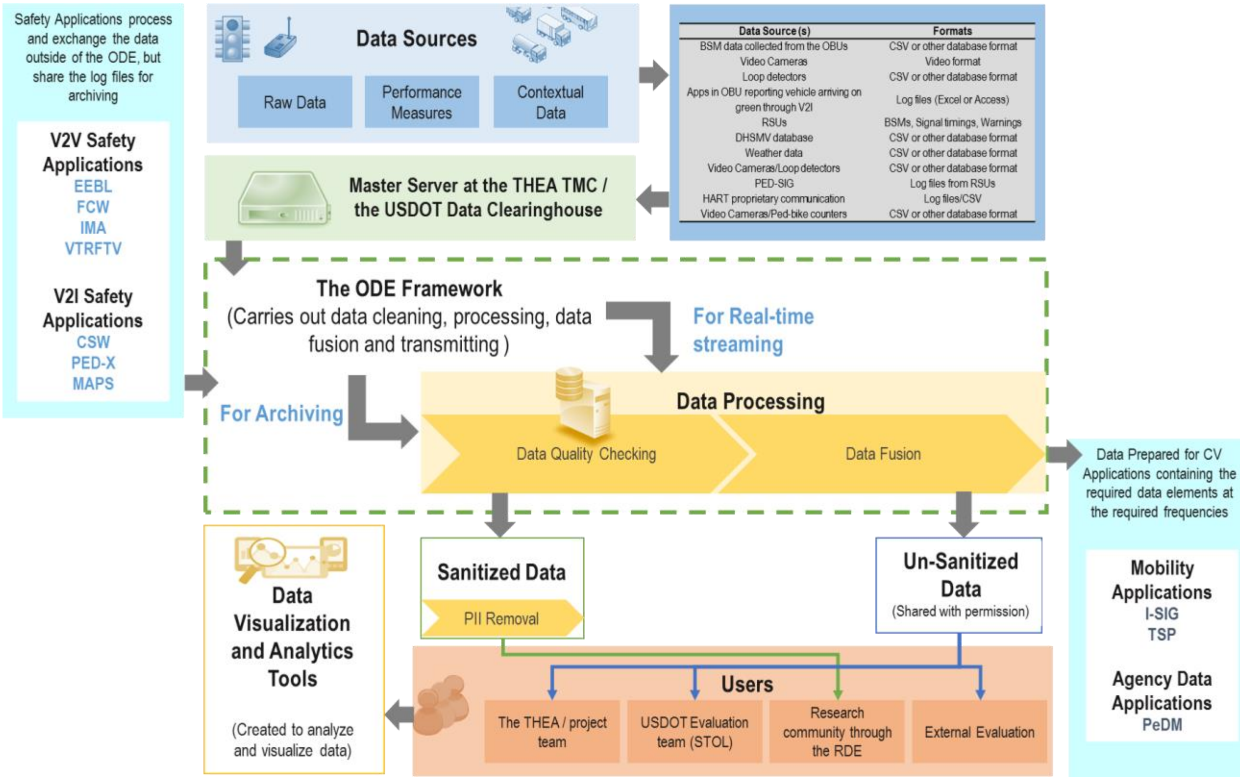

Figure 7-3 Data Flow Process Chart

Source: Booz Allen Hamilton, March 2016

As shown in Figure 7-3, the data that are collected from the various sources are transmitted to the main server at THEA. The ODE framework is utilized to direct the data from the THEA server to the archiving mechanisms as well as to the CV applications running in real time. ODE is capable of processing data and fusing multiple streams of data to generate a continuous data feed for the CV applications that are subscribed to it. The data from ODE can also be redirected to archiving mechanisms. ODE is capable of verifying the credentials of the subscribers, and, accordingly, adjust level of access. For example, the RDE, which is a subscriber to the ODE, will only be granted access to the data free of PII.

Some data, like the video recordings, are very difficult to process in real-time and remove PII. These are archived in the THEA site, the Saxton Transportation Operations Laboratory (STOL), and provided to the external evaluators as required. The un-sanitized data can only be sent for storing/archiving after the appropriate permissions are obtained (Details in Section 11 of this report). The remainder of the data without any PII is stored on the RDE for general public access. The THEA site will act as a master archive. The ODE will continuously update this archive. Based on the granted permissions, the STOL will act as a secondary archive which will have all the data that is on the THEA server. The external evaluators and the RDE will receive the data based on the sensitivity of the data and the research value associated. Data from video cameras and loop detectors that are already collected by the local TMC may be used for validation purposes by the pilot team. These data will not be shared with the independent evaluators, the RDE, or STOHL.

The sections below describe data processing steps and also mechanisms for archiving the data.

7.3.1 Data quality checking and cleaning

A complete list of data sources and a thorough understanding of the data generation capabilities of these sources are required. The formats in which all these data sources output data may be unique. Some of the sensor data sources and their formats are listed below in Table 7-1. Table 7-2 provides the list of data produced by each application or taken as input by each application. All these data transactions will be obtained from the respective log files to examine their performance. Using this information, instantaneous performance monitoring, as well as post-test performance evaluation can be carried out.

Table 7-1 Sensor data Sources and Formats

Data Source(s)	Formats
Video Cameras	Video format
Loop detectors	CSV or other database format
FLHSMV database	CSV or other database format
HART proprietary communication	Log files
Ped-bike counters	CSV or other database format

Table 7-2 Data inputs and outputs of applications

Users	Data Inputs	Format
V2I Safety Application - CSW	Map –provides the layout of the intersection and the curve	GIS File Format
	Queue length within the map – provides the length of the queue which is used to calculate the recommended speed	Log Files
	Recommended speed – provided to the OBU CSW application to compare to the vehicle speed	Log Files
	Standard BSM – transmitted by OBU equipped vehicles. The primary fields used are the latitude, longitude, position, and speed.	CSV
V2I Safety Application - PED-X	Pedestrian PID location – provides the location of the pedestrian. The expected data is the latitude, longitude, heading, and speed.	CSV
	Proxy BSM – provides a BSM for unequipped vehicles/ pedestrians in the crosswalk. The primary data is the latitude, longitude, heading, and speed.	CSV
	Crash alert message – provides a warning to the driver that a potential crash is about to occur.	Log Files
	Crash alert with vehicle message – provide a warning to the pedestrian that a potential crash is about to occur.	Log Files
V2I Safety Application - Mobile Accessible Pedestrian Signals	Standard BSM – transmitted by OBU equipped vehicles. The primary fields used are the latitude, longitude, position, and speed.	CSV

	Pedestrian PID location – provides the location of the pedestrian. The expected data is the latitude, longitude, heading, and speed.	CSV
	System Request Message – requests a pedestrian call to provide the right of way to the pedestrian	Log Files
	System Status Message – provides the feedback on the SRM which will be in the form of a walk phase.	Log Files
V2V Safety Application - EEBL	EEBL message – contains the braking effort of the lead vehicle.	Log Files
	Driver Alert Message – contains the hard braking warning to the driver.	Log Files
V2V Safety Application - FCW	BSM – contains latitude, longitude, heading, and speed.	CSV
	Driver Alert Message – contains the potential crash warning to the driver.	Log Files
V2V Safety Application - IMA	BSM – contains latitude, longitude, heading, and speed.	CSV
	Driver Intersection Message – contains the “proceed with caution” message to the driver.	Log Files
V2V Safety Application - VTRFB	BSM – contains latitude, longitude, heading, and speed.	CSV
	Vehicle Right Turn Message – contains the vehicle turning right warning message.	Log Files
Mobility Application - I-SIG	Standard BSM – transmitted by OBU equipped vehicles. The primary fields used are the latitude, longitude, position, and speed.	CSV
	Proxy BSM – provides a BSM for unequipped vehicles in a detection zone. The primary data is the latitude, longitude, heading, and speed.	CSV
	SRM – provides the request to active a signal phase.	Log Files
	SSM – provide the status of the active signal phase.	Log Files
	Active Phase Message – provides a message to the driver of the active signal phase.	Log Files
Mobility Application - TSP	SRM – requests priority for a transit vehicle pedestrian	Log Files
	SSM – provides priority to the transit vehicle.	Log Files
	Driver Priority Message – provides the priority message to the driver.	Log Files
	Signal Phase Selection – provides the requested phase to the signal controller	Log Files
	Active Phase – provides the confirmation the phase has been initiated.	Log Files
Agency Data Application - PDETM	Standard BSM – transmitted by OBU equipped vehicles. The primary fields used are the latitude, longitude, position, and speed.	CSV
	Travel Time Message – communicated to drivers in minutes.	Log Files

The quality checks for each of these data sources and data outputs are different. A generalized set of basic quality checks is detailed below. This list is borrowed from the online book "Data Quality: High-impact Strategies.” [23]

- Degree of excellence exhibited by the data in relation to the portrayal of the actual scenario.

- The state of completeness, validity, consistency, timeliness and accuracy that makes data appropriate for a specific use.
- The totality of features and characteristics of data that bears on their ability to satisfy a given purpose; the sum of the degrees of excellence for factors related to data.
- The processes and technologies involved in ensuring the conformance of data values to business requirements and acceptance criteria.
- Complete, standards based, consistent, accurate and time stamped.

Each dataset generated by the above-mentioned data sources will be rigorously tested against these quality standards. If there are errors like missing fields or other common data errors, the sources will be investigated for equipment/sensor failures. Some common errors encountered while collecting and storing large datasets are:

- Missing values
- Unrealistic values
- Leads or Lags in recording data
- Issues with file formats
- Mislabeled variables
- Corrupted data due to equipment failure or sensor failure
- Fewer or excess fields than anticipated
- Repeated records
- Unreasonable size of data, etc.

We assume that the CV devices, i.e., the RSEs, the OBEs, and other sensors are certified for data standards conformance. The data standards conformance is ensured at that level during deployment. When the ODE receives the data, it is free of obvious problems like corrupted data. As part of the data quality checks, the data are checked for format and structure.

The rigor of the data checking for format and structure is dependent on the requirements of the end users, which are the RDE, STOL, Independent Evaluator, THEA server, and CV applications that are deployed in Tampa. At the very least, data shared with the Independent Evaluator will be the same as that on the RDE. If all data sharing permissions are in place, sharing of unsanitized data with the Independent Evaluator may be considered. Some of the basic requirements of the subscribers to the ODE are provided in Table 7-3.

Table 7-3 Requirements of the subscribers to the data coming from the ODE

Users	Requirements
Mobility Application - I-SIG	Collect Vehicle Situational Data (VSD) and Infrastructure Situational Data (ISD) and provide them to the I-SIG application
Mobility Application - TSP	Collect Vehicle Situational Data (VSD) and Infrastructure Situational Data (ISD) and provide them to the TSP application
Agency Data Application - PDETM	Collect VSD and provide it to the PDETM application
RDE	The data files are organized into datasets, which are provided under the data environment. All data environments have to be accompanied with metadata documents. Each dataset is a collection of a certain type of data, such as highway

	detector data or traffic signal timing data. The datasets can be updated in the RDE in real time. The data files are a collection of data that can be text, zip, binary, or other file types.
STOL	Same as the RDE requirements for formatting of the data
Independent Evaluators	Same as the RDE requirements for formatting of the data
THEA Server	Same as the RDE requirements for formatting of the data

Upon completion of the basic quality checks, PII will be removed.

7.3.2 PII removal

Most of the collected datasets will undergo some form of cleansing before they are posted to the RDE. BSM data from the OBU's, the Roadside Unit (RSU) /sensor data, and any other driving data collected are typical candidates for cleansing. The execution of the cleansing procedure will be different from one data set to next, even if there are similar data files, because each of these datasets may contain a number of different files, file types, and file structures. Theoretically and technologically, the ODE is capable of real-time sanitization. If technical challenges arise, back of the envelope methods will be adopted for sanitization.

The four categories of datasets are as follows:

1. Trajectory based - Host Vehicle files – this category of files includes those that contain a host vehicle's detailed latitude and longitude data, as well as additional temporal information, that could support the uncovering of (sensitive) Personal Identifiable Information ((S)PII), which will likely not be collected or stored
2. Event Based - Host Vehicle files – these files capture details regarding the occurrence of particular events, such as those associated with forward collision warning or electronic emergency brake light activation, with respect to host vehicle
3. Trajectory Based - Remote Vehicle files – these files record latitude, longitude amongst other data elements from a remote vehicle that is in the vicinity of a host vehicle
4. Trip Summary files – this file type provides detailed trip level information for each trip completed by a host vehicle.

In addition to these, data elements like vehicle length, weight or width, which may potentially be sensitive, will be removed if deemed sensitive on a case by case basis.

Table 7-4 outlines some of the procedures that may be adopted to remove PII from datasets. These procedures can be adopted to clean the data collected at the THEA site (Some of these procedures were tested successfully for PII removal from the Safety Pilot datasets collected in Ann Arbor, MI 2012-2013).

Table 7-4 Some PII Removal Procedures based on the Category of Datasets

File to be Cleansed	Step	Purpose	Action	Output
Trajectory Based - Host Vehicle files (BSM data)	Test Bed Cordon Truncation	Limit data analysis to geographic confines surrounding the test bed area	Establish a mile cordon around the defined test site in Tampa and eliminate all records that place vehicles outside the cordon	All remaining records are those collected within the area of interest
	Distance based Trip Truncation	Protect (S) PII by establishing a distance based buffer zone around each trip's origin and destination	Eliminate host vehicle records that place a vehicle within 1-1.5km from the origin and destination of a trip	The closest coordinate pair, for a host vehicle, will be 1-1.5km away from the beginning or end of a trip, and, therefore, provide a layer of obscurity, protecting (S)PII
	Temporal Trip Truncation	Protect against the discovery of (S)PII for vehicles that the distance truncation step did not sufficiently obscure a trip's O/D (which is normally due to limited network / route choices around a trip's origin or destination)	Rid host vehicle trajectory file of records that were collected within 80 – 100 seconds of the start or end of a trip	Remaining records will only include those that place a vehicle sufficiently far away, both in terms of distance and time, from a vehicle's origin and destination to provide an additional layer of security to protect (S)PII
	Adjustments of Sequential Data Element	Prevent the extrapolation of location data with the aid of additional data elements such as speed	Reset sequentially collected data element, particularly those collected at a known and constant frequency, such that the data element restarts at "1" when the adjustment is complete.	After truncating trip records according to distance and time, the first entries for sequentially collected data elements will be "1," which does not indicate that any other records previously were collected for a given trip
Event Based - Host Vehicle files	Truncation of event based – host vehicle files	Control the possibility of having data elements contain relevant information that may be used to deduce (S)PII	Using truncated trip records, from the above steps, delete event records that may place a host vehicle within the distance and temporal buffer zones around a vehicle's start and end of a trip	This file will be void of records that may be combined with trajectory based records to ascertain the start and end of a host vehicle's trip
Trajectory Base - Remote Vehicle files	Truncation of trajectory based – Remote vehicle files	Guard against the deduction of the start and end of a host vehicle's trip from a remote vehicle's location data (upon knowing range of DSRC)	Remove remote vehicle location data that were collected outside of the time period present for a host vehicle's trip as well as those that places a remote vehicle within 1-1.5km from the start or end of a host vehicle's trip	All remote vehicle records that place a vehicle close enough to the start or end of a host vehicle's trip, will be eliminated to protect (S)PII

Trip Summary Files	Adjustment of Trip Summaries	Allow the summary of each trip to reflect the "new" reality of each truncated host vehicle trip	Mathematically edit trip summary information, such as trip duration and length, so that these summary data elements are consistent with summarized details from a host vehicle's file	Trip summary information will be consistent with the information contained in files with truncated trip information; additionally, trip summaries are not able to provide data that could be used to extrapolate location data to decipher (S)PII

Source: Proposed Data Cleansing Plan for the RDE's Safety Pilot Data Environment Report, September 2013

In addition to these, the mid trajectory stops may also be removed from the trajectories. For example, if a trip begins at home, stops at childcare and then continues to work, the trajectory may be trimmed to represent two trips with the ends of the trajectories truncated to remove identifiable origin or destination information.

7.3.3 Fusion of CV data with other sources

Data fusion and aggregation can ideally be carried out by a framework like ODE.

The ODE is currently operational and the framework has been tested using the SE-MI Testbed in a task sponsored by the US DOT. This framework can be leveraged to carry out real-time processing and propagation of the data generated from multiple data sources in the CV THEA Pilot in Tampa. Four key benefits of the ODE are listed below:

1. **Scalability and Transferability:** The ODE was developed with features and components that are scalable and transferable, and was developed to be able to support the full spectrum of transportation network environments, ranging from rural to urban. The ODE adopted a cloud-ready framework that makes it easily scalable to the needs of the CV Pilot site in Tampa. It can scale in terms of computing power and storage in the cloud. The transferability of the ODE allows it to be implemented at future deployments in other sites.

2. **Single repository for disparate but related data:** The ODE is a single repository of data that includes data communicating the performance of the transportation network and other contextual data like weather, temperature, etc.

3. **Availability of pre-processed data (to support user goals):** The ODE performs two levels of data processing: 1) source-based data processing, and 2) user-driven data processing. Source-based data processing is the processing of source data before it is propagated to users or for archival. This includes data valuation, data aggregation and data integration. User-driven data processing involves customizing the data to a particular subscriber. For example, if PED-X requires traffic counts at a certain frequency in a given geographic location on the network, the ODE can combine the multiple sources of data, i.e., OBU/BSM data and loop detector data to provide a data stream requested by the PED-X application.

An environment such as the ODE can carry out functions like data valuation or checking, data aggregation, data integration from multiple sources, and propagate the data as necessary to storage mechanisms for archiving in real-time or to propagate the data to other subscription services like CV applications, which can use the streamlined and cleaned data to generate alerts or guidance to the users of the network.

7.4 Document procedures for data archival

This section describes the long-term storage and handling of the data sets and related documentation, naming conventions, and organizational conventions of the data sets and data files. The team will develop documentation to facilitate education of the data users or other interested parties regarding the data sets, and to publicize the addition of the data to the wider RDE.

The data need to be aggregated and structured for the RDE and other archival mechanisms. This process includes the following steps:

1. Generate a comprehensive metadata document describing all data elements being collected, their connections to their larger data sets, and a description of how they are stored and captured.

2. Organize the data using the data hierarchy structure that was commonly used in the DCM program. This may include structuring or restructuring the captured data so that it fits the DCM program's data hierarchy structure (i.e., 'Data Environment'-'Data Set'-'Data File').

The components of the DCM program's current hierarchy structure (Source: Adding Data to the Research Data Exchange and Saxton Transportation Operations Laboratory: Process and Issues to Consider, September 2014) are the following:

- Data Environment – a logical collection or grouping of data sets which were obtained under the same contract or agreement. (It is anticipated that the data from a given prototype, demonstration, or project will make up one data environment on the RDE or repository of choice)

- Data Set – contains a certain type of data, such as highway detector data, traffic signal timing data, or weather data. Each type of file in a data set contains the same contents, in the same format with the only difference among these files being the time and the location at which the data elements were collected. There are two data set types: archived and real-time.

- Data File – an archived collection of data that can be comma separated values (CSV), text, binary, or other file types, which might be zipped/compressed depending on the size of the original file.

The structured data may be transmitted to RDE or STOL, based on several criteria described in Section 11 of this document. The transmission of the data can be carried out online or over physical storage devices based on the size of the data and the established archiving requirements.

Real time transmittal: If a server is created for hosting the data, processing and uploading can be carried out in real-time. This archiving method demands technology and resources. If there is a clear research purpose for this archival mechanism, a channel can be created for real-time archival. The

RDE provides an API for real time archiving of data. This can be utilized for transmitting the data in real-time to the RDE.

Off-line transmittal: This can be carried out at established frequencies, such as a day, a week, etc. All data generated between the established frequency will be structured, cleansed and packaged for delivery either online using large file transfer services or through physical storage devices (CDs or hard drives).

8 System Impact Evaluation Plan

This section discusses the procedures and methods for estimating each identified performance measure of Section 4. It details the empirical measurement of each performance measure and the methods to ascertain system improvements that can be attributed to the CV Pilot Deployment.

Backups are defined in this report as level of service (LOS) F conditions, where there is an apparent breakdown in the traffic stream and queuing and queue spillback are observed.

8.1 UC1: Morning Peak Hour Queues

The proposed experimental design for this use case will allow obtaining and measuring performance at the outset of the CV Pilot deployment, using a treatment/control study consisting of two phases. Performance assessment will be conducted on mobility, safety, and environmental metrics as detailed in Section 4. Below is the proposed approach to performance measurement for each of the identified measures.

8.1.1 Mobility

As detailed in Section 4, mobility will be measured in terms of:

- Travel time (using segment level travel time analysis for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St.)
- Travel time reliability (using segment level travel time reliability analysis for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St.)
- Queue length (maximum queue length measured lane by lane from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St.)
- Delay (average delay for auto mode: compared to the average delay data obtained during *before implementation*, as explained under Section 6)
- Throughput (for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St.)
- Percent (%) arrival on green (at REL off-ramp exit and E. Twiggs St.)

At the individual level, mobility will be measured in terms of changes in average travel time savings and travel time reliability (to be calculated using the Lyman and Bertini, 2008 approach) along the travel segments of the Selmon Expressway REL leading to the intersection of Meridian Avenue and Twiggs Street. In addition, the queue length and delay on the Selmon Expressway REL leading to the intersection of Meridian Avenue and Twiggs Street will be analyzed using video cameras/wavetronics software to report actual maximum queue length (lane by lane) in feet and average delay in seconds/minutes. Additionally, for assessing mobility, the percent of vehicles arriving on green will be analyzed through obtaining the number of vehicles that progress through the intersection on green. Throughput will be measured using loop detectors and/or video data for the segment.

Frequency of measurement will be 15-minute and hourly intervals so that morning and evening rush hours can be captured in the analysis. The reporting will be done at daily, weekly, and monthly levels. To gauge the impact of CV technology deployment to users of the system, average changes in the above mentioned performance measures during normal conditions (no backups) will be compared to average changes for the same measures during activation conditions (backups).

At mesoscopic level, mobility will be measured by comparing mean travel times between treated and control groups, controlling for concurring changes in the observed confounding factors. When comparing changes between normal and activation conditions for all participants, the analysis will be carried out in the context of panel data using the general specification of equation (1).

Changes in travel time reliability will be assessed by comparing the 90th or 95th percentile travel times during normal and activation conditions. Travel time distributions along the UC1 travel segment will be constructed, along with mean and standard deviations. Distributional differences between normal and activation conditions will be estimated.

For reporting purposes, measurements will be automated to produce daily, weekly, and monthly performance reports that include mean travel time, the 95th percentile travel time, and the percent of daily, weekly, and monthly readings (at a 5-minute level) that were congested, with a threshold determined by a multiple of the free-flow travel time.

The first step will consist of comparing differences in the distributions between treatment and control. This will be done numerically via parametric and nonparametric (entropy based) measures and graphically for recurrent performance measurement and independent evaluation.

For this UC, the performance measures for the analysis segment are expected to improve (all are expected to decrease except travel time reliability and percent arrival on green, since the progression is expected to get better and, therefore, these measures to increase) for the CV applications case, when compared to the baseline scenario. The target improvement rates are as discussed in Section 4.

8.1.2 Safety

As detailed in Section 4, safety will be measured in terms of:

- Crash reduction / crash rate, measured in crashes per X vehicles or segment miles
- Number of conflicts / near misses in the segment
- Severity of conflicts / near misses in the segment
- Approaching speed on REL, measured in mph in the segment

As a system wide measure, safety will be measured by the crash reduction or crash rate in the segment. Specific crashes (rear-end) that occur due to congestion will be counted for a historic 5-year period baseline. This will be compared to the number of crashes occurring during the CV pilot period. A crash rate per vehicle mile or vehicle volume can also provide a good metric. However, it is expected that this number might not provide much information, since it may not fluctuate significantly for a statistical difference to be established.

To mitigate this, surrogate measures of safety, such as conflicts or near misses will be counted by means of high deceleration rates (<-0.5g) and/or alerts of FCW. In addition, the type of conflict or severity will be categorized to provide a more detailed level of analysis. It is being contemplated to deploy video cameras at the roadside equipped with a specific algorithm to detect changes in speed and/or near misses and, therefore, to provide a way to validate some of the more severe conflicts that can be observed on video. If the algorithm does not work, the video will be used as a manual validation of high deceleration rates in the data streams.

Another metric is the EEBL warning provided to the drivers. This, in conjunction with the oncoming speed of vehicles towards the queue, will determine the safety parameters that are enhanced during CV activation conditions. It is expected that the fewer EEBL alerts, the more efficient and safer the system is.

With the above information and adequate sample size, it is possible to provide probabilities of a vehicle being involved in a crash due to the existing conditions and compare those with the CV activation conditions.

Conflict-based Safety Performance Functions (SPFs) can be utilized to predict conflicts and then predict expected crashes in a nested Poisson-gamma model. This modeling technique developed in [24] and [25] has been shown to provide a consistent result, especially when mixed types of conflicts are combined.

For reporting purposes, the alerts from the CV technologies deployed will be automatically compiled into reports for daily, weekly, and monthly performance reporting.

8.1.3 Environment

Air pollution will be estimated using vehicle speed and distance traveled along the relevant segments of THEA REL Expressway and Twiggs Street, comparing changes occurring during Phase I and Phase II outlined in the proposed experiment design. Vehicle speed and distance traveled will come from the BSMs. Default emission rates come from the EPA's latest version of MOVES. The following emission rates will be estimated from MOVES:

- Atmospheric Carbon Dioxide (CO2)
- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO2)
- Nitrogen Oxide (NO)
- Nitrous Oxide (N2O)
- Particulate Matter (PM10)
- Particulate Matter (PM2.5)
- Sulfur Dioxide (SO2)
- Volatile Organic Compounds (VOC)

The approach to obtain emission rates from MOVES follows the methodology employed by FHWA in assessing the potential environmental benefits of automated vehicles [26]. To obtain detailed emission rates, MOVES will be employed at the project level, customizing the model to reflect the vehicle stock of study participants, taking in account vehicle type, age, fuel. Non-relevant input parameters will be obtained by using the default MOVES parameters.

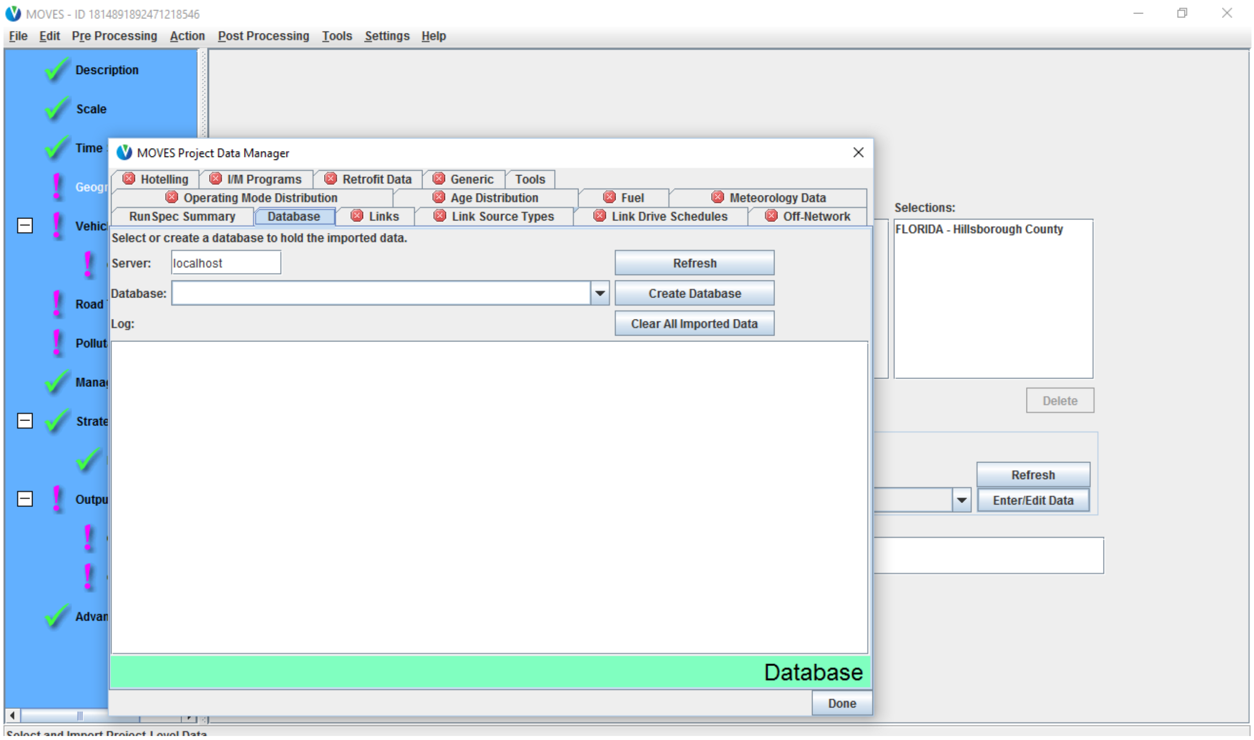

Figure 8-1 Moves Project Data Manager

Source: MOVES Model

To estimate the CV deployment impact on emission, baseline emission will be computed during Stage I of the experiment design.

During Stage I and Stage II, speed, idling time, and acceleration data will be obtained to establish baseline emissions (Stage I) for treatment and control units, and subsequently (Stage II) to compare emissions (idling, running) between treatment and control by applying the ATE estimation approach detailed in Chapter 6.

8.2 UC2: Wrong-Way Entries

The proposed experimental design for this use case will allow obtaining and measuring performance at the outset of the CV Pilot deployment using a treatment/control study consisting of two phases. Performance assessment will be conducted on mobility, safety, and environmental metrics as detailed in Section 4. Below is the proposed approach to performance measurement for each of the identified measures.

8.2.1 Mobility

As detailed in Section 4, mobility will be measured in terms of:

- Travel time delay on REL (average delay for auto mode: measured from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the REL signalized intersection of E. Twiggs St., and compared to the average delay data obtained during *before implementation*, as explained under Section 6)
- Travel time delay on adjacent arterial (average delay for auto mode: from N. Nebraska Avenue to N. 12th Street intersections on E. Twiggs St. This delay is compared to the average delay data obtained during *before implementation*, as explained under Section 6)

For UC 2, mobility will be measured in terms of changes in average travel time delay for all vehicles that are on the Selmon Expressway REL as well as at the intersection of Meridian Avenue and Twiggs Street. The average travel time delay on these segments will be analyzed using video cameras/wavetronics software to report actual delay in seconds/minutes.

Frequency of measurement will be 15-minute and hourly intervals so that morning and evening rush hours can be captured in the analysis. The reporting will be done at daily, weekly, and monthly levels. To gauge the impact of CV technology deployment to users of the system, average changes in the above mentioned performance measures during normal conditions (no backups) will be compared to average changes for the same measures during activation conditions (backups).

For this UC, the travel time delay for the analysis segment is expected to decrease for the CV applications case when compared to the baseline scenario. The target improvement rates are discussed in Section 4.

8.2.2 Safety

As detailed in Section 4, safety will be measured in terms of:

- Crash reduction / crash rate on East Twiggs Street
- Number of conflicts / near misses on East Twiggs Street
- Severity of conflicts / near misses on East Twiggs Street
- Approaching speed on East Twiggs Street

As a system-wide measure, safety will be measured by the crash reduction or crash rate in the segment. Specific crashes (rear-end) that occur due to congestion will be counted for an historic 5-year period baseline. This will be compared to the number of crashes occurring during the CV pilot period. A crash rate per vehicle mile or vehicle volume can also provide a good metric. However, it is expected that this number might not provide much information, since it may not fluctuate significantly for a statistical difference to be established.

To mitigate this, surrogate measures of safety, such as conflicts or near misses, will be counted by means of high deceleration rates (<-0.5g) and/or alerts of FCW. In addition, the type of conflict or severity will be categorized to provide a more detailed level of analysis. It is being contemplated to deploy video cameras at the roadside equipped with a specific algorithm to detect changes in speed and/or near misses, and, therefore, to provide a way to validate some of the more severe conflicts that can be observed on video. If the algorithm does not work, the video will be used as a manual validation of high deceleration rates in the data streams.

With the above information and adequate sample size, it is possible to provide probabilities of a vehicle being involved in a crash due to the existing conditions and compare those with the CV activation conditions.

Conflict-based Safety Performance Functions (SPFs) can be utilized to predict conflicts and then predict expected crashes in a nested Poisson-gamma model. This modeling technique developed in in [24] and [25] has been shown to provide a consistent result especially when mixed types of conflicts are combined.

For reporting purposes, the alerts from the CV technologies deployed will be automatically compiled into reports for daily, weekly, and monthly performance reporting.

8.3 UC3: Pedestrian Safety

8.3.1 Mobility

As detailed in Section 4, mobility will be measured in terms of:

- Travel time (using segment level travel time analysis for auto mode: from REL exit at E. Twiggs St. to N E St.)
- Travel time reliability (using segment level travel time analysis for auto mode: from REL exit at E. Twiggs St. to N E St.)
- Queue length (maximum queue length measured lane by lane from REL exit at E. Twiggs St. to N E St. The queue lengths are projected to be higher in the after CV implementation case compared to the before scenario, because drivers will get warnings and are projected to react to the warnings by stopping more often for pedestrians than in the before CV implementation case. However, the safety aspect is projected to be better. We anticipate there will be some compromise between mobility and safety.)
- Vehicle Delay (average delay for auto mode: compared to the average delay data obtained during *before implementation*, as explained under Section 6)
- Throughput (for auto mode: from REL exit at E. Twiggs St. to N E St.)

At the individual level, mobility will be measured in terms of changes in average travel time savings and travel time reliability along the segment of E. Twiggs Street near the courthouse crosswalk. In addition, maximum queue length (lane by lane) in feet and average delay on the E. Twiggs Street segment near the courthouse crosswalk will be analyzed using video cameras/wavetronics software to report maximum queue length (lane by lane) in feet and average delay in seconds/minutes. Additionally, throughput will be measured using loop detectors and/or video data for the segment.

Frequency of measurement will be 15-minute and hourly intervals so that morning and evening rush hours can be captured in the analysis. The reporting will be done at daily, weekly, and monthly levels. To gauge the impact of CV technology deployment to users of the system, average changes in the above mentioned performance measures during normal conditions (no backups) will be compared to average changes for the same measures during activation conditions (backups).

At mesoscopic level, mobility will be measured by comparing mean travel times between treated and control groups, controlling for concurring changes in the observed confounding factors. When comparing changes between normal and activation conditions for all participants, the analysis will be carried out in the context of panel data using the general specification of equation (1) detailed in Section 6.

Changes in travel time reliability will be assessed by comparing the 90th or 95th percentile travel times during normal and activation conditions. Travel time distributions along the UC3 travel segment will be constructed, along with mean and standard deviations. Distributional differences between normal and activation conditions will be estimated

For reporting purposes, measurements will be automated to produce daily, weekly, and monthly performance reports that include mean travel time, the 95th percentile travel time, and the percent of daily, weekly, and monthly readings (at a 5-minute level) that were congested, with a threshold determined by a multiple of the free-flow travel time.

The first step will consist of comparing differences in the distributions between treatment and control. This will be done numerically via parametric and nonparametric (entropy based) measures and graphically for recurrent performance measurement and independent evaluation.

For this UC, the maximum queue lengths for the analysis segment are expected to be higher (worse) in the after CV implementation case compared to the baseline scenario. This is due to the fact that drivers and pedestrians will get warnings, and the drivers are projected to react to the warnings by stopping more often for pedestrians than in the baseline scenario. Mobility is expected to be sacrificed for safer crosswalk conditions, and a compromise between mobility and safety will result.

8.3.2 Safety

As detailed in Section 4, safety will be measured in terms of:

- Crash reduction / crash rate on East Twiggs Street
- Number of conflicts / near misses on East Twiggs Street
- Severity of conflicts / near misses on East Twiggs Street
- Reduction in approach vehicle speed on East Twiggs Street at the crosswalk

As a system-wide measure, safety will be measured by the crash reduction or crash rate in the segment. Specific crashes (rear-end and pedestrian) that occur due to congestion and high volumes will be counted for a historic 5-year period baseline. This will be compared to the number of crashes occurring during the CV pilot period. A crash rate per vehicle mile or vehicle/pedestrian volume can also provide a good metric. However, it is expected that this number might not provide much information, since it may not fluctuate significantly for a statistical difference to be established.

The pedestrian application deployed in this case will warn drivers to stop because a pedestrian is in the crosswalk or about to cross. Pedestrians will get a warning about an oncoming vehicle. As mentioned previously in chapter 6, a controlled experiment might have to be performed to control for both drivers and pedestrians arriving at the crosswalk at the same time and equipped with CV technologies.

With the above information and adequate sample size, it is possible to provide probabilities of a vehicle being involved in a crash due to the existing conditions and compare those with the CV activation conditions.

Conflict-based Safety Performance Functions (SPFs) can be utilized to predict conflicts and then predict expected crashes in a nested Poisson-gamma model. This modeling technique developed in in [24] and [25] has been shown to provide a consistent result especially when mixed types of conflicts are combined.

For reporting purposes, the alerts from the CV technologies deployed will be automatically compiled into reports for daily, weekly, and monthly performance reporting.

8.4 UC4: Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety

8.4.1 Mobility

As detailed in Section 4, mobility will be measured in terms of:

- Bus travel time (average using segment level analysis for transit/bus mode: along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
- Bus route travel time reliability (average using segment level analysis for transit/bus mode: along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
- Percent (%) arrival on schedule (at bus stops along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
- Percent (%) arrival on green (at signalized intersections along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
- Signal Priority: (at signalized intersections along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center)
    - Number of times priority is requested and granted
    - Number of times priority is requested and denied
    - Number of times priority is requested, granted, and then denied due to a higher priority

For this use case, mobility will be measured in terms of changes in average bus travel time savings and bus travel time reliability along the travel segments of Marion Street, starting from the Kennedy Boulevard and Marion Street intersection to the Marion Transit Center. In addition, for assessing mobility, the percent of buses arriving on schedule, arriving on green will be analyzed through obtaining the number of buses arriving to their bus stop on schedule, that progress through the signalized intersections on this segment on green.

In addition, signal priority data, such as the number of times priority is requested and granted, the number of times priority is requested and denied as well as the number of times priority is requested, granted and then denied to due to a higher priority being granted such as an EMS vehicle, will be collected and analyzed.

Frequency of measurement will be 15-minute and hourly intervals so that morning and evening rush hours can be captured. The reporting will be done at daily, weekly, and monthly levels.

For this use case, the performance measures for the analysis segment are expected to improve (all are expected to decrease except bus route travel time reliability and arrival on schedule and percent arrival on green, since the progression is expected to get better and, therefore, these measures to increase) for the CV applications case when compared to the baseline scenario. The target improvement rates are as discussed in Section 4.

8.4.2 Safety

As detailed in Section 4, safety will not be measured for this use case. No safety metrics were identified for analysis.

8.5 UC5: TECO Line Streetcar Trolley Conflicts

8.5.1 Mobility

As detailed in Section 4, mobility will not be measured for this UC.

8.5.2 Safety

As detailed in chapter 4, in order to determine the safety benefits for UC5, the research team will analyze the following performance measures:

- Crash reduction / crash rate at the length of the TECO line in the focus area
- Type of conflicts / near misses at the length of the TECO line in the focus area
- Severity of conflicts / near misses at the length of the TECO line in the focus area

This is a fairly complicated case involving almost all ground transportation modes. Safety will be evaluated in terms of reduction of crashes and conflicts measured by video cameras deployed or by participants that have CV technologies deployed on their vehicles and smartphones. The TECO Line Streetcars will be equipped with CV technologies and monitoring video cameras to be able to record conflicts that occur between the streetcars and vehicles, pedestrians and bicyclists. Also the number of alerts from the CV technologies will be counted as a measure of potential conflicts and compared to the same conflicts in the “before” period.

8.6 UC6: Enhanced Signal Coordination and Traffic Progression

8.6.1 Mobility

As detailed in Section 4, mobility will be measured in terms of:

- Travel time (using segment level travel time analysis for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the Channelside Dr. signalized intersection on Meridian Avenue)
- Travel time reliability (using segment level travel time reliability analysis for auto mode: from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the Channelside Dr. signalized intersection on Meridian Avenue)
- Queue length (maximum queue length measured lane by lane from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the Channelside Dr. signalized intersection on Meridian Avenue)
- Delay (average delay for auto mode: compared to the average delay data obtained during *before implementation*, as explained under Section 6)
- Throughput (for auto mode, from the beginning of REL off-ramp, 1500-ft ramp influence area from the gore per the HCM, to the Channelside Dr. signalized intersection on Meridian Avenue)
- Percent (%) arrival on green (at all signalized intersections from the beginning of REL off-ramp exit to the Channelside Dr. signalized intersection on Meridian Avenue)

Backups are defined in this report as level of service (LOS) F conditions, where there is an apparent breakdown in the traffic stream and queuing and queue spillback are observed. At the individual level, mobility will be measured in terms of changes in average travel time savings and travel time. In addition, the queue length and delay on the above-mentioned segments will be analyzed using video cameras/wavetronics software to report actual maximum queue length (lane by lane) in feet and average delay in seconds/minutes. Additionally, for assessing mobility, the percent of vehicles arriving on green will be analyzed. Throughput will be measured using loop detectors and/or video data for the segment.

Frequency of measurement will be 15-minute and hourly intervals so that morning and evening rush hours can be captured in the analysis. The reporting will be done at daily, weekly, and monthly levels. To gauge the impact of CV technology deployment to users of the system, average changes in the above-mentioned performance measures during normal conditions (no backups) will be compared to average changes for the same measures during activation conditions (backups).

At a mesoscopic level, mobility will be measured by comparing mean travel times between treated and control groups, controlling for concurring changes in the observed confounding factors. When comparing changes between normal and activation conditions for all participants, the analysis will be carried out in the context of panel data using the general specification of equation (1) detailed in Section 6.

Changes in travel time reliability will be assessed by comparing the 90^{th} or 95^{th} percentile travel times during normal and activation conditions. Travel time distributions along the UC6 travel segment will be constructed, along with mean and standard deviations. Distributional differences between normal and activation conditions will be estimated.

For reporting purposes, measurements will be automated to produce daily, weekly, and monthly performance reports that include mean travel time, the 95th percentile travel time, and the percent of daily, weekly, and monthly readings (at a 5-minute level) that were congested, with a threshold determined by a multiple of the free-flow travel time.

The first step will consist of comparing differences in the distributions between treatment and control. This will be done numerically via parametric and nonparametric (entropy based) measures and graphically for recurrent performance measurement and independent evaluation.

For this UC, the performance measures for the analysis segment are expected to improve (all are expected to decrease except travel time reliability and percent arrival on green, since the progression is expected to get better and therefore these measures to increase) for the CV applications case when compared to the baseline scenario. The target improvement rates are as discussed in Section 4.

8.6.2 Safety

As detailed in Section 4, safety will be measured in terms of:

- Crash reduction / crash rate on Meridian
- Number of conflicts / near misses on Meridian
- Severity of conflicts / near misses on Meridian
- Average speed on Meridian

As a system-wide measure, safety will be measured by the crash reduction or crash rate in the segment. Specific crashes (rear-end) that occur due to congestion will be counted for a historic 5-year period baseline. This will be compared to the number of crashes occurring during the CV pilot period. A crash rate per vehicle mile or vehicle volume can also provide a good metric. However, it is expected that this number might not provide much information, since it may not fluctuate significantly for a statistical difference to be established.

To mitigate this, surrogate measures of safety, such as conflicts or near misses, will be counted by means of high deceleration rates (<-0.5g) and/or alerts of FCW. In addition, the type of conflicts or severity will be categorized to provide a more detailed level of analysis. Video cameras deployed at the roadside are expected to provide a way to validate some of the more severe conflicts that can be observed on video.

Another metric is the EEBL warning provided to the drivers. This in conjunction with the oncoming speed of vehicles towards the queue will determine the safety parameters that are enhanced during CV activation conditions. It is expected that the fewer vehicles that form a queue, the fewer EEBL alerts will exist and, therefore, the system works more efficiently and safely. With the above information and adequate sample size, it is possible to provide probabilities of a vehicle being involved in a crash due to the existing conditions and compare those with the CV activation conditions.

Conflict-based SPFs can be utilized to predict conflicts and then predict expected crashes in a nested Poisson-gamma model. This modeling technique developed in in [24] and [25] has been shown to provide a consistent result, especially when mixed types of conflicts are combined.

For reporting purposes, the alerts from the CV technologies deployed will be automatically compiled into reports for daily, weekly, and monthly performance reporting.

9 Performance Reporting

This section details the system performance reporting framework to inform the community, key stakeholders and the independent evaluators. It discusses the mechanisms to report the performance measures identified in Section 4, their tracking and benchmarking against the anticipated targets, and reporting frequency. In developing a performance reporting mechanism that suits the needs of the community and key stakeholders, this section draws from and follows recommendations from a series of FHWA reports on performance reporting practices (ref 1) and technical implementations (ref 2).

9.1 Reporting to the Community and Stakeholders

To effectively communicate to the public how well the CV Pilot will be performing against the identified performance measures, information will have to be provided to the community. In the process, it is relevant to understand that information must be presented and conveyed in a format to which the public can readily understand and relate. Information should help answer key questions, such as, has there been an improvement in the travel conditions due to CV deployment? If so, is this an improvement that matters? To effectively inform the public, a dashboard information design will be implemented.

9.1.1 Dashboard Approach

This plan proposes to develop a website that uses an interactive infographic approach to track and report performance measures. The website will be structured so that users will be able to assess how each one of the six use case studies is performing in terms of the performance measures identified in Section 4. The website will have a set of headers for each of the six use cases (Figure 9-1). Each use case will have clickable tabs labeled following the performance pillars (Mobility, Safety, Environment, and Efficiency).

Figure 9-1 Performance Measures Reporting
Source: CUTR

Performance tracking will not be static in terms of just providing a snapshot of conditions, but will allow mechanisms to measure and contextualize progress towards established targets of Section 4.

9.2 Reporting to Independent Evaluators

Independent evaluators will have access to data downloads and reports using a restricted area within the website as detailed in the ODE (Figure 7.1). Information will be downloadable using summary tables on each performance measure for every UC. In addition, custom queries can be made using an ad-hoc table query mechanism.

Sensitive data like driving logs or videos can only be shared with permission. If the IE team requires all data, then permissions have to be in place before the data can be transmitted. Transmission frequency for the IE can be the same as for STOL or customized as per their contractual requirements. Section 11 discusses the sharing framework.

9.3 Reporting Frequency

Information to the community infographic website will be provided on a daily basis. Users will be able to have information displayed by frequency (daily, weekday, monthly basis). Reporting frequency to the IE will be daily, weekly, monthly, or by custom-set date range. Modeled performance evaluation, based on statistical modeling output, will be provided on a weekly basis.

9.4 Prototype Website

To ensure maximum effectiveness, this plan proposes the development of a prototype website to be implemented during Phase II of the CV Pilot (Design/Build/Test). The prototype will be made available for testing and will showcase the website and report design.

10 Support to Independent Evaluation (IE) Effort

The THEA CV Pilot Deployment supports continuous monitoring of data capable of quantifying performance measures. The impact of the deployment on the set of key performance measures identified in Section 4 of this document will be monitored and reported on a daily, weekly, and monthly basis. Performance and other data supporting a comprehensive assessment of deployment impacts will be shared with an independent evaluator, to be determined by US DOT, and the data needs associated with an independent evaluation effort will be supported. Section 9 details the data access/sharing approach that will serve as a basis to support IE efforts.

10.1 Physical Elements Data Flow

To provide broader evaluation-related capabilities required to support the THEA site-specific independent evaluation effort, this plan identifies data flows between the physical elements. Data produced by the CV equipment for each UC will be stored in a database that is available to FHWA, the THEA team and the IE. This is illustrated in Figure 10-1. UC information flows are the source of data for the IE's performance measures, in whatever way the IE wishes to structure them.

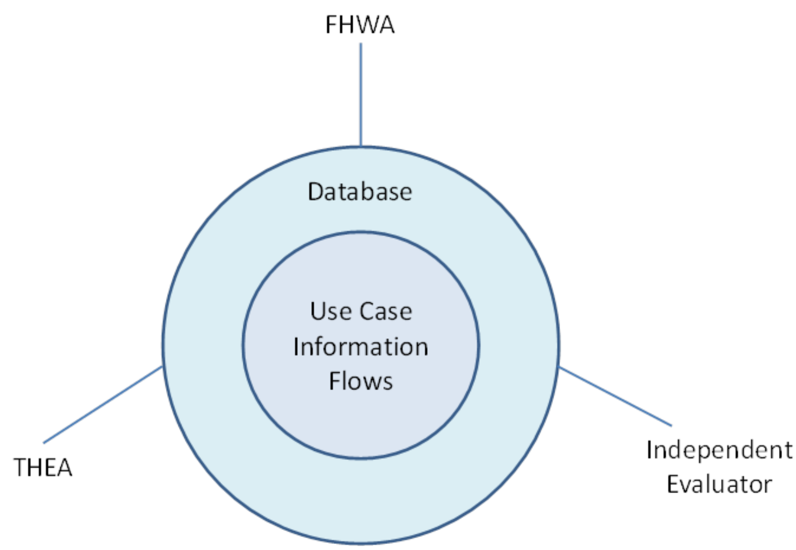

Figure 10-1 Data Production for Performance Measurement
Source: HNTB

11 Data Sharing Framework

The objective of the data-sharing framework is to facilitate the sharing of the data generated in the CV Pilots projects so that they can be used for further research into connected vehicle applications and deployments, including other CV Pilot projects.

11.1 Performance Measurement Data

The CV Pilot will gather several types of data that will be scrubbed of potential PII issues and then shared with US DOT. The data will be archived to the RDE for access by the research community. For each use case, a list of the data planned for sharing is listed below:

- **Morning Peak Hour Queues**
    - Normalized speed
    - Vehicle speed
    - BSMs
    - Signal timing updates
    - EEBL warnings
    - FCW warnings
    - CSW warnings
- **Wrong Way Entries**
    - Vehicle BSMs
    - Wrong way entry warnings
    - Wrong way driver warnings
- **Pedestrian Safety**
    - Pedestrian BSMs
    - GPS corrected pedestrian BSMs
    - Vehicle BSMs
    - Pedestrian warnings
    - Driver warnings
- **Bus Rapid Transit Signal Priority Optimization, Trip Times and Safety**
    - Bus location
    - Bus movement
    - Bus number
    - Bus route
    - Bus schedule
    - Priority granted

    - Priority denied
    - Priority granted, then denied

- **TECO Line Streetcar Trolley Conflicts**

    - Vehicle BSMs
    - Trolley BSMs
    - Pedestrian BSMs
    - GPS corrected Pedestrian BSMs
    - Vehicle turning right in front of trolley warnings
    - Pedestrian warnings
    - Vehicle warnings
    - Trolley warnings (to pedestrian only)

- **Enhanced Signal Coordination and Traffic Progression**

    - Vehicle BSMs

These data will be aggregated and cleansed into data sets. The actual aggregation and cleansing will be determined during the System Design. Raw and prepared data will be provided to the RDE once it has been stripped of all potential 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.

Once the CV Pilot is operational, the planned transmittal of data to the RDE will be on a quarterly basis, lagging by a quarter. This timeframe provides adequate time to amass an appropriate data sample and prepare the data.

11.2 Data Privacy

Privacy issues: privacy issues are considered in the context in which the collection occurs. Privacy concerns for state-owned service vehicles are different from those for data collected from private vehicles. The rules related to privacy must be communicated unambiguously.

1. Establish data ownership. As a general rule, whoever owns the vehicle, owns the data generated by that vehicle. An OEM may also claim ownership of data published on the vehicle's data bus. This has to be resolved.
2. Secure consent from the data owner. The owner of data must consent to providing the data in an agreement (drafted by the CV Pilot THEA team) that spells out how the data are used and by whom. This should include the re-distribution of data to third parties.
3. Protect the privacy of the data owner. Any information that reveals the identity of the data owner must be eliminated.
4. Identify data aggregation issues. In some cases, aggregating CV data over time can reveal patterns that are sensitive from the point of view of commercial, military, or other propriety information about the internal operations of firms or agencies. These situations will be handled individually as they arise.

Prior to uploading data to any repository, necessary data sharing agreements will be obtained. These data sharing agreements will need to be approved by all entities, and/or their representatives, whose data will be included in the data sets that the CV Pilot team will be providing to the RDE or the STOL repositories. Figure 11-1 illustrates a sample data sharing agreement form.

VOLUNTARY DATA CONTRIBUTION LICENSE
BETWEEN THE
U.S. DOT DATA CAPTURE & MANAGEMENT PROGRAM
AND

____

1. I, ______________________________, am authorized to execute this license for and on behalf of the identified State / Agency / Organization (hereinafter called the Data Contributor).
2. The Data Contributor desires to voluntarily contribute ____________________(describe data in this space)(here after called "the data") to the U.S. DOT Data Capture & Management Program.
3. The Data Contributor does not seek any compensation in exchange for providing the Federal Government with a copy and license of the data.
4. The Data Contributor agrees and grants the U.S. DOT the right to use, disclose, reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, in any manner and for any purpose, and to have or permit others to do so, all data provided under this agreement.

The undersigned approve the terms and conditions of this Data license and represent that they have the requisite authority to enter into it.

____ ____________

(*State, Agency, or Organization Representative, and Title*) Date

Figure 11-1 Snapshot of Data Agreement to be Completed by Data Providers
Source: Process for Capture and Addition of Data Sets for the Research Data Exchange and Other Federal Repositories, April 2013.

11.3 Data Preparation

Within this step, the objective is to prepare the data sets for either public consumption on the RDE or restricted consumption at STOL. When the data are cleaned and prepared as documented in Section 7 of this report, the team can proceed with readying the data sets for posting or storing.

First, the appropriate repository in which to store the data is determined. If datasets contain PII or have other privacy concerns, storage of the full extent of data is permissible at federal repositories with restricted access, such as STOL. In cases where the PII or other sensitive information can be removed, a venue such as the federally-hosted RDE may be appropriate for storage. If it is determined that a particular data set that contains sensitive information should be posted to the RDE, the data will be sanitized to remove PII as described in Section 7.

Some basic checks that are required in this stage are:

1. Data documentation is complete
2. Data are categorized and structured in a manner that is understandable and useful
3. Data elements are in standard formats (e.g., comma-separated value (CSV) format that enables other parties to read the data without the need of proprietary software)
4. Data conform to an appropriate ITS Standard (e. g., SAE J2735 for DSRC communications, SAE J2354 for center-to-center communications, or IEEE 1512 for incident management)
5. Data are cleared for sharing with appropriate data sharing agreements between the data providers and US DOT

These basic checks clear the data for archiving. Some special checks are required before data can be transmitted to the RDE:

1. Data are free of PII
2. Data are in a manageable size and format that is useful to the users (data are broken down into chunks that can be easily downloaded over the internet)
3. Data are tagged for efficient data queries
4. There are two types of data documentation that will accompany each data environment on the RDE (and most other repositories): 1) metadata documentation and 2) optional data handbook/dictionary documentation.
    a. Metadata documentation is in a format derived from the ASTM 2468-05 standard metadata format, so there is uniformity in content, structure, and format.
    b. The optional data handbook/dictionary document contains some of the same information as the metadata document but with additional information regarding files and data elements that were collected. In some cases, the data provider's existing documentation could serve or be slightly modified to serve as this optional data handbook/dictionary documentation. The additional information provided by the data handbook also includes:
        i. Details about how the data were collected and processed
        ii. Background information about the overall task that led to the collection of data being uploaded to the RDE
        iii. Specifics regarding how the data was structured
        iv. Supporting information as to how the aforementioned RDE requirements and procedures were completed for a particular data environment
        v. If a data handbook/dictionary document is being provided to the public via the US DOT, it must be in a Section 508 compliant format and it needs to undergo the US DOT publication process.

If all these checks are complete, the data can be cleared for transmission.

11.4 Transmitting Data

There are two main methods of transfer of the data to the public users (through RDE) or to the USDOT:

1. Archived means
2. Near real-time transmission

If there are clear established purposes for either means, they will be carried out as outlined below:

1. Archived data is prepared for transmission through acquiring and packaging data from the CV Pilot site over a length of time, such as over a period of hours, days or months. This form of transmission is appropriate where there is no established case for real-time communications. Also, the archived means of sharing data is appropriate in cases where sensitive data exists, like in the CV Pilot. For example, video data cannot be easily processed and sanitized in real time. The frequency of distribution of the archived data to US DOT should be as frequent as possible to ensure that the STOL and the external evaluators have access to the data for evaluation. The insights gained from these external evaluations are further helpful in enhancing the CV Pilot site.

2. Real-time transmission of the data to the US DOT RDE is possible if all the collected and compiled CV pilot data can be processed in real time using a framework like the ODE, which not only cleans the data, but also aggregates and categorizes them appropriately for archiving. Unless the archiving platform (STOL or RDE) offers a subscription service that allows users to use the data in real-time, the archived method is preferred. Currently, the RDE can archive data in real-time. It does offer an API that is capable of providing a subscription service like the ODE where users can connect to a live stream of cleaned data coming into the RDE.

3. Performance metrics interface and public facing metrics will be developed in detail in subsequent phase of the Pilot and the reporting will be formatted as a dashboard. The dashboard will allow the users to aggregate the metrics over time (hour, day, week, etc.) and also visualize metrics using map-based visualizations.

12 Conclusions

The Performance Measurement and Evaluation Support Plan for the Connected Vehicle Pilot Deployment Program Phase 1, Tampa Hillsborough Expressway Authority, outlines the goals and objectives for the Pilot as well as the proposed performance metrics. The document addresses problems and operational needs of the Pilot focus areas, the improvements desired for the focus area, the goal-related performance measures for each of the six Use Cases, confounding factors, system deployment impact evaluation, methods and procedures for data collection, methods for estimating each identified performance measure, the manner in which performance will be reported, and the interface between THEA and its core agency partners with the Independent Evaluation effort.

Because this deployment will utilize several CV technologies in different locations to deal with a collection of safety and mobility field conditions, an experimental design and set of performance measures are described for each of six Use Cases. A detailed approach to participant selection and to the treatment of confounding factors is presented as evidence of a scientifically sound approach to the design of the entire CV Pilot evaluation. The six use cases are considered individually for experimental design, participant selection, and measurements of performance. While each use case use may not be appropriate for evaluation in each of the four evaluation pillars (Safety, Mobility, Environment, and Agency Efficiency), the assessment of the full set of CV application deployments will address all of them.

The procedures and processes detailed in this plan will need to be modified as required as the Pilot deployment for Tampa moves into Phase II.

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