Connected Vehicle Pilot Deployment Program Independent Evaluation:

Mobility, Environment, and Public Agency Efficiency Refined Evaluation Plan—New York City

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16. Abstract

The purpose of this report is to provide a refined evaluation plan detailing the approach to be used by the Texas A&M Transportation Institute Connected Vehicle Pilot Deployment Evaluation Team for evaluating the mobility, environmental, and public agency efficiency (MEP) impacts of the New York City CV Pilot Deployment. Building upon the approach initially outlined by Noblis, this provides a mid-level view of the analyses related to quantifying the MEP benefits. Others entities are responsible for designing the safety and user acceptance evaluation approaches. The TTI CVPD Evaluation Team will integrate the detailed MEP approach with these safety and non-safety related data collection activities into a Comprehensive Evaluation Plan (CEP) for the New York City site. This document covers the following topics related to the MEP evaluation for the New York City Site:

- Site overview and performance measurement plan summary.
- USDOT goals and objectives for the deployment.
  - Key hypotheses that should be tested.
  - Performance measures that underpin the hypotheses.
- Potential confounding factors and risks that may affect the evaluation.
- Preliminary evaluation approach.
- Descriptions of a minimum set of additional sections to be included in a refined MEP approach document.
  - Data collection.
  - Observed data analysis.
  - Simulation-based evaluation.
  - Survey-based evaluation.

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1 Introduction

1.1 Background

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

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

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

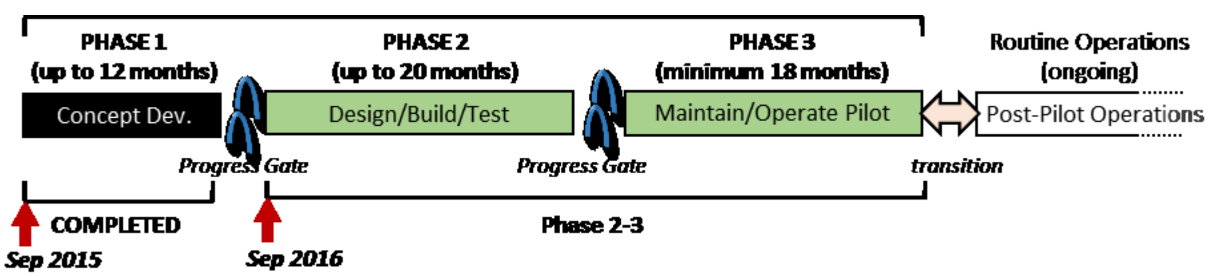


Figure 1-1. The Three Phases of a Connected Vehicle Pilot Deployment.

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

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

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

In parallel, the independent evaluation will help the Sites with the following:

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

While the sites' performance measurement activity will be limited to their study areas, project goals and corresponding performance measures, the roles of the Independent Evaluator are as follows:

- Conduct a comprehensive evaluation of the deployments as implemented.
- Assess short-term and long-term impacts of the deployments (by looking at various levels of market penetration of CV technology).
- Conduct a national-level evaluation of CV deployment, which is an assessment of potential impacts of CV technology and applications when deployed on a national scale (based on an extrapolation of findings from the three pilot sites.
- Conduct a program level evaluation of the CV Pilots Program to inform the Government if the CV Pilots program was able to achieve its vision cost effectively.

1.2 Purpose of the Report

The intent of this report is to update the preliminary evaluation plan developed by Noblis in October 2016. This document reflects the latest thinking by the Texas A&M Transportation Institute Connected Vehicle Pilot Deployment (TTI CVPD) Evaluation Team relative to approaches and data that will be used to assess the mobility, environmental, public agency efficiency (MEP), and cost-benefit impacts associated with New York City Connect Vehicle Pilot Deployment (NYC CVPD). The report also identifies additional data collection activities, including those needed to address safety-related data needs identified by Volpe that the TTI CVPD Evaluation Team may need to perform. The report provides the foundation for the overall evaluation approach. Other reports planned by the TTI CVPD Evaluation Team will be developed that provide the details of the planned evaluation. These include the following:

- *Stakeholder Acceptance/Satisfaction Evaluation Plan* – this plan describes the processes and procedures for collecting and analyzing feedback and lessons learned information from stakeholders, specifically decision makers, deployment operators, and mangers.
- *Stakeholder Survey/Interview Guide* -- this guide includes the questions, the process and procedures the TTI CVPD Evaluation Team will use to collect, process, and analyze data related to stakeholder satisfaction.
- *Site-Specific Data Plan* – this plan describes the processes and procedures the TTI CVPD Evaluation Team will follow to collect, protect, manage, and dissemination data collected as part to evaluation.
- *Site-Specific Analysis, Modeling, and Simulation (AMS) Plan* – this plan describes the processes and procedures that the TTI CVPD Evaluation Team will follow for modeling and assessing the MEP impacts associated with the deployment.
- *Site-Specific Acquisition, Installation, and Test Plan* – this plan describe the process and procedure that the TTI CVPD Evaluation Team will follow to procure, install, and test any additional data collection or system needed by the TTI CVPD Evaluation Team.
- *Site-Specific Participant Training and Evaluation Outreach Plan* – these plans describe the processes and procedures that will be used to train test and recruit test participants if needed for the evaluation.
- *Site-Specific Comprehensive Evaluation Plan* – this plan provides on overarching plan that provides a final summary of all the other plans developed to support the evaluation. The Comprehensive Evaluation Plan is a further refine of this plan.

1.3 Organization of Report

This report is organized as follows:

- Section 2 provides an overview of the NYC CVPD including a description of the deployment corridors and the applications planned as part of this deployment.
- Section 3 lists USDOT goals and objectives for the deployment as well as the goals, objectives, hypotheses, and anticipated performance measures that underpin the hypotheses.

- Section 4 provides a description of the potential confounding factors and risks that may affect the evaluation.
- Section 5 provides an overview of the approaches that will be used to conduct the assessment planned by the TTI CVPD Evaluation Team.
- Section 6 provides an overview of the data that will be collected by both the NYC CVPD Team as well as the TTI CVPD Evaluation Team.
- Section 7 discusses the role of observation-based data analysis in the overall evaluation of the NYC CVPD.
- Section 8 discusses the role of simulation in the overall evaluation of the NYC CVPD.
- Section 9 discusses the role of survey-based evaluation in the overall evaluation of the NYC CVPD.

2 New York City CV Pilot System Overview

This section describes the pilot deployment site, goals, and objectives associated with the deployment, and the set of applications chosen to meet these objectives, and summarizes the metrics and data associated with the site performance measurement activity.

The New York City Connected Vehicle Pilot Deployment focuses on utilizing Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) CV applications to alert vehicles of unsafe roadway conditions and to prevent collisions with other vehicles and pedestrians. The main objective of the NYC CVPD, which is anticipated to be the largest CV deployment to date, is to bring the City closer to achieving its *Vision Zero* initiative that seeks to eliminate traffic fatalities by 2024.

2.1 Site Description and Transportation Issues

The NYC CVPD project area encompasses three distinct areas in the boroughs of Manhattan and Brooklyn.

Source: NYCDOT

Figure 2-1. 1 NYC CVPD Overview Map.

The first area includes a 4-mile segment of Franklin D. Roosevelt (FDR) Drive from 50th Street to 90th Street. FDR Drive is a two-way, north-south limited-access highway with six travel lanes, three in each direction, on the east side of Manhattan. Its challenges include short-radius curves, a weight limit of 8,000 lb, and a minimum bridge clearance of 9 ft 6 in. It also runs through two tunnels underneath the New York Presbyterian Hospital from 68th Street to 71st Street and Carl Schurz Park from 81st Street to 90th Street. Commercial vehicles, trucks, and tractor-trailers are prohibited on all parts of the corridor and buses cannot access FDR Drive north of 23rd Street. The speed limit on FDR Drive is 40 mph, and the Average Annual Daily Traffic in 2013 was 136,060 vehicles. Through the use of CV technology, the New York City Department of Transportation (NYCDOT) hopes to reduce high-speed crashes with infrastructure in this area and to help cut down on the $2 million costs that are accrued annually in over-height incident delays.

The second area includes four one-way corridors of 1st Avenue, 2nd Avenue, and 5th Avenue from 14th Street to 67th Street and 6th Avenue from 14th Street to 59th Street in Midtown and Upper East Side neighborhoods of Manhattan. The segment lengths are 2.6 miles for 1st, 2nd, and 5th Avenues and 2.2 miles for 6th Avenue, respectively. The corridors are comprised of 4–6 total lanes each, with various lanes being reserved for buses/pedestrians/bikes. In addition to the north/south avenues, five east/west two-way cross streets (14th, 23rd, 34th, 42nd, and 57th Streets) will be secondary corridors. These cross streets are approximately 1.5 miles each and vary from 2–3 lanes per direction, with bus reserved lanes existing on 34th, 42nd, and 57th Streets.

The third area covers a 1.6-mile segment of Flatbush Avenue in Brooklyn from Tillary Street on the north and Grand Army Plaza near Prospect Park to the south. While FDR Drive is a freeway without signalized intersections, the four avenues and five cross-streets in Manhattan include 281 signalized intersections and Flatbush Avenue in Brooklyn includes 28 signalized intersections.

NYCDOT recently (on November 7, 2014) adopted a reduction in the citywide speed limit from 30 mph to 25 mph based on the assumption that slower speeds would provide drivers with more time to react to traffic conditions and to avoid pedestrians and bicycles. The City proposes to implement the CV technology at the aforementioned signalized intersections in Manhattan and Brooklyn to manage speeds by alerting drivers when they are exceeding the speed limit. As a city bustling with pedestrians, the pilot will also focus on reducing vehicle-pedestrian conflicts in these areas through V2I pedestrian applications that will deliver in-vehicle pedestrian warnings and an additional project component that will put mobile devices in the hands of visually impaired pedestrians to assist them in safely crossing the street.

The three geographic areas for this technology deployment are depicted in the following figure. FDR Drive is outlined in red while the arterial roads in Brooklyn and Manhattan are in green. Red marks indicate where at least one traffic fatality occurred between 2009 and 2014.

Source: NYCDOT

Figure 2-2. Infrastructure Deployment Map.

2.2 Goals and Objectives

The goals of the NYC CV Pilot Deployment project are aligned with New York City's Vision Zero initiative, which seeks to reduce the deaths of pedestrians and make the City's streets safer for all modes of transportation. Specific goals and objectives include:

- Encourage safe operations on the city's roadways by:
  - Reducing speeding and increasing adherence to posted speed limits.
  - Reducing crashes on sharp reduced speed curves on roadways.
- Improving work zone safety.
- Reduce the number of fatalities and injuries from crashes on NYC's roadways from vehicle to vehicle crashes.
- Reduce the number of pedestrian fatalities and injuries from crashes on NYC's roadways from pedestrian-involved crashes.
- Reduce the fatalities, injuries, and disruptions from truck crashes on NYC's roadways with low clearance bridges.
- Improve operations that suffer from lengthy clearance times of truck-bridge strike crashes.
- Improve safety and mobility for the traveling public through improved information dissemination during serious incidents.

2.3 Proposed CV System Description

2.3.1 Vehicles

The City is planning to equip up to 8,000 vehicles that frequent the deployment area with Aftermarket Safety Devices (ASD). The equipped vehicles will span four categories: taxis, buses, commercial fleet delivery trucks, and other City vehicles. Table 2-1 shows a breakdown of the specific fleet owners. In addition to the 8,000 vehicle ASDs, NYCDOT will purchase 600 spares. NYCDOT also anticipates about 900 re-installations due to turnover in the vehicle fleet.

This equipped fleet will provide an opportunity to experience a significant density of dedicated short range communications (DSRC)-based vehicle interactions. These vehicle's V2V safety applications will operate anywhere they encounter another DSRC-equipped vehicle.

Table 2-1. Summary of Devices for Deployment.

NYCDOT – Devices	Estimated Number
Total Roadside Units (RSUs)	**353**
• Intersections at Manhattan (on 1st, 2nd, 5th, and 6th Avenues and on 14th, 23rd, 42nd, 57th Streets)	281
• Intersections in Brooklyn (Flatbush Avenue)	28
• Critical Infrastructure on FDR	8
• Support locations outside the pilot area (e.g., river crossings, airports, and vehicle garages)	36
Total Equipped Vehicles with ASD*	**8,000**
• Taxis	5,850
• Metropolitan Transportation Authority (MTA) Buses	700
• United Parcel Service (UPS) Delivery Trucks	400
• NYCDOT Fleet Vehicles	800
• NYC Department of Sanitation (DSNY) Fleet Vehicles	250

**In addition, 600 spare ASDs will be purchased.*

Source: Reference (7)

2.3.2 Roadside and Communication Infrastructure

NYCDOT plans to integrate existing roadside elements into the system. These elements include NYC's traffic management system, advanced traffic signal controller, and supporting NYCWiN communications infrastructure. NYCDOT will also be deploying new CV infrastructure to support the operation and management services for the CV applications. RSUs, PED Detection Systems, Vulnerable Road User (VRU) devices, wired and wireless communication networks, and ATC upgrades comprise the new system elements.

NYCDOT plans to install approximately 310 RSUs at signalized intersections along 1st, 2nd, 5th, and 6th Avenues and on the major cross-town streets consisting of 14th, 23rd, 34th, 42nd, and 57th Streets in Manhattan and Flatbush Avenue in Brooklyn. In addition, NYCDOT will be installing eight RSUs along portions of FDR Drive. The vehicle's V2I safety applications will function where they encounter RSUs along these streets.

NYCDOT plans to install another set of RSUs at other strategic locations throughout the City such as river crossings, the airports, and at the vehicle barns (bus, taxi, and fleet depots). These units are positioned to have longer contact with the equipped vehicles in support of system management functions such as parameter configuration and event data collection.

At ten (10) selected intersections, the NYCDOT will also be installing PED Detection Systems. The PED Detection System will consist of traditional Intelligent Transportation System (ITS) pedestrian detection technology (e.g., video and/or infrared detection) and will be able to determine if there is a potential conflict between an approaching CV equipped vehicle and the presence of a pedestrian in the crosswalk. NYCDOT will also purchase personal information devices (PIDs) for a group of VRUs to support visually impaired pedestrian safety; however, these devices are relatively new and will be deployed on a very limited basis (100 devices).

2.3.3 Centers

Software residing at the Traffic Management Center (TMC) will monitor the operational integrity of the various elements of the system and will track the parameter and software management of the ASDs and RSUs. The CV back office systems will be housed on servers purchased by and owned by NYCDOT and placed in the TMC located at 28-11 Queens Plaza North where the current traffic control and incident management systems are housed. This facility also features 24×7 operations personnel and on-call maintenance both locally and remotely by NYC TMC personnel who can log into the systems for trouble shooting purposes and who can exchange hardware and restart systems when necessary. The computers are blades in the various chassis that feature remote control operations to start/stop/reset etc. Additions to the TMC will include network equipment as well as severs; the detailed equipment list will be developed and will include the servers, firewall changes, network equipment, and any additional displays that can be used to monitor the overall CV system. As part of the software development, NYCDOT will be developing dashboards and reports that can be used to track the reliability of the CV equipment and systems.

The back office facilities will provide the management functions for the following:

- Security credentials (SCMS) utilization.
- Roadside equipment performance (failure identification, repair, maintenance).
- Roadside equipment radio frequency footprints.
- CV application configuration.
- External data distribution (USDOT).
- Data collection from RSU/ASD.
- Data aggregation, data normalization, and system performance assessment.

2.4 Proposed CV Applications

NYCDOT will implement 15 CV applications for this Pilot site deployment: 14 safety-related applications and one data collection application. All but one of the 14 safety applications will be loaded on each vehicle, with the exception being the Vehicle Turning Right in Front of Bus Warning that will only be enabled on the MTA bus fleet vehicles. The V2I applications will function only where the RSUs support the application. Table 2-2 shows how NYCDOT plans to distribute these applications throughout the different vehicle fleets.

Table 2-2. Planned ASD Deployment by Vehicle Fleet Distribution.

CV Application	Taxi & Limousine 5850 75%	NYC DOT/ Sanitation 500 5%	MTA/NYCTA Buses 1250 15%	Commercial Vehicles 400 5%	Pedestrian 100
Speed Comply	✓	✓	✓	✓	
Curve Spd Comply	✓	✓	✓	✓	
Spd Comply/ Wrk Zn	✓	✓	✓	✓	
FCW	✓	✓	✓	✓	
EEBL	✓	✓	✓	✓	
BSW/LCW	✓	✓	✓	✓	
LCW	✓	✓	✓	✓	
IMA	✓	✓	✓	✓	
VTRFBW			✓		
RLVW	✓	✓	✓	✓	
PED in Xwalk	✓	✓	✓	✓	
PED-SIG					✓
Oversize Veh. Comply		Conditional	Conditional	Conditional	
EVAC Info	✓	✓	✓	✓	
I-SIGCVDATA					

Source: Reference (1)

2.4.1 V2V Applications

The NYC CVPD intends to use the same six proposed CV applications from their initial concept of operations. These applications are listed in the SAE J2945/1 standard for V2V communications and the USDOT's publication FHWA-JPO-13-058. These applications do not need to be re-engineered as components of this project as this work has already been completed.

2.4.1.1 Forward Collision Warning

The Forward Collision Warning (FCW) application warns the driver of the vehicle that an impending rear-end collision with another vehicle ahead in traffic in the same lane and direction of travel is about to occur.

2.4.1.2 Emergency Electronics Brake Lights

The emergency electronics brake lights (EEBL) application enables a vehicle to broadcast a self-generated emergency brake event to the surrounding vehicles. Upon receiving such event information, the host vehicle determines the relevance of the event and then provides a warning to the driver if appropriate.

2.4.1.3 Blind Spot Warning/Lane Change Warning

The Blind Spot Warning and Lane Change Warning (BSW+LCW) application warns the driver of the vehicle during a lane change attempt if the blind-spot zone into which the vehicle intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction.

2.4.1.4 Intersection Movement Assist

The Intersection Movement Assist (IMA) application warns the driver of a vehicle when it is not safe to enter an intersection due to high collision probability with other vehicles at stop sign controlled and uncontrolled intersections.

2.4.1.5 Vehicle Turning Right in Front of Bus Warning

The Vehicle Turning Right in Front of Bus application determines the movement of vehicles near to a bus stopped at a bus stop and provides an indication to the bus operator that a nearby vehicle is pulling in front of the bus to make a right turn.

2.4.2 V2I Applications

2.4.2.1 Speed Compliance

This application provides warnings to drivers when they exceed the posted speed limit and encourages them to reduce their travel speed. This application will use a regulatory speed limit provided by the CV infrastructure (via received MAP messages) in combination with the vehicle's speed and location to provide warnings to the driver. These warnings will occur when the vehicle speed exceeds the speed limit by a configurable amount or for a configurable period based on whichever occurs first. The warnings (alert) will be provided via an audio tone(s) and/or spoken warning, which will be determined during the detailed design.

2.4.2.2 Curve Speed Compliance

The Curve Speed Compliance will operate similarly to the Speed Compliance application. The difference will be the data source used to obtain the regulatory speed limit to be broadcast to vehicles. These data will be transmitted using the Traveler Information Message (TIM) described in SAE J2735 or revised per the CAMP Curve Speed Warning development currently underway. The message format selection will be the subject of an ongoing evaluation based on the progress of the CAMP work and the project schedule.

2.4.2.3 Speed Compliance/Work Zone

This application will provide over speed warnings for work or school zones that are either statically or dynamically located. If there is a static work zone, then it is essentially a speed zone and operates as described above. However, certain types of construction activities also may be moving work zones such as pothole repairs, striping, or even snow plowing under certain situations. This application is similar to the Speed Compliance application described above; however, regulatory speed limit information will be distributed by the infrastructure's RSU using the TIM message.

2.4.2.4 Red Light Violation Warning

This application will advise drivers if a vehicle is on an approach that is likely to result in the vehicle violating the red light. The application in the vehicle uses its speed and acceleration profile, along with the received signal timing (signal phase and timing [SPaT]) and geometry information (MAP) to determine if it appears likely that the vehicle will enter the intersection in violation of a traffic signal. If the violation seems likely to occur, a warning can be provided to the driver.

2.4.2.5 Oversize Vehicle Compliance

This application provides warnings to the driver as the vehicle encounters restricted facilities and height restricted infrastructure. For NYC, there is no infrastructure data equipment for detecting and measuring the approaching vehicle's height and width as in the Connected Vehicle Reference Implementation Architecture concept for this application. Therefore, vehicle size and vehicle type information will be configured into the ASD for each vehicle. Using the pre-configured vehicle height information, the ASD determines whether the vehicle is able to pass through the bridge or tunnel. While the CVRIA refers to vehicles' weight measurement and supporting unequipped vehicles, these concepts are beyond the scope of the NYC CVPD project.

2.4.2.6 Emergency Communications and Evacuation Information

NYCDOT added this application to support NYC's emergency communications and dissemination of evacuation traveler information. Centers including the NYCDOT TMC and Office of Emergency Response will partake in the emergency operations and management functions. However, rail operations center, transit management center, special needs registry, population and housing data sets, public health system, and shelter provider center as defined in the CVRIA are not included in the NYC CVPD.

Note that the distribution of this information will be limited to the RSU locations and will be kept within the vehicles with a time-out and location (area/street) of relevance and only provided to the operator when the vehicle is within the designated area during the time of relevance.

2.4.2.7 Intelligent Traffic Signal System (I-SIGCVDATA)

This functionality utilizes CV data as an input to the existing Adaptive Control Decision Support System (ACDSS), augmenting or replacing the existing data from the toll tag reader system that provides travel time and speed information. It is the intent of the project to determine if the CV technology provides input that is equivalent to the existing data collection mechanism such that expansion of the ACDSS adaptive control system can rely on only the CV data collected.

2.4.3 Pedestrian Applications

2.4.3.1 Pedestrian in Signalized Crosswalk Warning (PEDINXWALK)

This application will use the pedestrian detection information to indicate the presence of pedestrians in a crosswalk at a signalized intersection. As any pedestrian passes through a crosswalk at a signalized intersection with additional pedestrian detection equipment installed, the pedestrian's presence will be detected by the traffic control system. The traffic control system will notify the vehicle ASDs of a pedestrian's presence in the crosswalk. The ASDs will receive SPaT and MAP messages that indicate the intersection signal status and alert the driver in advance of the presence of a pedestrian in the crosswalk location based on the intersection geometry configured and scheduled by the NYCDOT TMC. It is currently anticipated that 10 RSU equipped intersections will be equipped with the pedestrian detection equipment.

2.4.3.2 Mobile Accessible Pedestrian Signal System (PED-SIG)

The NYC CVPD will deploy an application to support visually impaired (blind) pedestrians crossing the street. Unlike the PEDINXWALK application above, select visually impaired pedestrians will carry PID in the form of mobile devices that will receive the SPaT and MAP messages from the RSU.

The PID will support normal cellular communications such that the PID can monitor the SPaT and MAP messages received from nearby RSUs. Communications from the RSU will use DSRC (5.9 GHz. 1609.x, J2735) message sets. The NYC CVPD implementation of PED-SIG will only all the PIDs to receive information from the RSU to assist the visually impaired pedestrian to safely navigate the crosswalk in compliance with the pedestrian crossing phase. No serviced calls or changes to the signal timing, phasing, or actuation will be made based on the PID presence or actions.

Use of the Security Credentialing Management System (SCMS) is an important aspect of this application since it will require certificates to authenticate the SPaT and Map Data Message (MAP) messages from the RSU. Thus there will be security and subscription issues with the use of the application including enrollment certificates for the application and the licensed user, as well as the normal privacy concerns to protect the personal identification information (PII) that might be collected. This will also be an opportunity to work with the disabled community and the traffic signal operation to support safety improvements for this type of user.

2.5 Proposed Performance Measures

The New York City site identified seven use cases for characterizing improvement in system performance. Table 2-3 presents these seven use cases, the CV applications being deployed in an attempt to improve conditions, and the performance metrics, which have been identified to measure the impacts of the NYC CVPD for each use case. Please consult the performance measurement and evaluation document for details (3).

Table 2-3. Identified Performance Metrics by CV Application: Manage Needs.

Category	NYCDOT Needs	CV Application	Performance Measure Metrics	Question for Evaluation
Safety, Mobility	Discourage Spot Speeding	Speed Compliance	• 1a. Number of stops (average and distribution measures) • 1b. Speeds (average and distribution measures) • 1c. Emissions • 1d. Reduction in speed limit violations • 1e. Speed variation • 1f. Vehicle throughput (average and distribution measures) • 1g. Driver actions and/or impact on actions in response to issued warnings	Does speed limit adherence and speed variability within vehicle fleet on a given study roadway segment for a given time period (cycle length basis) decrease from the before period to the pilot period, and from control group to the treatment group? Is this accompanied by an overall increase, decrease, or no change in average segment speed?
Safety	Improve Truck safety	Curve Speed Compliance	• 2a. Speed related crash counts, by severity • 2b. Vehicle speed at curve entry • 2c. Lateral acceleration in the curve • 2d. Driver actions and/or impact on actions in response to issued warning • 2e. Number of curve speed violations at each instrumented location	Do the number of curve speed violations in each applications studied roadway segment decreases from the before period to the pilot period, and from control group to the treatment group?
Safety	Improve Work Zone Safety	Speed Compliance/ Work Zone	• 3a. Speed in work zone (average and distribution measures) • 3b. Speed variation (distribution) at work zone • 3c. Number of vehicle speed limit violations in variable speed zone areas • 3d. Work zone related crash counts in reduced speed zones, by severity • 3e. Driver actions and/or impact on actions in response to issued warning	Do the number of work zone speed violations on each applicable studied roadway segment decrease from the before period to the pilot period, and from control group to the treatment group?

Table 2-4. Identified Performance Metrics by CV Application: Reduce Vehicle to Vehicle Crashes.

Category	NYCDOT Needs	CV Application	Performance Measure Metrics	Question for Evaluation
Safety	V2V Safety Applications	FCW EEBL BSW LCW IMA	• 4a. Fatality crash counts • 4b. Injury crash counts • 4c. Property damage only crash counts • 4d. Time to Collision (vehicle to vehicle)	Do the number of reportable crashes decrease from the before period to the pilot period, and from control group to the treatment group?
Safety	Reduce Accidents at High Incident Intersections	Red Light Violation Warning	• 5a. Red light violation counts • 5b. Red light violation related crash counts, by severity • 5c. Time to collision (vehicle to cross vehicle path) at the intersection • 5d. Driver actions and/or impact on actions in response to issues warning	Do the number and severity of red light violations at each studied intersection decrease from the before period to the pilot period, and from control group to the treatment group?
Safety	Reduce Incidents, Improve Safety	Vehicle Turning Right in Front of Bus Warning	• 6a. Bus and right turn related crash counts, by severity • 6b. Right-turning related conflicts • 6c. Time to collision (vehicle to bus) • 6d. Number of warnings generated • 6e. Driver actions and/or impact on actions in response to issues warning	Do the number of bus/right turn vehicle crashes decrease from the before period to the pilot period, and from control group to the treatment group?

Table 2-5. Identified Performance Metrics by CV Application: Reduce Vehicle to Pedestrian Crashes.

Category	NYCDOT Needs	CV Application	Performance Measure Metrics	Question for Evaluation
Safety	Improve Pedestrian Safety	Pedestrian in Signalized Crosswalk Warning	• 7a. Pedestrian related crash counts, by severity • 7b. Number of warnings generated • 7c. Pedestrian-related conflicts/hard braking events • 7d. Time to collision (vehicle to pedestrian) • 7e. Driver actions and/or impact on actions in response to issues warning	Do the number of pedestrian related crashes decrease from the before period to the pilot period, and from the control group to the treatment group?
Safety	Improve Safety to Visually and Audibly-Impaired pedestrians	Mobile Accessible Pedestrian Signal System (PED-SIG)	• 8a. Number of pedestrian crossing violation reductions • 8b. Visually-impaired pedestrian-related crash counts, by severity • 8c. Conflicts with visually impaired pedestrians • 8d. Time to collision (vehicle to pedestrian) • 8e. User satisfaction with PID in assisting to safely navigate • 8f. Time to cross at intersection	Do the number of pedestrian related crashes decrease from the before period to the pilot period?

Table 2-6. Identified Performance Metrics by CV Application: Reduce Vehicle to Infrastructure Crashes.

Category	NYCDOT Needs	CV Application	Performance Measure Metrics	Question for Evaluation
Mobility	Address Bridge Low Clearance Issues	Oversized Vehicle Compliance	• 9a. Number of warnings generated • 9b. Number of truck route violations	Do the number of low clearance violations decrease from the before period to the pilot period, and from control group to the treatment group?

Table 2-7. Identified Performance Metrics by CV Application: Inform Drivers of Serious Incidents.

Category	NYCDOT Needs	CV Application	Performance Measure Metrics	Question for Evaluation
Mobility	Inform Drivers	Emergency Communications and Evacuation Information	• 10a. Number of vehicle receiving information when generated	Do CV vehicles receive the information warning when generated?

Table 2-8. Identified Performance Metrics by CV Application: Provide Mobility Information.

Category	NYCDOT Needs	CV Application	Performance Measure Metrics	Question for Evaluation
Mobility	Replace Legacy Measurements	Intelligent Traffic Signal System Connected Vehicle Data (I-SIGCVDATA)	• 11a. Segment speed (average and distribution measures) from CV compared to legacy detection systems • 11b. Travel time (average and distribution measures) from CV compared to legacy detection systems	Do the CV based mobility metrics compare favorably to legacy detection system or provide better information?

Table 2-9. Identified Performance Metrics by CV Application: Manage System Operations.

Category	NYCDOT Needs	CV Application	Performance Measure Metrics	Question for Evaluation
System Operations	Ensure Operations of the CV Deployment	NA	12a. System performance statistics (system activity, down time, radio frequency monitoring range on ASDs and RSUs, number of event warning by app)	Does the system operate reliably?

Source: Adapted from Reference 3

2.6 NYC CV Data Files

Data will be collected in the field, both from the deployed CV devices and from the traditional non-CV data sources. For the CV data, in-vehicle ASD devices will collect two distinct types of data: detailed action logs and breadcrumb data (3, 8). The RSUs will then be able to upload ASD data via DSRC communication. Please note that these data are those slated for collection by the site to support their performance measurement activities. Additional data collection may be required to satisfy USDOT evaluation objectives.

2.6.1 CV-data: Action Logs

An ASD action log of data (including BSMs, SPaT, and MAP messages, and vehicle data available from the vehicle CAN bus) will be collected for a period surrounding specific events. An event will most commonly be when one of the installed CV apps determines to issue a warning to the driver (in either an active or silent operations mode), but may also be another pre-defined condition (e.g., hard braking) that occurs without an issued warning from one of the CV applications on the ASD.

2.6.2 CV-data: Mobility Data

In addition to the action log data collected surrounding CV application warning events, a BSM data point from each CV vehicle will be recorded each time a CV vehicle passes an RSU. These CV vehicle sighting records, once uploaded to the TMC, will be used to calculate travel times over the study roadways. These data would not include the detailed BSMs records or BSMs from surrounding vehicles (since they themselves would have their own RSU sighting recording). It is also noted that a ASD based breadcrumb collection system is currently being planned but is considered for future implementation beyond the scope of the current NYC CV Pilot Deployment.

Details are still under development for the collection of data for the pedestrian applications; however, the deployed devices are likely to be mobile phone based and not dedicated ASDs as installed in the vehicles. The same data privacy and data obfuscation rules will apply to the pedestrian data.

Non-obfuscated data will be destroyed following the obfuscation process.

2.6.3 Non-CV Data

- Traditional accident record geodatabases already collected will be available and included in the performance evaluation process.
- Real-time weather data feeds available from the National Weather Service (NWS) will also be included in the performance evaluation plan.
- Monitoring of volume data and travel time data will provide a benchmark of system-wide and localized traffic conditions during the pilot period in which the CV-related data are observed. The intent is to quantify fluctuations in the network—in terms of volumes and travel time—to better manage the effects of those confounding factors.
- An anonymous survey instrument will be developed to gather feedback from the operators as to how the ASD and PID devices and applications are operating. It is anticipated that the vehicle driver/operator surveys would be a completed through a web based survey tool. NYC

CVPD team members may survey PID participants in person or through a more guided process.

3 NYC CVPD Goals, Objectives, Hypotheses, and Performance Measures

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

3.1 Definitions

The following definitions are used in the document for the various stakeholder groups:

- Pilot Deployment Agencies: These include pilot managers and decision-makers, partnering agencies, and technical staff involved in application design, development, and testing, etc.
- Transportation Managers: These include the TMC operators, fleet managers, maintenance personnel, etc.
- End Users: These include the taxi drivers, DOT vehicle drivers, bus drivers, commercial truck drivers, and visually impaired pedestrians.

3.2 NYC CVPD Goals and Objectives

The key USDOT goals for the CV Pilots are as follows:

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

The specific objectives for the NYC CVPD evaluation are as follows:

1. Reduce vehicle to vehicle crashes and incidents (or other safety surrogate measures if crashes are rare) in the pilot deployment area through CV deployment.
2. Reduce crashes and incidents (or other safety surrogate measures if crashes are rare) and number of signal violations at high-accident intersections through red-light violation warning.

3. Reduce truck-bridge strike crashes (or other safety surrogate measures if crashes are rare) in the pilot deployment area roadways that have low clearance bridges through oversized vehicle compliance warning.
4. Improve truck safety on curves through curve speed compliance warning.
5. Improve work zone safety through work zone speed compliance warning.
6. Reduce pedestrian fatalities and injuries by reducing vehicle to pedestrian crashes and incidents in the pilot deployment area.
7. Improve safety of visually impaired pedestrians through Mobile Accessible Pedestrian Signal System.
8. Encourage safe driving by reducing speeding and increasing adherence to posted speed limits.
9. Improve mobility for all vehicles, both equipped and unequipped, through reductions in crashes or improved clearance times from less severe crashes.
10. Reduce negative environment impacts through reductions in crashes and increase in speed adherence.
11. Improve decision-making by transportation managers through CV-based data sets.
12. Improve customer satisfaction of end users.

Table 3-1 shows a matching between the NYC CVPD objectives and the applications planned for deployment in NYC.

3.3 Mobility, Environmental, and Public Agency Evaluation Hypotheses

Table 3-2 lists the key hypotheses related to the MEP benefits as well as the user satisfaction and stakeholder acceptance perceptions that the TTI CVPD Evaluation Team will evaluate as part of the independent evaluation of the NYC CVPD. The TTI CVPD Evaluation Team identified these key test hypotheses based on a comprehensive review of the pertinent Phase 1 documentation and discussion with the NYC CVPD Team at a site visit conducted on May 15–16, 2017. These key hypotheses will guide the development of the rest of the components of the evaluation plan. These hypotheses examine whether the overall goals and objectives are met by the deployment for the current deployment period as well as projected over time, and at current scale and in a larger deployment at the site.

The reader should note that the TTI CVPD Evaluation Team is not responsible for assessing the safety benefits associated with the NYC CVPD. The reader should consult the NYC CVPD Safety Evaluation Plan to find information on the safety-related hypothesis and proposed evaluation procedure.

Table 3-1. Mapping of Planned Applications to USDOT Objectives for NYC CVPD.

CVPD Deployment Objectives	FCW	EEBL	BSW/ LCW	IMA	Vehicle Turning Right Front Bus	Speed Compliance	Curve Speed Compliance	Speed Compliance Work Zones	Red Light Violation Warning	Oversize Vehicle Compliance	Emerg Comm / Evac. Information	I-SIG System Data	Ped in Crosswalk	Pedestrian Signal
1	X	X	X	X	X									
2									X					
3										X				
4							X							
5								X						
6													X	X
7													X	X
8						X	X							
9	X	X	X	X	X	X	X	X	X	X	X	X	X	X
10						X	X	X	X	X	X	X		
11						X	X	X	X	X	X	X		
12	X	X	X	X	X	X	X	X	X	X	X		X	X

Source: Reference (1)

3.4 Performance Measures

The TTI CVPD Evaluation will consist of analysis in each of the following areas:

- Mobility.
- Environmental.
- Public Agency Efficiency.
- Benefit/Costs.
- User Satisfaction.
- Stakeholder Acceptance.

Table 3-3 through Table 3-8 shows performance measures, data sources, and analysis type associated with evaluating the hypotheses in each of the evaluation area.

Table 3-2. Key MEP, User Satisfaction, and Stakeholder Acceptance Evaluation Hypotheses for New York City CV Deployment.

ID	Hypothesis
1.	The pilot deployment will increase compliance with speed limit/speed advisories due to speed compliance warning applications for work zones, curve speed advisories, and speed limits.
2.	The pilot deployment will not adversely affect mobility for all vehicles while improving travel reliability, both equipped and unequipped, in the deployment corridors.
3.	By reducing crash frequencies and severity, the pilot deployment will improve travel reliability in the deployment corridors.
4.	As the market penetration of CVs increases, benefits will increase in terms of reduced queues, delays, emissions, and increased vehicle throughput and travel time reliability.
5.	As the market penetration of CVs increases, non-equipped vehicles traversing the pilot deployment area will see reductions in queues, delays, and emissions.
6.	The pilot deployment will reduce negative environment impacts through reductions in crashes and increase in speed adherence.
7.	The pilot deployment will result in improved public agency efficiency and decision-making by transportation managers.
8.	The safety, mobility, environmental, and public agency efficiency benefits exceed the costs associated with deploying the CV technologies in the deployment corridors.
9.	Incremental increases in CV deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold, after which benefit-cost ratio will reduce.
10.	End users will be satisfied with performance of CV applications and with the impact of the CV deployment on their travel.
11.	End users will be satisfied with the performance of the CV devices.
12.	Pilot deployment agencies and transportation managers will find that their safety, mobility, environmental, and public efficiency (SMEP) goals were met.

Table 3-3. Hypotheses and Performance Measures Used to Assess Mobility Impacts of the NYC CVPD.

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
1	The pilot deployment will increase compliance with speed limit/speed advisories due to speed compliance warning applications for work zones, curve speed advisories, and speed limits.	• Change in the proportion of vehicle traveling 5 mph at or above speed limit • Change in the proportion of trucks entering curves 5 mph above recommended speed • Change in the proportion of vehicles traveling 5 mph at or above the work zone speed limit	• ASD Action Logs	• With/Without using Observed data
2	The pilot deployment will not adversely affect mobility for all vehicles while improving travel reliability, both equipped and unequipped, in the deployment corridors.	• Change in Average Travel Time • Change in Average Intersection Delay • Change in Average Speed • Change in Vehicle Throughput	• Midtown In Motion Travel Time Monitoring System • MIM Traffic Signal Performance Monitoring System	• Before/After using Observed data
3	By reducing crash frequencies and severity, the pilot deployment will improve travel reliability in the deployment corridors.	• Change in 95th percentile Travel Time • Change in Buffer Time	• Change in 95th percentile Travel Time • Change in Buffer Time	• Before/After using Observed data
4	As the market penetration of CVs increases, benefits will increase in terms of reduced queues, delays, emissions, and increased vehicle throughput and travel.	• Average Trip Time per vehicle (VHT/V) • Average User Delay/Wait Time • Average Speeds • Average vehicle-miles traveled (VMT) per vehicle	• Total Vehicle-hours Traveled (VHT)/ Total Vehicle Count • Difference in VHT/Mile at speed limit and VHT/Mile • VMT/Vehicle-hours Traveled • VMT/ Total Vehicle Count	• Modeling analysis to assess the impacts of the With vs Without cases

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
5	As the market penetration of CVs increases, non-equipped vehicles traversing the pilot deployment area will see reductions in queues, delays, and emissions.	• Average Trip Time per vehicle (VHT/V) • Average User Delay/Wait Time • Average Speeds • Average vehicle-miles traveled per vehicle	• Total Vehicle-hours Traveled/Total Vehicle Count • Difference in VHT/M at speed limit and VHT/M • VMT/Vehicle-hours Traveled • VMT/ Total Vehicle Count	• Modeling analysis to assess the impacts of the With vs Without cases

Table 3-4. Hypotheses and Performance Measures Used to Assess Environmental Impacts of the NYC CVPD.

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
6	The pilot deployment will reduce negative impacts on the environment through reduction in crashes and increases in speed adherence.	• Change in the vehicle emissions • Change in fuel consumption	• Simulation of incident/crash situations	• Modeling analysis to assess the impacts of the With vs Without cases

Table 3-5. Hypotheses and Performance Measures Used to Assess Public Agency Efficiency Impacts of the NYC CVPD.

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
7	The pilot deployment will result in improved public agency efficiency and decision-making by transportation managers.	• Change in perception of agency awareness of conditions in the deployment corridors • Changes in the perceived accuracy of alerts/warnings/advisories/ traveler information • Changes in the perceived effectiveness of alerts/ warnings/advisories/ traveler information • Changes in timeliness of agency responses to changing travel conditions • Number and type of operational changes (such as signal timing adjustments) and business practice changes made by transportation managers • Perceived impact/effectiveness of operational and business practice changes • Changes in notification and/or response times to major incidents and crashes • Changes in perceived effectiveness of traffic management system responses to changing traffic conditions	• Surveys/ Interviews • Agency MIM Operations logs • NYCDOT Incident Management Logs	• Qualitative perception data from surveys • Quantitative data from system logs

Table 3-6. Hypotheses and Performance Measures Used to Assess Benefit/Costs Effectiveness of the NYC CVPD

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
8	The safety, mobility, environmental, and public agency efficiency benefits exceed the costs associated with deploying the CV technologies in the deployment corridors.	• Total Deployment Costs ○ Development ○ Procurement ○ Installation ○ Operations ○ Maintenance ○ Salvage • Dollar Value of Benefits ○ Safety ○ Mobility ○ Environmental ○ Public Agency Efficiency	• Safety Analysis • Mobility Analysis • Environmental Analysis • Public Agency Efficiency Analysis • Agency Cost Records	• Benefit/Cost
9	Incremental increases in CV deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold.	• Benefit-cost ratio at various market penetrations	• Cost data • Dollar value of benefits	• Simulation

Table 3-7. Hypotheses and Performance Measures Used to Assess User Satisfaction Associated with the NYC CVPD

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
10	End users will be satisfied with the performance of the CV applications and with the impact of the CV deployment on their travel.	• Perception of whether advisories/ alerts/warnings/traveler information were: o Timely o Sufficiently detailed o Easy to understand o Accurate o Useful o Appropriateness • Perceived impact (if any) that alerts/warnings/advisories/ traveler information had on safety and/or mobility. • Attitudes toward the consistency of the alerts (Did they fell they consistently received an alert under similar situations?) • Attitudes toward CV systems (related to trust in information, privacy and security, etc.)	• Surveys/ Interviews	• Qualitative perception data from surveys
11	End users will be satisfied with the performance of the CV devices.	• Overall satisfaction with performance of CV devices • Number and nature of problems with CV devices	• Survey/Interviews	• Qualitative perception data from surveys

Table 3-8. Hypotheses and Performance Measures Used to Assess Stakeholder Acceptance of the NYC CVPD.

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
12	Pilot deployment agencies and transportation managers will find that their SMEP goals were met.	• Changes needed in business processes • Changes needed in agency systems and technologies capabilities • Changes needed in agency culture • Changes needed in the organizational structure and workforce requirements • Changes needed in institutional arrangements and collaborations • Changes needed in performance measurement practices • Perceived impact/effectiveness/ acceptance of those changes • Perceived extent to which safety, mobility, environmental, and public agency efficiency goals were met • Lessons learned by agencies	• Stakeholder Surveys/ Interviews	• Qualitative perceptions from interview data

4 Confounding Factors and Risks

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

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

4.1 Key Confounding Factors

This section identifies a few key confounding factors that can impact the New York City Pilot deployment evaluation process. For a detailed discussion of the confounding factors, please refer the *NYCDOT CV Pilot Performance Measurement and Evaluation Support Plan* (3). This section also describes potential strategies to mitigate the impacts of identified confounding factors.

4.1.1 Vehicular and Pedestrian Demand Variations

Traffic demands and the resulting observed vehicle volumes vary across the study area corridors by time of day and day of week. As the study corridors are within a dense urban area, seasonal variation of demands is less pronounced, but still present to some degree. In some sections of the deployment area (e.g., in Manhattan in the vicinity of the East River crossings, such as the Queens-Midtown Tunnel and the Ed Koch Queensboro Bridge) there is significant variability. Traffic volumes are also intermittently affected by closures, incidents, or disabled vehicles on the approaches to or within those facilities. Special events (e.g., UN week) can have significant impacts on vehicular demands in localized areas of the study area.

Similar to vehicular volumes, pedestrian volumes vary by time of day and day of week. Unlike vehicular demands, pedestrian volumes do see seasonal surges marked by increased tourism and holiday time periods. Pedestrian volumes also vary spatially with increased volumes near transit hubs, especially during typical commute periods.

4.1.2 Weather

New York City sees significant variation across seasons. Winter months can experience below freezing temperatures with frozen precipitation and snow accumulation, nor'easters and blizzards. Some months can experience heavy rains or tropical storms. Over the 18-month period of Phase 3, such weather events may occur and such conditions can affect travel demand, vehicle operating characteristics, and roadway conditions.

4.1.3 Accidents and Incidents

A significant number of crashes and incidents have been reported in the study area. Based on 2010–2014 data, the 1st Avenue ranks in the top third of Manhattan corridors, while 2nd, 5th and 6th Avenues rank in the top 10 percent. Similarly, Flatbush Avenue ranks in the top 10 percent for Brooklyn. Crashes and incidents on adjacent streets and facilities outside of the deployment area can also impact flows into the study area due to the dense, congested nature of the city's network. Incidents can affect throughput, routing and driving patterns across large areas of the network. In addition, the interrelationship of accidents and observed traffic volumes on an hourly and daily basis (see 4.1.1 above) is important.

In addition to crashes, the study area also sees very short-term lane blockage disruptions due to truck double-parking for loading and unloading or taxi pick-up/drop-off activity. These incidents are generally very short in duration, typically the range of less than a minute to a few minutes. Additionally, they occur frequently enough that they are almost common occurrence and part of the typical operations of the city's roadways, particularly on Manhattan roadways.

Transit service disruptions can also have impacts on both vehicular and pedestrian volumes. Disruptions may cause travelers to change their travel patterns. Even minor disruptions may cause travelers to shift from one transit route to another or change modes (walking, biking, or taxi). In the case of major disruptions, the potential to shift to personal auto modes is also possible.

4.1.4 Work Zones – Short Term or Unplanned

Short-term work zones—including lane closures for emergency utility work—are omnipresent in the city and have a cumulative effect on travel conditions on the study corridors. Moreover, the nature of these work zones, particularly for emergency utility work, are difficult to track and account for in the observed traffic conditions.

4.1.5 Planned Special Events

Special events occur with regularity, especially for the Manhattan study area, but are generally given advanced notice and can be documented.

4.1.6 Economic Conditions

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

4.1.7 Fuel Prices

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

4.1.8 6th Avenue Reconstruction

A capital improvement project is planned for 6th Avenue that will modify the lane configurations, add a protected bike lane and floating parking spaces, and adjust signal timings. These changes are highly likely to alter travel patterns and increase congestion on 6th Avenue during the deployment period. The planned changes on 6th Avenue also may alter travel patterns on other Manhattan avenues.

4.1.9 Ridesharing Program

Ridesharing applications/programs, like Uber and Lyft, have the potential to impact taxi utilization in deployment corridors. These programs have the potential to cause significant reductions in VMT by taxi cabs in the deployment area and/or a shift in revenue VMT in taxi cabs to cruising (non-revenue) VMT or increased idle/parked time while waiting for fares. Reductions or changes in taxi cab VMT may impact the potential frequency that connected taxis may interact with each other in the deployment corridor.

4.1.10 Changes in Transit Routes/Schedules

The possibility exists that the MTA may make revisions to routes and schedules of transit vehicle that operate in the deployment corridors. NYC DOT has little or no control if and when these changes may take plan. If changes in transit routes and services occur, the potential exists that these changes may impact traffic and pedestrian traffic in the corridors.

Additionally, anticipated suspension of the L Train subway service to allow for substantial repairs to the Canarsie Rail Tunnel under the East River is expected to modify mode splits, travel patterns, and surface street vehicle operations in the 14th Street corridor in Manhattan.

4.1.11 Vision Zero Projects

The City of New York is working to reduce fatal and injury crashes throughout the city. These efforts involve multiple agencies within NYC, including the NYC DOT, NYC Taxi and Limousine Commission, NYC Citywide Administrative Services, NYC Department of Education, and NYC Department of Health. Example of traffic related Vison Zero project include the following:

- Installing Leading Pedestrian Intervals.
- Reducing speed limits to 25 mph.
- Implementing left turn traffic calming techniques.
- Installing high-visibility crosswalks citywide.
- Evaluating the use of new sensors and data analysis systems.

Several intersections in the deployment are have been upgraded already as part of this project, while several other are scheduled to be upgraded during 2017. New intersections and additional treatment may be implemented throughout the duration of the deployment testing.

4.1.12 Potential Mitigation Approaches

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

4.1.12.1 Experimental Designs with Control/Treatment Groups

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

4.1.12.2 Use Statistical Techniques (e.g., Counterfactual Modeling, Cluster Analysis, Propensity Scoring)

- **Statistical counterfactual**: In experimental designs that make use of control/treatment groups, the control group serves as the counterfactual. Alternately, counterfactuals can be developed using a statistical model, such as a regression analysis, to estimate what would have happened in the absence of an intervention.

- **Pairwise Matching Enabled by Cluster Analysis:** An evaluation design that makes use of the classic Before/After analysis is not effective in controlling for confounding factors. However, statistical techniques (e.g., cluster analysis, propensity score matching) may be used to account for the impact of confounding factors. For example, cluster analysis may be performed to group data in the pre (Before) and post (After) deployment periods into clusters such that data in each cluster have similar characteristics (i.e., similar traffic demand, freight demand, weather, incidents). Cluster analysis controls for the effects of confounding factors by ensuring that comparison is only made between pairs of before and after data within each cluster.

4.1.12.3 Traffic Simulation Tools

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

4.2 Key Risks

This section discusses key risks that may impact the evaluation effort.

4.2.1 Participants Exploiting Limits of Application

Some participants may develop a false sense of complacency from a perceived protection afforded by CV technology and applications, and may demonstrate risky driving behaviors. For example, a cab driver may not decelerate when approaching a yellow signal because he/she knows that a red light violation warning will be issued if it is determined that the vehicle cannot come to a stop prior to the start of the red. If these risky behaviors are not controlled, there may be an increase in crashes. Appropriate participant training by the NYC CVPD Team may be needed.

4.2.2 Degree of Obfuscation of Data May Limit the Usefulness of Data

NYCDOT plans to obfuscate the ASD action logs to protect the privacy of the drivers and to mitigate liability concerns. Time and date information will be translated into categories or bins of date and time. For example, an action log data set recorded on Tuesday, January 5, 2016, starting at 8:35 a.m. may be recorded only as "January Tuesday 8–9 a.m." or "January Weekday 8–9 a.m." Location information will be converted to an undefined Cartesian coordinate system. Each event data set will still be recorded with full precision for all trajectory points relative to each other in the same event data set, but will not be tied to an exact real-world coordinate. If a driver fails to react to a warning and a second related event is initiated, the interrelationship between the initial and the second warnings may be lost. This may prevent an assessment of driver behaviors and responses, and effectiveness of crash prevention, which in turn can hinder accurate impacts assessment. The TTI CVPD Evaluation Team will work with NYCDOT to identify a feasible obfuscation process, including suitable time windows.

4.2.3 Ongoing Maintenance and Support

The NYC CVPD Deployment Team identified ongoing maintenance and support as a potential risk associated with the deployment. The NYC CVPD is a large-scale deployment with devices and application being installed in over 8,000 vehicles. Many of these are revenue generating vehicles and constantly on the road (over 16 hours per day with multiple drivers). This will definitely test the durability of installed technology. A risk exists that as the technology ages, drivers and garage owners will not keep the equipment maintained at its peak level of performance, which could potentially compromise driver usage and trust in the system.

4.2.4 Technical Capability of Equipment in Dense Urban Environment

The NYC CVPD is unique in that the equipment is being installed in a dense urban environment with relatively short block lengths (250–300 feet for the short blocks and 650–700 feet for the long block). The range of the DSRC radio is approximately 1000 feet for vehicle units and almost 2000 feet for the roadside units. The NYC CVPD Deployment Team is having to make special provisions to manage radio transmission so that the vehicle can clearly determine which intersection it is approaching. On top of that issue, tall buildings and signal interference issues may impact the ability of vehicles to receive GPS signals for accurate vehicle locating.

4.2.5 Poor Performance of Safety Applications in NYC Environment

Because the applications being deployed in NYC are new, very little actual experience exists as to how the applications will perform in the NYC environment. If the applications do not perform as expected, drivers may have a tendency to lose trust in the systems and disregard the alerts.

5 Evaluation Design

This section describes the evaluation plan that the TTI CVPD Evaluation Team will use to evaluate the MEP impacts of the NYC CVPD.

5.1 Potential Experimental Designs

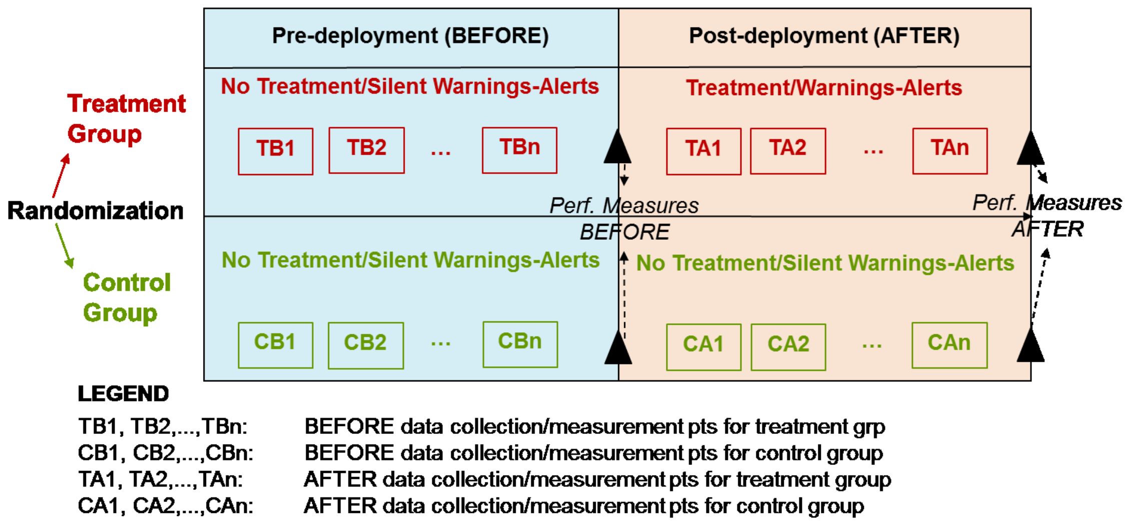
This section briefly discusses three key designs that may be applied to the pilot deployment evaluation.

5.1.1 Randomized Experiments

In randomized experiments, study subjects are randomly assigned to the control group (i.e., the group that does not receive any intervention or treatment) and the treatment group (i.e., the group that receives the intervention). Data for each group are collected before (pre-test or pre-implementation) and after the treatment (post-test or post-implementation). At the end of the experiment, differences between the treatment and control groups can be attributed directly to the effect of the treatment, if the sample is large enough. Randomization ensures that the control and treatment groups are equivalent with respect to all factors other than whether they received the treatment. Here, the control group serves as the counterfactual of what would have happened in the absence of the treatment, which is a key requirement in determining whether a treatment caused a particular outcome. Please see Figure 5-1 for a graphical illustration of the design.

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

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



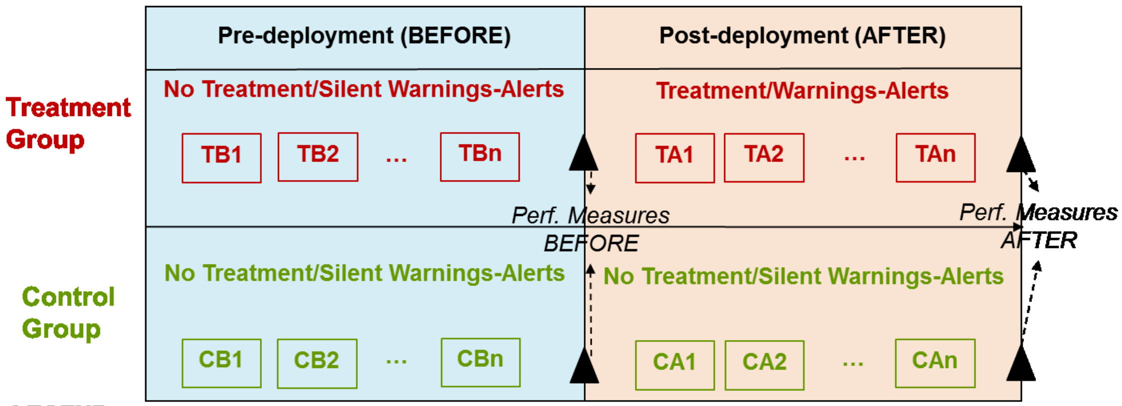
Source: Noblis

Figure 5-1. Randomized Experimental Design.

5.1.2 Quasi-Experiments

Quasi-experimental design is an approximation of the randomized experiment. Quasi-experimental designs use control and treatment groups, but assignment to the groups is non-random (unlike randomized experiments). The control and treatment groups cannot be assumed to be similar. Results may not be conclusive, since there may be a possible selection bias. Hence, the differences in the two groups must be assessed during the pre-test and accounted for in the analysis. Please see Figure 5-2 for a graphical illustration of the design.

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



LEGEND

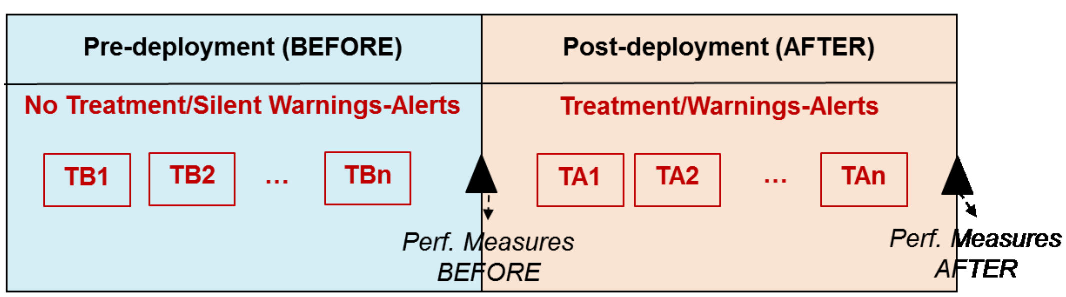
TB1, TB2,...,TBn:	BEFORE data collection/measurement pts for treatment grp
CB1, CB2,...,CBn:	BEFORE data collection/measurement pts for control group
TA1, TA2,...,TAn:	AFTER data collection/measurement pts for treatment group
CA1, CA2,...,CAn:	AFTER data collection/measurement pts for control group

Source: Noblis

Figure 5-2. Quasi-Experimental Design.

5.1.3 Non-Experimental Design

In this design, the impact of the treatment is assessed by examining changes in the post-test period given the trend in the pre-test period. The non-experimental design does not include a control group, making it the weakest study design. Without a control group, it is difficult to assess what would have happened in the absence of the improvements. It does not account for confounding factors, and does not control for other threats to internal validity, possibly leading to false conclusions. Before-After studies and longitudinal studies are examples of such a design. Please see Figure 5-3 for a graphical illustration of the design.



LEGEND

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

Source: Noblis

Figure 5-3. Non-Experimental Design.

5.2 Planned Evaluation Approaches

The following section describes the types of evaluation approaches that will be used the TTI CVPD Evaluation Team to conduct the assessment of the NYC CVPD. NYC CVPD Team plans to divide the taxi study participants into two user groups, active and silent mode. For all other user groups, they will always be in active mode (following the initial baseline period when everyone is in silent mode).

5.2.1 Safety Impacts Assessment

The primary goal of the NYC CVPD is to further the city's Vision Zero initiative. Most of the applications being deployed by the NYC CVPD Team are focused at reducing the number and severity of vehicle-to-vehicle collisions as well as vehicle-to-pedestrian collisions in the deployment corridor; therefore, the improvement in safety will factor heavily into the evaluation.

Volpe is responsible for developing the safety evaluation plan for the NYC CVPD. Volpe's plan for evaluating the safety impacts associated with the pilot deployment by:

- Assessing the safety impacts via an analysis of exposure and response driving conflicts (or violations).
- Evaluating driver performance with and without V2X safety applications in non-conflict driving situations.
- Recommending and designing any additional safety experiments, if needed, to supplement the safety evaluation.

Because of the rarity of crashes in the corridor, Volpe expects to use surrogate safety measures and conflict analysis in place of examining actual crash experiences. In looking at conflicts, Volpe plans to focus on high-risk, near-crash scenarios where the driver had to intervene to avoid a crash. Volpe will use current crash records and vehicle logs to first assess exposure to driving conflicts with and without V2X safety applications. Using the ASD action logs, Volpe will analyze driver responses to conflicts with and without V2X safety applications and then estimate the probability of a crash for specific driving scenarios with and without V2X applications.

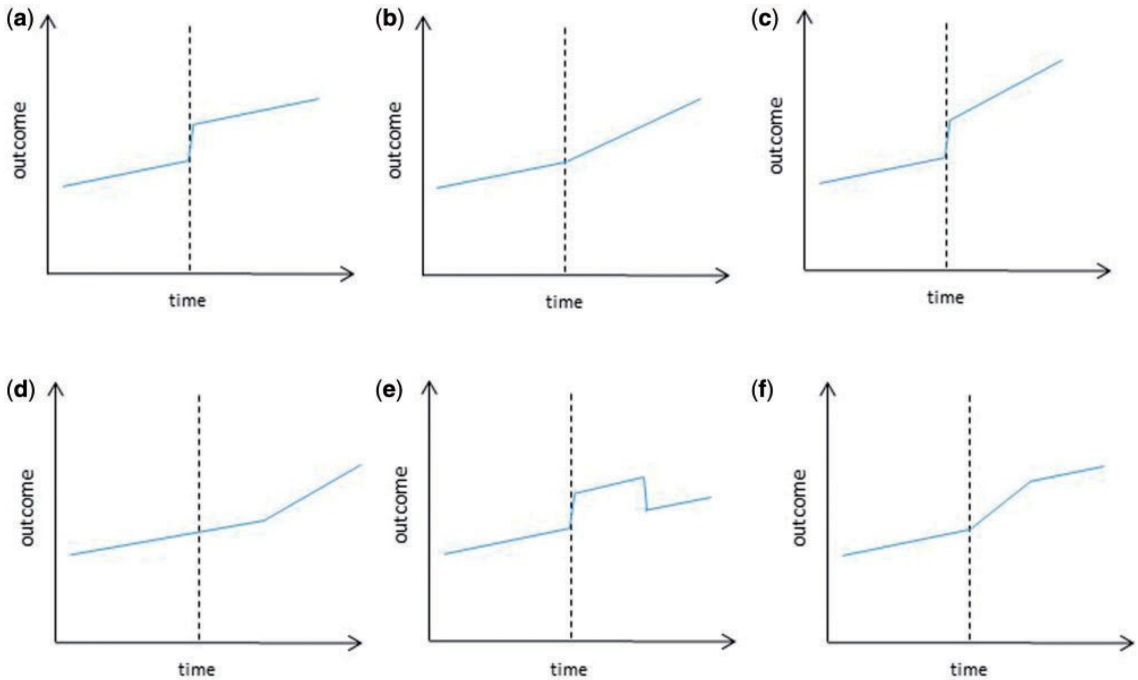
5.2.2 Mobility Impact Assessment

Although most of the applications being deployed are aimed at improving safety, the TTI CVPD Evaluation Team has been tasked to assess the mobility benefits associated with introducing CV technologies in the deployment corridor. The analysis will focus on quantifying the extent to which the technologies impacted overall mobility and travel reliability of both equipped and unequipped vehicle traveling in the deployment corridors.

Because of the way the applications are being implemented and the way the CV data are being obfuscated, most of the applications can be evaluated using only a Before-and-After evaluation methodology. However, where possible, the TTI CVPD Evaluation team may use an interrupted time series design to assess some performance measures (such as observed travel time data). An interrupted time series design is a quasi-experimental method used to determine the impact of an intervention where multiple observations have been made over time, both before and after the intervention has been made. In an interrupted time series design, observations are made prior to the treatment in order to establish an underlying trend, which is then interrupted by an intervention (in this case the activation of the CV applications, at a known point in time. The idea of an interrupted time series analysis is that trends established in the data prior to the intervention would continue to exist over time if it had not been for the intervention. Figure 5-4 shows some potential interpretations of impact models using an interrupted time series analysis.

In order to use an interrupted time series analysis, the following conditions must be satisfied (9):

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



Source: Reference (9)

Figure 5-4. Examples of Intervention Effects in an Interrupted Time Series.

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

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

Where,

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

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

Y_t = the outcome at time t.

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

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

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

As part of the NYC deployment, CV technologies will be installed in over 8,000 vehicles. Currently, the NYC CVPD Team plans to divide the study participants into two user groups: one group that will receive alerts produced by the application and another group that will not receive alerts (or silent mode. This second group could potentially serve as a control group for the active group (i.e., the group that will actively receive the alerts from the devices). Vehicles operating in the silent mode will function the same as those vehicle receiving alerts, only no alerts will be issues to the drivers. This may allow a direct comparison of the performance of vehicles with and without the CV applications active. Depending upon the number of individuals assigned to the control group, it may be possible to use that group to control for effects of confounding factors in the corridor as both the treatment and control group would be experiencing the same conditions in each of the study corridors throughout the study period. The TTI CVPD Evaluation Team will have to wait until NYC CVPD Team has finalized their deployment plans to determine if the sample size of observations in this group is adequate to perform this type of analysis. Additionally, updates may be required to sections of the plan to reflect pilot system (including pedestrian-related applications and devices, see page 17 section 2.6) that is finally procured.

The mobility analysis will be divided into three parts: system level mobility benefits, CV vehicle mobility benefits, and mobility benefits due to safety improvements. Each of these levels of assessments is discussed below.

5.2.2.1 System Level Mobility Impacts

The purpose of this level of the evaluation is to determine the extent to which deploying the CV technologies in the deployment corridor impacted overall travel (or mobility) in those corridors. For this analysis, the TTI CVPD Evaluation Team will use performance measures that reflect how overall mobility in the deployment corridor changed after the introduction of the vehicle equipped with CV technologies compared to mobility before the technologies were introduced. For this analysis, the TTI

CVPD Evaluation team will use performance measures that reflect all vehicles traveling in the corridors, both those equipped with CV technologies and those without. This level of analysis is designed to specifically answer the following evaluation questions:

- To what extent did introducing CV technology applications impact overall travel times in the deployment corridors?
- To what extent did introducing CV technology applications impact travel time reliability for all users in the deployment corridors?
- To what extent did introducing CV technology applications impact travel speeds in the deployment corridors?
- To what extent did introducing CV technology applications impact total delays in the deployment corridors?
- To what extent did introducing CV technology applications impact vehicle throughput in the deployment corridors?
- To what extent did introducing CV technology applications impact the proportion of the deployment corridors operating in a congested conditions?

For this level of analysis, the TTI CVPD plans to utilize mobility data observed or computed by traditional detection systems, such as the Midtown-in-Motion travel time and traffic signal performance monitoring systems.

5.2.2.2 Vehicle-Level Mobility Impacts

The TTI CVPD Evaluation team will also conduct an assessment to determine the extent to which vehicles equipped with CV technologies received mobility benefits compared to those vehicles not equipped with the CV technologies. For this comparison, the TTI CVPD Evaluation Team will focus on comparing the mobility performance of those vehicle equipped with CV technologies <u>and</u> actively receiving alerts compared to those vehicles equipped with CV technologies but not actively receiving alerts (i.e., the CV technologies are operating in the silent mode). For this analysis, vehicles that are operating in the silent mode are assumed to operate similarly to those vehicles that are not equipped with CV technologies at all. This level of analysis is designed to answer the following evaluation questions:

- Do vehicles equipped with CV technologies have better speed compliance than vehicles not equipped with the technology?
- Are vehicles equipped with CV technologies able to maintain consistent speeds compared to vehicles not equipped with CV technologies?

For this level of analysis, the TTI CVPD plans to utilize data logs collected by the CVs themselves.

5.2.2.3 Mobility Benefits due to Safety Improvements

Quantifying the mobility effects of improving safety is needed to assess the economic benefits associated with deploying CV technologies in the deployment corridors. TTI CVPD Evaluation Team plans to use simulation to assess the extent to which mobility benefits can be derived from improvements in safety. For this analysis, the TTI CVPD Evaluation Team will rely heavily on field data to determine how CV and non-CV vehicles behave during different safety-related situations. The TTI

CVPD Evaluation Team will use a cluster analysis to identify different safety scenarios that exist in the corridors. Using field data to calibrate traffic demands and travel patterns during these events, the TTI CVPD Evaluation Team will develop modeling scenarios that can be used to quantify the mobility benefits resulting from the safety improvement generated by the CV equipped vehicle traversing the corridors. The simulation model will be used to collect mobility-based performance measures such as delays, stops, travel time, travel speeds, etc.

5.2.3 Environmental Impacts

An important part of the economic evaluation of the NYC CVPD involves estimating the environmental benefits resulting from introducing CV technologies in the deployment corridors. The TTI CVPD Evaluation Teams plans to use the results of the simulation analysis to estimate the impacts of the deploying the CV technologies on environment. The environmental analysis will focus on estimating the reductions in both vehicle emissions and fuel consumption in the deployment corridors. Simulation will be used to capture the vehicle trajectories on a second by second basis for different types of common events in the corridors. These vehicle trajectories will be fed into the MOVES model to estimate both fuel savings and emission reductions in the deployment corridors under different situations. Vehicle emissions and fuel savings benefits will be estimated for both equipped and unequipped vehicles.

5.2.4 Public Agency Efficiency Impact Assessment

CV technologies can potentially provide public agencies with a new and rich source of data that can be used to improve decision-making by public agencies. Public agencies can potentially use this new source of data to improve operational decision-making, make adjustments to traffic control strategies, respond faster and better to incident conditions, provide travelers with better information about road surface conditions, etc. One part of the TTI CVPD Evaluation is to assess the degree to which deploying CV technologies in the deployment corridor helped public agencies improve their efficiency and effectiveness of detecting, responding, and managing changing traffic conditions—whether they be incidents, unscheduled road closures, inclement weather conditions, or normal day-to-day travel congestion.

5.2.5 Benefit Costs Analyses

The TTI CVPD Evaluation Team will also conduct a benefit cost analysis associated with the deployment. The purpose of the benefit cost analysis is to determine whether the safety, mobility, environmental, and public agency benefits exceeded the total costs associated with deploying the CV technologies in the deployment corridors.

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

For many transportation projects, the value of travel time savings is the largest benefit category. In this evaluation, the actual travel time (with the CV deployment projects) will be compared to travel times in a hypothetical base case where the CV deployment projects did not happen. Travel times can either be measured from field data or modeled depending on data availability and model accuracy. The travel times should include all travelers, with those in automobiles, trucks, transit vehicles, and pedestrians potentially deriving specific travel time benefits from these CV deployment projects. The TTI CVPD Evaluation Team will derive values of time using the procedures specified in the *Tiger*

Benefit-Cost Analysis (BCA) Resource Guide (10) or, when appropriate, local values of time. The values of time often differ by mode and therefore the time savings and number of travelers by mode will all be needed for this calculation.

Changes in the number of crashes will also be an important part of these CV deployment projects. The TTI CVPD Evaluation Team will not be estimating the change in crashes but Volpe will be making that estimate. Preferably the estimated changes will be on the AIS scale (from AIS1 being a minor injury to AIS6 where there was a fatality) plus property damage only crashes. Using Volpe's estimate, the TTI CVPD Evaluation Team will determine the monetary value of the changes in crashes based on federal guidance (10).

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

Similarly, the total change in fuel used will be monetized. The U.S. Energy Information Administration website shows current and predicted costs for fuel (11). Note the TTI CVPD Evaluation Team will remove the taxed portion of the cost of fuel prior to the calculations since that is a transfer and not a change in societal benefits.

The final category of benefits will be vehicle operating costs. Vehicle operating costs will based on the American Automobile Association (AAA) values that are published annually (12). Any reduction/increase in vehicle miles traveled will result in reduced/increased maintenance, tires, and depreciation based on average per mile vehicle operating costs as calculated by AAA. The costs will not include ownership costs, as it is assumed that those costs remain constant.

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

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

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

In addition to examining changes in performance with different penetration rates, changes in background traffic demands will also be projected. Over the course of the next five years, some areas of the Midtown area of New York City are expected to experience substantial redevelopment with increased commercial office space and residential units. This is anticipated to change traffic demands and travel patterns significantly in some areas of Midtown Manhattan, and may have impacts on the CV study area as well.

The TTI CVPD Evaluation Team will solicit the assistance of the regional planners for the New York Metropolitan Transportation Council and its Best Practices Activity Based Model (NYBPM) to develop realistic projections of traffic growth in the downtown area over the next seven years. In the case that this model cannot be used, the TTI CVPD Evaluation Team will make straight line projections of traffic growth based off current growth trends. The TTI CVPD Evaluation Team will make three levels of traffic predictions:

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

5.2.6 User Satisfaction Assessment

The TTI CVPD Evaluation Team, with the assistance from Volpe, will also evaluate user satisfaction associated with the deployments. In this part of the assessment, the TTI CVPD Evaluation Team will analyze user (i.e., vehicle operator and pedestrian) survey responses collected by the deployment team to determine how well they liked the technology and if it satisfied their needs. The TTI CVPD Evaluation Team recommends that the deployment include survey questions that measure the usability of the systems and applications. The TTI CVPD Evaluation Team also recommends that users be surveyed at various points throughout the deployment to determine how user satisfaction changes throughout through the deployment.

5.2.7 Stakeholder Acceptance

This analysis focuses on assessing the extent to which the stakeholders (NYC Department of Transportation and others) believe that their goals were achieved. This analysis will primarily consist of information collected during the stakeholder acceptance interview. As part of the interview process, the TTI CVPD will ask a series of questions that focus on how public agency practices changed because of introducing CV technologies in the deployment corridor. Questions will be designed to solicit information related to the six dimensions in AASHTO's Transportation System Management and Operations Capability Maturity Model (CMM) framework (14).

To assess stakeholder acceptance, the TTI CVPD Evaluation Team will conduct structured interviews of the major stakeholders to assess their perceptions of how well deployment achieved their desired goals and objectives. Through these interviews, the TTI CVPD Evaluation Team will collect information about what went right with the deployments and what agencies would change related to their deployments. The TTI CVPD Evaluation Team will also query the stakeholders to determine the steps agencies have taken to sustain the deployments. The TTI CVPD Evaluation Team also plans to conduct stakeholder workshops with the deployment team stakeholders to collect lesson-learned information and other information need to assess the long-term viability and sustainability of the deployment.

6 Data Collection

For the most part, the TTI CVPD Evaluation Team plans to use the data collected by the NYC Deployment Team to conducts its assessment of the mobility, in assessing the MEP benefits associated with the deployment.

6.1 Data Available from Pilot Deployment Site

The following sections discuss that data that will be made available by the NYC CVPD Team to the TTI CVPD Evaluation Team to use in the independent evaluation.

6.1.1 In-Vehicle Data Logs

According to the NYC's Data Management Plan (8), NYC will be collecting and retaining data from both the ASDs and RSUs. Table 6-1 shows NYC's estimates of the approximate number of hours and days of week that each of the equipped vehicle type.

Table 6-1. Quantity of CV Data by Vehicle Type.

Vehicle Type	Quantity	Approximately Daily Operating Hours	Days of Week
Taxis	5,850	16	7
Buses	1,250	12	7
NYDOT Vehicles	250	8	5
UPS Trucks	400	12	5
Sanitation Vehicles	250	10	5

Source: Reference (8)

The NYCVPD Team plans to collect two distinct types of data from the CV devices: detailed ASD Action Logs and RSU mobility data. The ASD Action Logs contain detailed vehicle movement and condition data surrounding specific events or warning alerts and are recorded on the ASD devices. The RSU Mobility data contain less detailed snapshots of vehicle locations and is recorded from the RSUs as it hears each ASDs pass by. Details about the content of these logs are provided below.

While previously planned for and included in the specifications for the ASDs being procured by NYCDOT, the ability of the ASDs to record periodic Breadcrumb data on the ASDs themselves is not anticipated to be collected during the CV Pilot. The ASD Breadcrumb data collection is instead envisioned as a potential future expansion of CV technology in NYC.

6.1.1.1 ASD Action Log Data

ASD Action logs contain data associated with events experienced by the CV as it travels throughout the NYC study area. The NYC CVPD Team defines an event as a situation or circumstance in which one or more of the embedded applications installed in the ASD issues a warning alert to the driver or when a pre-defined condition occurs (e.g., hard braking) without an warning being issued from one of the CV applications on the ASD. The Action Log collects high resolution data (every 10th of second) from a number of sources for a configurable time window surrounding the event (for example, 10–20 seconds before the event and 20–50 seconds after the event). The data contained in this log include the following:

- Details regarding the CV application which generated the warning alert.
- The transmitted BSM data of the subject vehicle.
- The received BSM data of other vehicles within view of the subject vehicle.
- The SPaT and MAP data received from RSUs within a configurable range of the subject vehicle.
- Vehicle data available from the vehicle's CAN bus (e.g., directional signal, hard braking, steering wheel angle, trajectory, speed).

These data can be used to reconstruct the situation and circumstances, which led up to alert being issued by the application as well as document how the driver responded to the alert that was provided.

For the privacy purposes, all PII including vehicle ID will be removed from these data before they are made available to the TTI CVPD Evaluation Team. In addition to PII removal, the ASD Action Log data will have the general time and location of the Action Log obfuscated to prevent matching of individual ASD Action Logs to non-CV data sets, most notably crash records. While the general time and location of the Action Log will be obscured, the relative precision of the Action Log data in terms of both time and space will be preserved. This type to data is intended to aid the Safety Evaluation associated with particular types of events.

6.1.1.2 RSU Mobility Data

Mobility data will be collected from the RSUs in the form of an ASD sighting of a BSM heard from each equipped vehicle that passes by the RSU. These recordings of the ASD's BSMs will be recorded once per RSU each time the vehicle passes through the intersection (within the intersection box, or the closest point to the center of the intersection), and will be transmitted back to the NYCDOT TMC for further post-processing. As individual BSMs are collected in the TMC, the vehicle's pseudo ID in the BSM will be compared to other BSM sightings at nearby RSUs looking for the same vehicle pseudo ID. When records with matching pseudo IDs from nearby RSUs are found and are also within a reasonable timeframe, the two data points will be used to compute a travel time to traverse a defined roadway segment from one RSU to a neighboring RSU. The individual BSMs will be discarded, and the observation of the travel time for that roadway segment will be stored in the RSU mobility database. No obfuscation of time or location is anticipated.

6.1.1.3 Pedestrian Aftermarket Safety Devices/Smartphone

The NYC CVPD Team is deploying a pedestrian application that would allow visually impaired individuals to receive CV SPaT and MAP messages using a portable PID to improve their navigation at RSU equipped intersections. This application is likely to be mobile phone based and not a dedicated ASD. While the NYC CVPD Team expects the same location and PII protection rules that exist with the in-vehicle ASDs will be applied to the PIDs, the specific recruitment of the PID users through the IRB approved process and their signed consent of the use of the data recording of their movements on the PIDs are anticipated to allow the more detailed data collection from the PID devices. The TTI CVPD Evaluation Team will be informed of the exact nature and content of the PID data to once a vendor has been selected, and the IRB approval process is finalized. At a minimum, the TTI CVPD Evaluation Team would expect to use data from the pedestrian device logs to obtain information related to frequency of use of the PID devices.

6.1.1.4 Roadside Safety Units

The NYC CVPD Team also plans to log data from select RSUs. The NYC CVPD Team plans to use select RSUs in the deployment corridors and in the user locations to download data collected by the vehicles (i.e., ASD Action Logs and other ASD sighting data). As an equipped vehicle passes near these RSUs, they can upload their logged data to the RSU. After uploading the data, the vehicle will then purge its onboard database after receiving confirmation from the RSU. Data collected from the RSUs will also include the RSU mobility data as described above.

6.1.2 Vehicle Crash Records

The NYC CVPD Team also plans to make available to the TTI CVPD Evaluation Team a database that contains the vehicle crash information that can be used in the evaluation. This database would include data associated with all crashes (both equipped and unequipped) for which a police report (MV-104) is generated, regardless of roadway or facility type. As this form is maintained by other agencies, it is not likely that the data elements could be added to the data form that would allow CV vehicles to be specifically identified. Due to privacy and liability concerns, it will not be possible to tie ASD/RSU data to collision reports.

6.1.3 Weather Data

The NYC CVPD Team also plans to retain and integrate weather data with the CV vehicle log data. Real-time weather data feeds are available from the NWS via an RSS feed. This data feed contains the following weather information:

- Wind speed and direction.
- Visibility distance.
- Weather conditions (e.g., fair, overcast, partly cloudy).
- Sky conditions.
- Air temperature.
- Dew point temperature.
- Relative humidity.
- Wind chill and heat index temperatures.
- Barometric pressure.
- Precipitation amounts (1-hour, 3-hour, and 6-hour increments).

These data are aggregated hourly and reported at least every hour.

There are three NWS weather reporting stations are located within New York City area: Central Park (KNYC), Kennedy International Airport (KJFK), and La Guardia Airport (KLGA). The NYC CVPD Team plans to merge the data from the nearest NWS station based on the vehicle's location. Weather information will be stored with the ASD Action log data set prior to the time and location obfuscation process. For severe weather events, such as very high hourly precipitation amounts or extreme temperatures, the weather data will be slightly obfuscated to prevent matching data to a particular time and date. The NYC CVPD Team plans to use a cluster analysis to determine appropriate groupings and obfuscation procedures for the weather data to prevent linking of vehicle performance data to a usual weather condition.

6.1.4 Traditional Traffic Management Data Sources

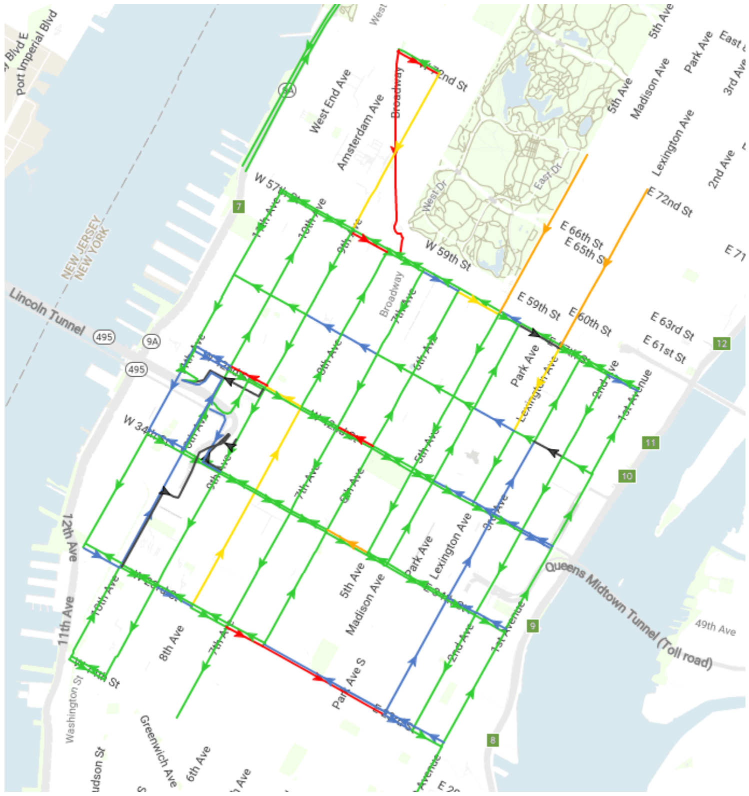
6.1.4.1 Travel Time

Travel time is the primary measure of mobility that will be used in the evaluation. In addition to using the RSU Mobility data, the TTI CVPD Evaluation Team also plans to use travel time data from other sources to assess the effects of the deployments on mobility. A number of sources of travel time data are already available for use in the deployment corridors as well as other routes of importance in NYC. These include the Midtown in Motion System, the Taxi GPS data sets, and the MTA Bus Time system. Each of these systems provide probe-based travel times, which can be used to compare before and after travel times in the corridors. These systems, particularly the Midtown in Motion system, would include data from both equipped data and unequipped vehicles. The overall coverage area of the MIM's travel time monitoring system runs from 1st to 11th Avenues and from 23rd to 57th Streets. Readers are already installed that all travel times on the facilities to be segmented at the following major cross streets: 57th, 49th, 42nd, 34th, and 23rd Streets. Figure 6-1 shows a screen capture of the locations were linked travel times are available through the MIM system.

6.1.4.2 Traffic Volumes

Traffic volumes are another important source of data that will be used by the TTI CVPD Evaluation Team. Traffic volume data are needed not only to compute throughput performance measures, but also to normalize performance measures to account for differences in traffic demands. Traffic volume data are also needed to assist in developing and calibrating simulation scenarios.

As part of the deployment, the NYC CVPD Team plans to install new continuous traffic volume count stations at strategic points in the deployment corridors. The exact nature of the volume count stations is currently under review by NYCDOT as different technologies and vendor solutions are being tested and evaluated; however these counters will most likely be video-based. If a volume count system is identified that can provide sufficient accuracy of volume counts in the varying environmental and traffic conditions of the CV corridors, the NYC CVPD Team plans to have the continuous count data aggregated into 15-minute intervals and stored in the TMC database. After some minor degree of obfuscation, the NYC CVPD Team plans to fuse these data with CV Action Log data. If a permanent count system cannot be found that reliably and accurately can provide count data for the CV corridors, a secondary plan of deploying non-real time video-based count systems will be deployed instead to provide periodic data on the varying volume conditions over the course of the CV deployment evaluation phase.



Source: Reference (13)

Figure 6-1. Screen Capture of Midtown-In-Motion Travel Time Application.

6.1.5 Fusion of Operational Condition Data and CV Action Logs

The NYC CVP Evaluation Team plans to fuse both CV Action log data and real-time non-CV Data together to generate one data set that contains information available to the CV vehicles as well as the circumstances leading to that event. The following data will be merged by location and placed in 15-minute bins:

- Traffic count data (if available) at 15-minute intervals.
- Midtown in Motion segment travel time data (if available) at 15-minute intervals.
- NWS weather data at 1-hour intervals.
- DSNY plow data (when applicable) at 15-minute intervals.
- TRANSCOM traffic incident data on study corridors at 15-minute intervals.

Other non-CV data that are not available in real-time would be stored separately. These data would include the following:

- Taxi activity and MTA Bus Time data.
- Crash data.
- Summary log/calendar of special events and related street closures.

- Summary log/calendar of short- and long-term work zone presence.
- External project related changes (Vision Zero, transit, reconstruction, and signal timings).

6.2 New Data Collection

At this time, the TTI CVPD Evaluation Team does not anticipated the need to collect any additional data; however, this recommendation may change as the TTI CVPD Evaluation Team and Volpe gets deeper the detailed planning for the Safety Evaluation, User Surveys, Stakeholder Interviews, and Analysis, Modeling Simulation efforts. If during the planning effort, the TTI CVRD Evaluation Team determines that additional source of data are needed, the TTI CVRD Evaluation Team will update the analysis approaches.

7 Observed Data Analysis

This section describes how the observed data will be used to measure performance and to evaluate the NYC CVPD. This section describes the methods used for estimating performance measures as well as the potential statistical testing that may be performed on observed data.

Table 7-1 provides a description of the types of observed data the TTI CVPD plans to use to in assessing the effects of the CVPD on mobility, reliability, and public agency efficiency.

Table 7-1. Types of Observed Data.

Observation Types	Performance Measure	Data Source
Mobility	• Travel Time • Delays • Speeds • Vehicle Throughput	• Mid-town in Motion Travel Times • Observed Travel times – Ideal Travel times • BSM logs from equipped vehicles • Traffic Volume counts
Reliability	• 95% Travel Times • Buffer time	• Probe vehicle data from equipped vehicles • 95th Percentile – Average Travel Time
Public Agency Efficiency	• Responses Times • Frequency of changes • Better utilization of system assets	• Time difference between notification and action by operators • Time difference between notification and activation of traveler information alerts • Number of signal timing plan changes • Average duration between timing plan changes • Number of operator adjustments • Green time utilization • Mean time between failures • Average outage time

7.1 Mobility Measures

7.1.1 Travel Times

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

For this analysis, the CVPD Evaluation plans to compare average (mean) travel times of all vehicles (equipped and unequipped) for the same time periods (peak and off-peak) before and after deployment of the CV technologies. These data will be collected using either the probe vehicle data logs or vehicle re-identification systems, such as Bluetooth or similar vehicle tracking systems. Typically, these data measurements are aggregated into 15-minute periods throughout the entire day. These data are generally collected automatically by the systems and can be aggregated to the appropriate analysis period (peak hour, peak period, etc.) desired by the evaluation team. A cluster analysis will be applied to data to determine the effects that confounding factors (such as incidents, weather, special events, etc.) have on the travel time data. A separate analysis will be performed for normal conditions (no backups) and congested conditions (when the applications are most likely to be issuing alerts).

A generalized linear segment regression analysis can be used to determine the statistical significance of activating the CV technologies on travel times in the deployment corridors. The following equation represents the minimum general form of the regression analysis:

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

Where,

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

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

Y_t = the outcome at time t (in this case average travel time).

In this form of the regression model, β_0 represents the baseline level at T=0, β_1 represents the change in outcome associated with a time unit increase (representing the underlying pre-intervention trend), β_2 represents the level change following the activation of the CV applications, and β_3 represents the slope change following the activation of the applications. Other variable may be included in the regression analysis to control for confounding factors.

7.1.2 Delay

Delay is a performance measure commonly used by traffic management agencies to measure performance on urban arterials. On urban arterials, delay is defined as the increase beyond a travel time corresponding to a baseline speed (a speed below which travel would be considered delayed). Delay can be computed by subtracting the ideal travel time from the actual travel time. Figure 7-1 illustrates the concept of delay as it might apply to an urban arterial street.

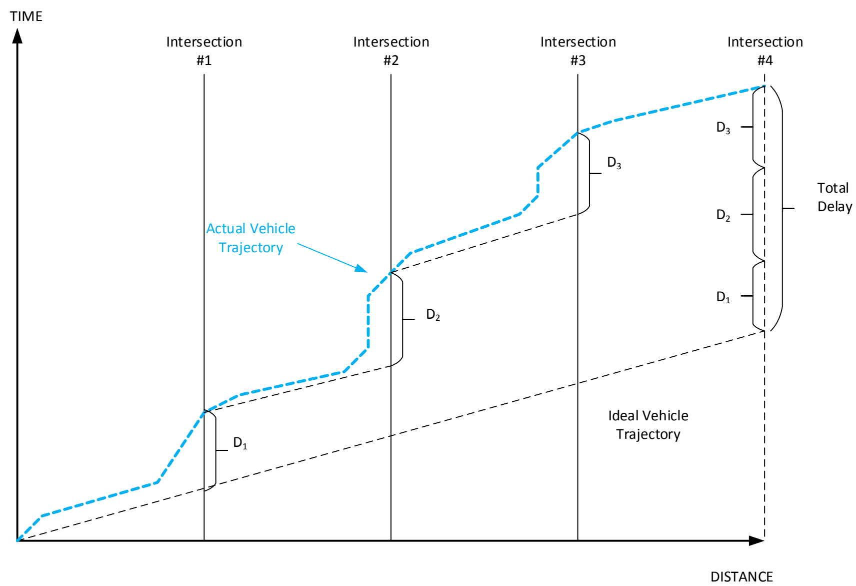


Figure 7-1. Concept of Delay on Urban Arterial.

For this analysis, the CVPD Evaluation plans to compare average (mean) total delay of all vehicles (equipped and unequipped) for the same time periods (peak and off-peak) before and after deployment of the CV technologies. Actual vehicle travel times will be collected using either the probe vehicle data logs or vehicle re-identification systems, such as Bluetooth or similar vehicle tracking systems. Typically, these data measurements are aggregated into 15-minute periods throughout the entire day. These data are generally collected automatically by the systems and can be aggregated to the appropriate analysis period (peak hour, peak period, etc.) desired by the evaluation team. A cluster analysis will be applied to the data to determine the effects that confounding factors (such as incidents, weather, special events, etc.) have on the travel time data. A separate analysis will be performed for normal conditions (no backups) and congested conditions (when the applications are most likely to be issuing alerts).

7.1.3 Travel Speeds

The TTI CVPD Evaluation Team will also examine how speed changed as a result of deploying CV technologies in the deployment corridors. Speed values will be measured by two sources: spot speed measures via radar detectors installed to the NYC CVPD Team vehicles, and through the ASD Activity logs. For this analysis, the TTI CVPD Evaluation Team will focus on two types of changes in the speed data: changes in average speeds and changes in the distribution of speeds. Figure 7-2 illustrates the differences in these types of test.

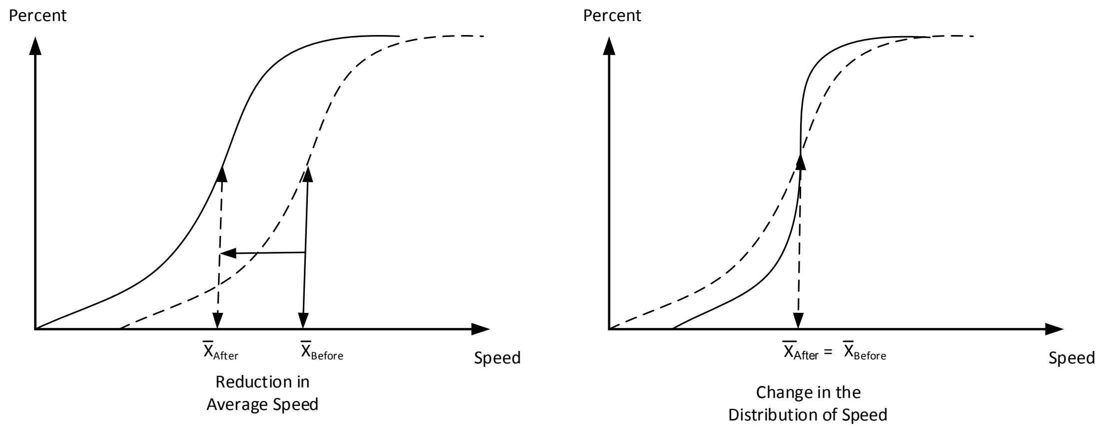


Figure 7-2. Types of Speed Comparisons.

When testing to see if reduction in average speeds have occurred, the TTI CVPD Evaluation Team will employ a standard comparison of mean techniques to determine whether a change in the observed mean speeds occurred. The TTI CVPD Evaluation Team will test the assumption of equal variances to determine which type of mean comparison is most appropriate (with or without equal variances).

In order to determine whether the distribution of speed remained constant among driver with active CV technologies compared to those operating in the silent mode, the TTI CVPD will compare the distribution of speeds from drivers that received alerts to drivers that did not receive alerts. Two types of test are used to compare the speed distributions: the Chi-Square Test and the Kolmogorov-Smirnov (K-S) test. The Chi-Square test is most appropriate for binned data while the K-S test is most appropriate for continuous data. The TTI CVPD Evaluation Team proposes to use the Chi-Square test to compare before and after speed distributions and the K-S test to compare speed distribution during specific events using the ASD Activity log data.

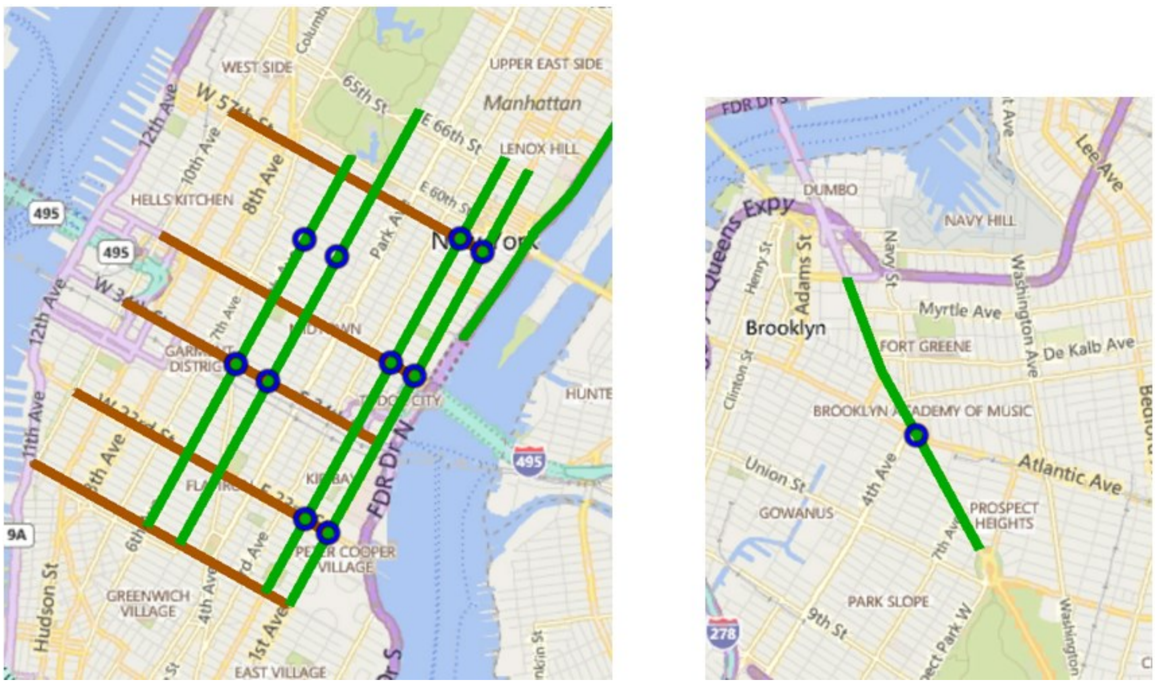
To test hypothesis related to compliance with speed limits and advisory, the TTI CVPD Evaluation Team proposes to use a test of proportions. This test would be used to compare whether the proportion of drivers complying with speed limit and/or speed advisories was different for those drivers that received alerts compare to those whose devices were operating in the silent mode.

7.1.4 Throughput/Traffic Volumes

Throughput is a measure of the number of users served by the transportation system. Throughput is computed by dividing the total number of vehicle miles traveled during a given time period by the total number of vehicles during that same period. Vehicle throughputs are needed to develop and calibrate the traffic simulation model and to assist in performing cluster analysis around different travel demand levels. Vehicle throughputs are also needed to help normalize safety and performance measures (e.g., collision rates). Ideally, traffic volume/throughput data should be collected continuously in 15-minutes intervals throughout the deployment period. Traffic volume data should include both equipped and unequipped vehicles and should be collected at strategic locations within each of the major deployment corridors. Sensors for collecting traffic volume/throughput data should be located in mid-block locations outside areas where queues form. Data should be collected and reported by direction of flow.

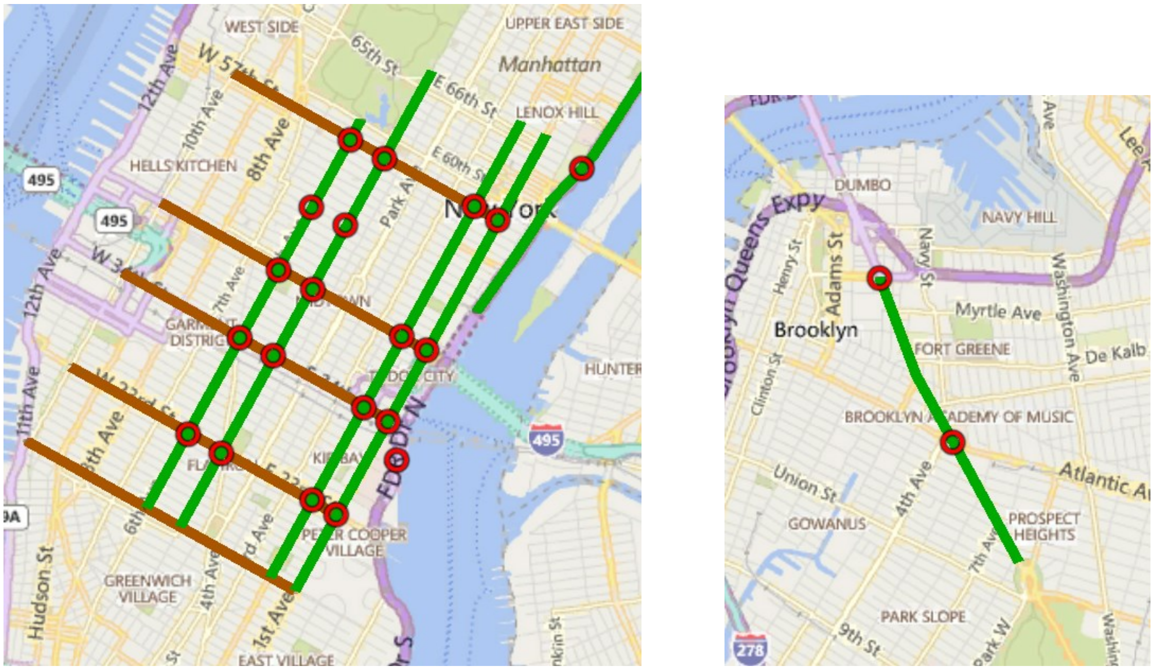
As discussed above, NYCDOT is currently evaluating different technologies and vendor solutions for permanent volume count systems that can both reliably and accurately count vehicles in NYC's varying environmental and traffic operational conditions and is also deployable within the NYCDOT ITS infrastructure and communication bandwidth constraints. If a sufficiently reliable and accurate permanent count system can be deployed, it will be deployed prior to the start of the CV pilot's phase 3. If not, a series of temporary data collection points will be deployed in a recurring manner (estimated as a two-week period per three-month quarter).

Figure 7-3 shows the location of both the proposed permanent count stations NYCDOT hopes to deploy as part of the CVPD. Figure 7-4 shows the alternative temporary traffic monitoring stations that NYCDOT plans to deploy if permanent count stations cannot be installed. The TTI CVPD Evaluation Team plans to use whichever count system is deployed as the primary source of traffic volume and vehicle throughput data.



Source: NYC CV Team

Figure 7-3. Proposed Location for NYC Permanent Traffic Volume Monitoring Stations.



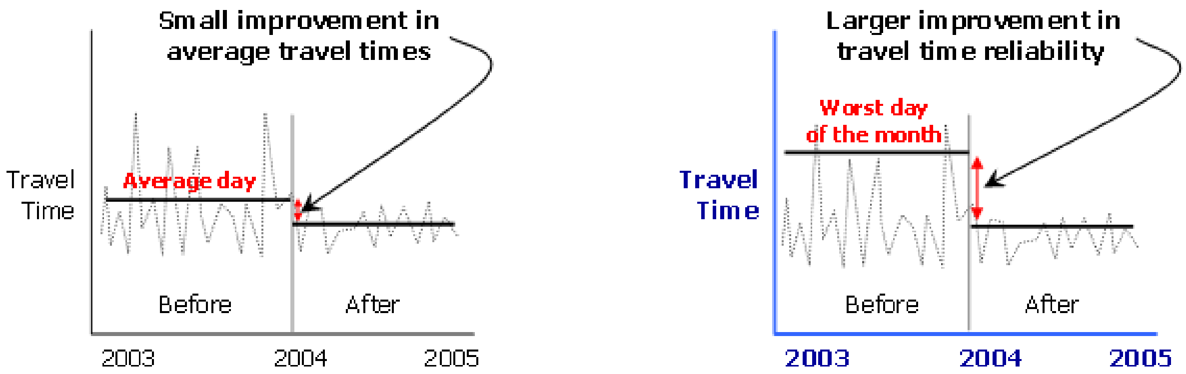
(Source: NYC CV Team)

Figure 7-4. Proposed Location for NYC Temporary Traffic Volume Monitoring Stations Reliability Measures.

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

7.1.5 Travel Time Reliability

In addition to travel time, travel time reliability measures will also be analyzed in the deployment area before and after activation of the CV technologies. Travel time reliability is “a measure of consistency or dependability in travel times, as measured from day-to-day and across/over different times of the day” (15). As illustrated in Figure 7-5, agencies often use travel time reliability in before-and-after studies. Travel time reliability captures the consistency or dependability in travel times between the worst days as opposed a typical or average day.



Source: Reference (15)

Figure 7-5. Travel Time Reliability.

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

7.2 Public Agency Efficiency

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

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

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

8 Simulation-Based Evaluation

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

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

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

The TTI CVPD Evaluation Team will provide specific details related to the AMS in the NYC AMS Evaluation Plan, scheduled for development in August 2017.

8.1 Selection of Simulation Models

Because of the anticipated limitation associated with observed data, the TTI CVPD Evaluation Team expects that most of the mobility benefits associated with the NYC CVPD will have to be estimated using microscopic simulation. The TTI CVPD Evaluation Plans has identified two options for developing a simulation model. The first option would be to build a simulation model from scratch. Because of the size and complexity of the deployment area, this could be a significant undertaking. Building a new model of the deployment area could add between $250,000 and $350,000 in costs to the evaluation effort, and between 6 to 9 months to the evaluation schedule.

The second option would be to use an existing model already developed that includes the deployment areas. The Manhattan Traffic Model (MTM) is an Aimsun-based, microscopic simulation model covering Midtown Manhattan from 14th Street to 66th Street. The model, originally developed in 2011 and updated most recently in 2015, covers the planned NYC CVPD area in Manhattan. The boundaries of the current MTM model are 14th Street to 66th Street from the Hudson River to the East River. It includes all the roadway geometries, signal timings, MTA and NYCT bus transit lines, and enforced truck routes in midtown Manhattan. It also can model existing curbside parking activities, including bus stops, double parking, and existing parking time of day parking regulations. This simulation will be developed for A.M. (6–9 A.M) and P.M. (4–7 P.M.) weekday peak periods. Updates will be completed by the NYC CVPD team to reflect current traffic demands and changes in the network configurations that may have occurred since its last update in 2015. Data from the baseline period could be used to update the model to existing conditions. A new driver behavior component would need to be added to the model to reflect the different behaviors of CV-equipped vehicles from non-CV vehicles.

The current MTM does not include Flatbush Avenue in Brooklyn. A new simulation model would need to be developed and calibrated to support the evaluation needs along Flatbush Avenue. The coding and calibration of the microsimulation model will follow the FHWA Traffic Analysis Tools, Volume III, Microsimulation Guidelines (the 2016 update of those guidelines) (16).

The preference of the TTI CVPD Evaluation Team would be to use the existing MTM model, updated to meet the requirements of the evaluation. The model is planned to be updated by the NYC CV Pilot team for use in their own evaluation. In addition to the AM and PM peak periods, it is likely to be recalibrated to include an off-peak and/or overnight hour to allow for evaluation of the CV impacts outside of the core peak periods. This model will be made available to the TTI CVPD Evaluation team once updated.

8.2 Modeling Approach

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

- Assemble Data.
    - Use available data to estimate the frequency of collision events (crash records) and the impacts (duration, # of lanes blocked, capacity reduction, etc.) they have on traffic operations when they occur.
    - Assemble volume (demand) data as collected by the NYC CVPD Team.
    - Review ATM logs and City calendar for special events.
    - Review available ATM logs for work zones. It is noted that short-term work zones are not usually documented.
    - Assemble weather data from ATM logs and NOAA data.
    - Assemble 511 travel times, Bluetooth data, ISIG delays, and queues into estimates of total vehicle hours traveled for each observation day in the before and after data sets. Normalize for differences in demand by dividing by vehicle counts.
- Identify Scenarios to be Simulated in Model.
    - Select travel time objective function for use in grouping observations into clusters.
    - Determine maximum number of distinct scenarios (with differing CV participation percentages) that can be modeled within the available evaluation budget.
    - Perform statistical tests to determine if cluster analysis can be performed on the pooled set of before and after days, or whether it needs to be limited to just the observations in before period, or the observations in the after period.
    - Use a cluster analysis to group the days into the target number of clusters.

  - Examine each cluster and select a representative day (combining demand level, weather, incident type) to represent each cluster in the simulation model run. Ensure that weather, demand, and incident variations are adequately represented in the selected days for simulation.
  - Compute the probabilities for each cluster (to be used later when assembling the individual scenario results into a total year performance).
- Calibrate Simulation Model (Before Deployment Runs).
  - Obtain calibrated baseline simulation model from Deployment Team.
  - Calibrate model against FHWA criteria for each scenario (demand, weather, event, incident, etc.). Validate against field data for the before condition. These runs will provide the before condition results.
- Analyze Before Condition.
  - Use the microscopic simulation model to estimate the delay associated with typical events, incidents (crashes), weather, and demands when they occur in the deployment area for the after deployment condition. Apply probabilities of each scenario under the before condition to microsimulation model results to obtain estimate of total annual performance under the before condition.
- Analyze the After Condition.
  - Re-run the before model scenarios but this time with CV deployed. This will get us the mobility effects of CV deployment without crash reductions.
  - To get the crash reduction mobility benefits of CV, do the following:
    - Identify those scenarios containing incidents of the type that Volpe has computed crash frequency reduction factors.
    - Convert Volpe crash frequency reduction estimates into estimates of reduced probabilities for the selected simulation model scenarios. These estimates would vary by market penetration level. Compute the After performance for each level of market penetration (taking into account the mobility effects of crash reductions) by computing again the annual performance under the new probabilities.

8.3 Modeling Future Travel Demand and Market Penetrations

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

- No change in market penetration – this scenario assumes that the number of vehicles equipped with CV technologies remains at its current level of deployment and that no new vehicles will be equipped with the current suite of applications.

- Slight growth in market penetration – this scenario assumes that the number of vehicles equipped with CV technologies will reach 5 percent of the background traffic over the next seven years.
- Moderate growth in market penetration – this scenario assumes that the percentage of vehicles equipped with CV technologies will reach 25 percent of the background traffic over the next seven years.

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

In addition to examining changes in performance with different penetration rates, the TTI CVPD Evaluation Team will project changes in background traffic demands. While NYCDOT expects significant growth in the Hudson Yards (lower 30s near 10th and 11th Avenues) and continued redevelopment of Brooklyn, NYCDOT does not expect significant growth in the study corridors.

The TTI CVPD Evaluation Team will solicit the assistance of the NYC Department of Transportation and other regional stakeholders to develop realistic projections of traffic growth in the downtown area over the next seven years. If these entities are unable to provide realistic traffic projections, the TTI CVPD Evaluation Team will make straight-line projections of traffic growth based off of current growth trends. The TTI CVPD Evaluation Team will make three levels of traffic predictions:

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

8.4 Modeling Environmental Impacts

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

8.4.1 Emissions

Past research examines emissions impacts of various CV technologies. The most common methodology in these estimations uses output from a traffic simulation model as input to an emissions model, and then measures the change in emissions along a given segment of road before and after the technology is installed. The TTI CVPD Evaluation Team plans to use the MOtor Vehicle Emission Simulation (MOVES) model to estimate emissions impacts. MOVES is a project-level simulator that uses a vehicle's operating characteristics—including idling, acceleration, deceleration, and cruise—to measure emissions and petroleum consumption.

The TTI CVPD Evaluation Team plans to use the probe approach to link the traffic simulation models the Aimsun with the MOVES model. The team will use the second-by-second vehicle trajectory output from the simulation models as the input to MOVES. The main assumption is that the traffic simulation model accuracy of the traffic simulation model in capturing the changes in travel behavior in a world with and without the CV technology. The TTI CVPD Evaluation Team will use total emissions and change in emissions along a link as the measure of performance measure in the emissions analysis. The TTI CVPD Evaluation Team will compare emissions levels with and without CV technology cases. The TTI CVPD Evaluation Team will measure greenhouse gas emissions and certain criteria pollutant emissions, like nitrogen oxide (NOx), particulate matter (PM), and carbon monoxide (CO). Various inputs to the MOVES model will be provided, as available, from the NYC CVPD Team.

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

8.4.2 Fuel Consumption

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

9 Survey-Based Evaluation

The TTI CVPD Evaluation Team plans to use survey-based evaluations to assess user satisfaction and stakeholder acceptance associated with the NYC CVPD. This section provides a brief overview of the approaches that will be used conduct data from these two groups. Details of the survey-based evaluations will be provided in the Stakeholder Acceptance Evaluation Plan and the Survey/Interview Guide, which are scheduled for completion later in the evaluation planning effort.

For the purpose of the evaluation, users are those individual who are interfacing directly with the applications. They include taxi drivers, fleet operators, pedestrians, etc. Stakeholders include those individuals involved in the planning, design, deployment, installation, operations, and maintenance of the technologies and applications. For the purposes of this study, stakeholders include agencies as the NYCDOT, NYC Police Department, the Metropolitan Transit Authority (MTA), and the NYC CVPD Team.

9.1 User Satisfaction Surveys

The NYC CVPD Team, with the support and direction of USDOT and The Volpe Center, will be responsible for developing an anonymous driver survey instrument to obtain feedback as to how well the ASD devices and applications operated. The NYC CVPD Team has not finalized the exact modality of the survey instrument but it is anticipated that it would be a combination of web forms (over the internet) and mobile application on tablets available to the operators where the vehicles are service/stored and where the operators will start or stop shifts (taxi barns, MTA depots, etc.).

The TTI CVPD Evaluation Team does not know the exact content of the survey at this time, but it should include questions that allow the following information to be collected from the users:

- Perception of whether advisories/alerts/warnings/traveler information were:
  - Timely.
  - Sufficiently detailed.
  - Easy to understand.
  - Accurate.
  - Useful.
- Perceived impact (if any) that alerts/warnings/advisories/ traveler information had on safety and/or mobility.
- Perception of whether trip expectations (e.g., speeds, red light violation, oversized vehicle warning) matched trip experiences.
- Perception of the overall satisfaction with performance of CV devices.
- The number and nature of problems with CV devices.

The TTI CVPD Evaluation Team will work with Volpe and the NYC CVPD Team in the development of appropriate questions and protocols for collecting user satisfaction data. The TTI CVPD Evaluation Team is responsible for analyzing survey users (i.e., actual vehicle operators) collected by the deployment team to determine how well they liked the technology and if it satisfied their needs. The TTI CVPD Evaluation Team recommends that the deployment include survey questions that measure the usability of the systems and applications. The TTI CVPD Evaluation Team also recommends that users be surveyed at various points throughout the deployment to determine how user satisfaction changes throughout through the deployment. The TTI CVPD Evaluation Team will also review survey instruments and, if directed, protocols to ensure that user-based financial information is collected that can be used in the Financial Assessment (Task C). Examples of these types of questions include willingness to pay, perceived value, and other financial types of questions.

9.2 Stakeholder Acceptance/Satisfaction

The TTI CVPD Evaluation Team is also responsible for measuring stakeholder acceptance and satisfaction with the deployment. The purpose of this element of the evaluation is to determine how well the pilot deployment program fulfilled stakeholder goals and objectives. In developing this stakeholder acceptance/satisfaction plan, the TTI CVPD Evaluation Team will select a manageable list of high-level goals, drawn from written documents of NYC deployment leaders. Generally, stakeholder goals are related to mobility, environment, and public agency efficiency. In addition, the stakeholder acceptance/satisfaction surveys are intended to capture the lessons learned by the stakeholders in the planning and design phase as well as the operations phase of the deployment.

To capture stakeholder acceptance information, the TTI CVPD Evaluation Team will conduct interviews with pertinent deployment stakeholders. Potential stakeholders that will be interviewed include the NYCDOT administrators and decision makers, NYCDOT traffic managers and operations, NYCDOT technical maintenance personnel, NYC CVPD Deployment Team members, and other key personnel recommend by the Deployment Team. The TTI CVPD Evaluation Team will develop a script of open-ended questions to follow during the interview process. The TTI CVPD Evaluation Team will pattern the development the interview questions after the American Association of State Highway and Transportation Officials' (AASHTO) Transportation Systems Management and Operations (TSMO) Capability Maturity Model (CMM) Guide (14). The interview questions will be structured to obtain stakeholder input on the six agency capability maturity dimensions defined by AASHTO to support TMO. The TTI CVPD Evaluation Team would develop interview questions that would solicit stakeholder input and lessons learned related to the following:

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

- *Organization and Workforce* – these questions would be related to the organizational structure, staff development, and staff recruitment and retention processes needed to support and sustain a CV deployment.
- *Collaborations* – these questions would be related to the type and nature of the relationships that a deploying agency needs to have with public safety agencies, local governmental entities, and others to develop and sustain a CV deployment.

The TTI CVPD Evaluation Team recommends that stakeholder acceptance be sampled at least twice during the evaluation period: the first being shortly before or after the systems and applications become active, and the second being right before the end of the evaluation period. Sampling twice during the evaluation would allow the TTI CVPD Evaluation Team to determine whether processes, procedures, and agency capabilities had to change as the deployment transitioned from planning and design to operations.

Because of the potential sensitive nature of the data collected through these interviews, the TTI CVPD Evaluation Teams will be under the control of Texas A&M University's (TAMU) Institutional Review Board (IRB). All survey questions and protocols will first be cleared through TAMU's IRB and protocol would be in place to ensure confidentiality and privacy of responses before any interviews would be performed.

9.2.1 NYC Pilot Stakeholders

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

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

- Key Agency Partners:
  - NYCDOT Bureau of Traffic Operations.
- Operating Agencies:
  - Metropolitan Transportation Authority (MTA).
  - NYC Department of Information Technology and Telecommunications (DoITT).
  - NYCDOT TMC Operators.
- Fleet Operators:
  - City of New York Department of Sanitation (DSNY).
  - Metropolitan Transportation Authority (MTA).
  - NYC Taxi and Limousine Commission (TLC).
  - United Parcel Service (UPS).
  - Taxi Garage Operators.

- Ancillary Stakeholder Agencies:
    - Pedestrians for Accessible and Safe Streets Coalition (PASS).
- Deployment Team Members:
    - TransCore.
    - Cambridge Systematics.
    - KLD Engineering.
    - OnBoard Security.
    - New York University (NYU) University Transportation Research Center (UTRC).

The TTI CVPD Evaluation Team plans to conduct pre-deployment telephone interviews and survey these stakeholders to determine which goals and objectives (from Table 3-1) are relevant for the concerns of the various key stakeholders.

9.2.2 Information Gathering Approach

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

The TTI CVEPD Evaluation Team also plans to use workshops and interviews to collect best practices information from key stakeholders and the deployment Teams. The TTI CVPD Evaluation Team will design a workshop/interview guide that follows best practice principles to achieve a balance between maximizing data quality while minimizing respondent burden and cost. The interview guide will be structured to capture three categories of information:

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

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

Table 9-1 shows the type of survey/interview techniques that the TTI CVPD Evaluation Team will use to collect stakeholder input data.

Table 9-1. Data Collection Method by Stakeholder Type.

Stakeholder Type	Pre-Deployment Interviews	Pre-Deployment Workshop	Post-Deployment Interviews	Post-Deployment Survey	Post-Deployment Workshop
Primary Stakeholders	X		X		
Operating Agencies		X			X
Fleet Operators				X	
Ancillary Stakeholders				X	
Policy makers[1]	X		X		
Deployment Team		X			X

[1]Champion may not be in office post-deployment

9.2.3 Schedule

The TTI Evaluation Team will determine the interview schedule based on the anticipated progress of the pilot site. The informal conversions to confirm the accuracy and relevance of goals, objectives, and metrics would take place prior to deployment. The actual stakeholder assessment interviews will be conducted after the deployment has been ongoing for a minimum amount of time (to be determined together with FHWA) or recently concluded. Table 9-2 shows the anticipated schedule for conducting these studies.

Table 9-2. Anticipated Schedule for Collecting Stakeholder Acceptance Information.

Data Collection Type	Pre-deployment	Initial After	Long-term After
Interviews	3–6 weeks prior to Activation	3–6 months	9–12 months
Surveys	-		9–12 months
Workshops	3–6 weeks prior to activation	3–4 months following activation	9–12 months following activation

9.2.4 Data Analysis

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

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

- Perceptions on whether goals/objectives were fulfilled, along with why or why not.
- Lessons learned from the pilot experience.

- Assessment of the agency/organizations changes in terms of capability maturity dimensions: business processes, systems and technology, performance measurement, culture, organization and staffing, and collaboration.

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

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