# Connected Vehicle Pilot Deployment Program Independent Evaluation

## Public Agency Efficiency Impact Assessment—New York City

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**Final Report—June 17, 2022**
**FHWA-JPO-22-941**

U.S. Department of Transportation

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**16. Abstract**

In September 2015, the U.S. Department of Transportation Intelligent Transportation Systems Joint Program Office selected three Connected Vehicle Pilot Deployment (CVPD) Program sites: Wyoming, New York City, NY, and Tampa, FL. Each deployment represents different potential settings for connected vehicle technologies and was comprised of different applications that address vastly different problems. This report provides an independent assessment of the public agency efficiency impacts associated with the New York City (NYC) CVPD. This evaluation is primarily qualitative in nature and based on data provided by the NYC CVPD Team. The assessment shows that there is little evidence to support that the deployment had a significant impact on public agency efficiency in the deployment area, primarily because the deployment focused on improving safety. The COVID-19 pandemic also substantially altered travel patterns in NYC and significantly reduced the availability of post-deployment data to complete the evaluation as originally planned.

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# Executive Summary

On September 14, 2015, the U.S. Department of Transportation Intelligent Transportation Systems Joint Program Office (ITS JPO) launched the Connected Vehicle Pilot Deployment Program.(1) ITS JPO selected New York City, NY, (NYC) as one of three locations to serve as Connected Vehicle Pilot Deployment (CVPD) sites. The New York City Department of Transportation (NYCDOT) led the deployment. Located primarily in the Manhattan area and along Flatbush Avenue in Brooklyn, the NYC CVPD had the primary objective of developing and demonstrating the use of vehicle-to-vehicle, vehicle-to-infrastructure, and infrastructure-to-pedestrian communications to improve safety. The NYC CVPD was also part of NYCDOT's Vision Zero goal to eliminate traffic-related fatalities and reduce crash-related injuries and damage throughout the city.

For this deployment, the NYC CVPD Team equipped 3,000 city-owned fleet vehicles with aftermarket safety devices running the following applications as part of its NYC CVPD:

- Speed Compliance (SPDCOMP).
- Curve Speed Compliance (CSPDCOMP).
- Speed Compliance in Work Zone (SPDCOMPWZ).
- Forward Crash Warning (FCW).
- Emergency Electric Brake Light (EEBL).
- Blind Spot Warning (BSW)/Lane Change Warning (LCW).
- Intersection Movement Assist (IMA).
- Red Light Violation Warning (RLVW).
- Vehicle Turning Right Warning (VTRW).
- Pedestrian in Crosswalk Warning (PEDINXWALK).
- Mobile Accessible Pedestrian Signal System (PED-SIG).
- Oversize Vehicle Compliance (OVC).
- Emergency Communications and Evacuation Information (EVAC).
- Intelligent Traffic Signal System Data (I-SIGCVDATA).

The NYC CVPD Team also installed 457 roadside units (RSUs) at intersections in Manhattan and the Brooklyn Bridge and along Franklin D. Roosevelt Parkway on the east side of Manhattan.

The NYC CVPD Team collected pre- and post-deployment performance data, which the team used to assess the safety, mobility, environmental, and public agency impacts of the deployment. The before period ran from January 1, 2021, through May 19, 2021 (a total of 139 days). During this period, all vehicles operated in the silent mode (the applications were operational, but no alerts were issued). The after (or post-deployment) period ran from June 1, 2021, to December 31, 2021 (a total of 222 days). During this period, vehicles assigned to the treatment group issued alerts to drivers, while vehicles assigned to the control group continued operating in the silent mode. The NYC CVPD Team used the period between May 20, 2021, and May 31, 2021, to transition treatment vehicles from the silent mode to the active mode.

For evaluation purposes, the Texas A&M Transportation Institute (TTI) Evaluation Team defines *public agency efficiency* as any activity or response that impacts the agency's ability to respond to changing conditions or unexpected events in the deployment area or improve the agency's ability to manage its infrastructure assets. Because of delays in the deployment and because of unforeseen external factors (e.g., the COVID-19 pandemic), the Federal Highway Administration revised TTI's evaluation scope to include only data collected by the sites during the evaluation. TTI did not perform an extensive quantitative analysis of the data collected by the NYC CVPD Team. Instead, TTI's evaluation is primarily qualitative in nature with some supporting explanatory quantitative analyses appropriately scoped to reduce technical risk, and consistent with the nature, quality, and quantity of underlying data.

TTI assessed the impacts of the deployment on the following two public agency efficiencies areas:

- Improved speed and regulatory compliance.
- Improved information dissemination and situational awareness.

The NYC CVPD Team deployed four different applications aimed to achieving better compliance by the equipped vehicles:

- SPDCOMP.
- CSPDCOMP.
- SPDCOMPWZ.
- OVC.

Better compliance with regulatory speed limits helps reduce speed variability and promote smoother flow in roadway networks. Better compliance with reduced speeds in work zones also helps to improve worker safety in and around lane closures and capacity restrictions.

Based on the data available, the NYC CVPD Team reported the following related to the effectiveness of these applications to achieve better speed compliance in fleet vehicles:

- The SPDCOMP application was effective at achieving better speed limit compliance by fleet vehicles. The NYC CVPD Team reported that drivers receiving alerts had a reduced number of speed limit violations compared to those that did not receive alerts. Vehicles receiving SPDCOMP alerts decelerated faster and took less time to reach compliance than vehicles that did not receive alerts.
- Limited observations prevented the NYC CVPD Team from reaching a conclusive finding about the effectiveness of the CSPDCOMP and the SPDCOMPWZ applications to produce better compliance with curve speed advisories and work zone speed limits, respectively, within the deployment area.
- The NYC CVPD Team operated the OVC application in a test mode only. The NYC CVPD Team used an artificially low bridge height to generate compliance with the over-height compliance application. As a result, the NYC CVPD Team could not form any meaningful conclusion or evaluation on the efficacies of the application's ability to changing vehicle motions or driver behaviors.

The NYC CVPD included two applications that had the potential to allow NYCDOT to better manage the roadway network using CV data. These applications include EVAC and I-SIGCVDATA.

The NYC CVPD Team developed the EVAC application to help transmit information from NYC's Office of Emergency Management and NYCDOT's Office of Emergency Response to connected vehicles (CVs) near or within affected areas during defined incidents and events. The intent of this application was to provide custom traveler information messages to CVs when entering a geofence-defined area near an RSU.

The NYC CVPD Team never needed to implement EVAC for a true emergency condition throughout the deployment phase. Instead, the NYC CVPD Team activated EVAC test messages at a handful of locations during the initial stages of the before period and at one location throughout the entire before period.(2) The NYC CVPD Team stopped all EVAC test messages before beginning the after period to ensure that no vehicles received test messages during the post-deployment period.

The NYC CVPD Team developed the I-SIGCVDATA application to test the feasibility of using CV data to monitor CV movements as an alternative technology for producing travel time data for use with the adaptive traffic signal system.(2) The purpose of evaluating this application was to investigate whether the data produced by CVs was comparable to those produced by NYCDOT's current travel time system data, which uses electronic toll collection (ETC) technology.

The NYC CVPD Team compared the 1-week and 1-month average and median travel times and speed estimates produced by the two systems (the ETC and the CV systems).(2) The NYC CVPD Team made the following observations between the travel times and speeds produced by these two systems:(2)

- The CVs generated similar average and median 24-hour travel time profiles compared to those produced by the ETC system.
- The CVs generated similar average speed 24-hour travel time profiles compared to those produced by the ETC system.
- There were hours of the day when the NYC CVPD Team observed significant differences in average travel times. The NYC CVPD Team attributed this finding to the few CVs traversing the network.

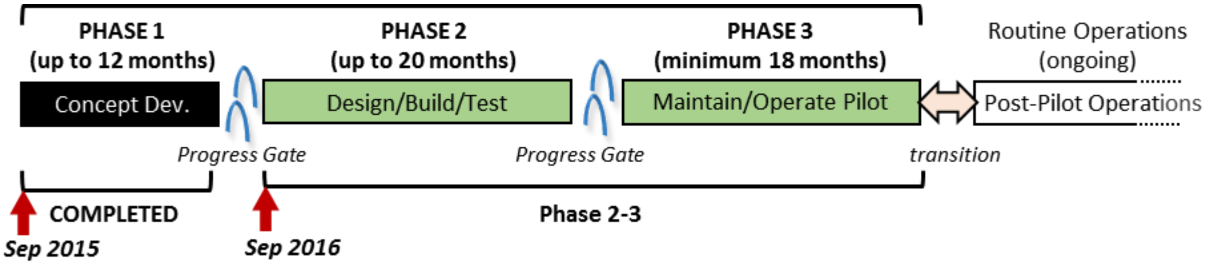
Based on available data, the NYC CVPD Team concluded the availability of block-by-block CV travel time data can help NYCDOT better identify bottleneck conditions than the ETC travel time data can. The CV data allowed operators to better understand the spatial and temporal evolution of traffic congestion patterns in the network.

# Chapter 1. Introduction

Connected vehicle (CV) technologies offer immense potential to improve safety and enhance mobility. The technologies use advanced mobile communications to share information between users of the transportation system (passenger vehicles, buses, pedestrians, etc.) and the infrastructure. Applications embedded in vehicles, mobile devices, and infrastructure use new levels of information to issue alerts. Using data from CVs, agencies can deploy traffic management strategies designed to improve safety, enhance mobility, and reduce emissions and fuel consumption. To explore the benefits of CV technologies, the U.S. Department of Transportation (USDOT) initiated the Connected Vehicle Pilot Deployment (CVPD) Program. USDOT's goals for this program included the following:(1)

- To spur early CV technology deployment, not just through wireless connected vehicles but also through other elements such as mobile devices, infrastructure, and traffic management centers (TMCs).
- To target improving safety, mobility, and environmental impacts and commit to measuring those benefits.
- To resolve various technical, institutional, and financial issues commonly faced by early adopters of advanced technologies.

On September 14, 2015, USDOT's Intelligent Transportation Systems Joint Program Office (ITS JPO) launched the CVPD.(1) ITS JPO selected three locations as pilot deployment sites: Wyoming, New York City, NY, and Tampa, FL. Each deployment represents different potential settings for CV technologies. Each site developed different applications to address vastly different problems specific to its needs. For example, the Wyoming deployment focused on better dissemination of travel information during winter weather events to reduce the potential of multi-vehicle collisions involving commercial trucks. The New York deployment focused on improving safety and traffic flow in a very dense urban environment, while the Tampa deployment focused on improving safety and mobility in a typical central business district of a smaller community. As illustrated in Figure 1, each deployment went through a similar life cycle. In Phase 1 of the life cycle, each site developed and refined the concepts behind its deployment. In Phase 2, each site, following the systems engineering approach, designed, built, and tested its deployments. In Phase 3, each site was responsible for managing and operating its deployments under actual traffic conditions. This report focuses on Phase 3 and includes an evaluation of the overall mobility benefits associated with the deployment.



*Source: Federal Highway Administration, 2015*

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

# New York City Pilot Deployment

ITS JPO selected New York City (NYC) as one of three CVPDs. The New York City Department of Transportation (NYCDOT) led the deployment. Located primarily in the Manhattan area and along Flatbush Avenue in Brooklyn (see Figure 2), the NYC CVPD focused on developing applications using vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-pedestrian communications to improve safety as part of its Vision Zero goal to eliminate traffic-related fatalities and reduce crash-related injuries and damage throughout the city.(2) Originally, the NYC CVPD Team planned to deploy ASDs in pay-for-hire taxi cabs (yellow cabs) and United Parcel Service (UPS) vehicles that traverse the midtown area, however, both disengaged prior to the deployment phase. As part of its deployment, NYCDOT installed onboard units (OBUs) with embedded safety applications in approximately 3,000 city vehicles from a wide variety of city departments. (A complete list of departments is provided in Chapter 2.) NYCDOT also installed over 450 roadside units (RSUs) in Manhattan and along Flatbush Avenue in Brooklyn to provide CVs with signal phase and timing (SPaT) information from the traffic signal system. The NYC CVPD Team also installed RSUs at strategic locations, such as bus depots, fleet vehicle storage facilities, river crossings, and airports, to facilitate the downloading of evaluation data and the uploading of application updates.

NYCDOT completed the Planning and Concept Development Phase (Phase1) of the deployment in August 2016 and began the transition to the Design, Build, and Test Phase (Phase 2) in September 2016.(2) The NYC CVPD Team started deploying RSUs in January 2019 and completed the deployment of RSUs in October 2020. Installation of the OBUs began in April 2019. NYC's COVID-19 pandemic restrictions in place in 2020 delayed full implementation until after the start of the Operations and Maintenance Phase (Phase 3), which began January 1, 2021. At the start of 2021, the NYC CVPD Team had equipped over 2,150 vehicles. The deployment did not reach its target installations until August 17, 2021.(2)

# Purpose of Report

ITS JPO selected the Texas A&M Transportation Institute (TTI) CVPD Evaluation Team to be the independent evaluator for the mobility, environmental, and public agency efficiency benefits for the CVPD Program. An independent evaluation by a third party who has no personal stake in the project will eliminate potential bias in the findings. USDOT has sponsored an independent evaluation of CVPD to help inform USDOT of the following:

- The extent to which the CVPD Program was effective in achieving its goals of transformational safety, mobility, public agency efficiency, and environmental improvements.
- The lessons learned that others could use to improve the design of future projects.
- The institutional and financial impacts of the CVPD.
- How to apply resources in the future.

*Source: New York City Department of Transportation, 2022*

**Figure 2. Map. NYC CVPD Deployment Corridors.**

This report provides an independent public agency efficiency impacts assessment (PAEIA) associated with the NYC CVPD. Because of delays in the deployment and because of unforeseen external factors (e.g., the COVID-19 pandemic), the Federal Highway Administration (FHWA) revised TTI's evaluation scope to include only data collected by the sites during their evaluation. TTI did not perform an extensive quantitative analysis of the data collected by the NYC CVPD Team. Instead, TTI's evaluation is primarily qualitative in nature with some supporting explanatory quantitative analyses appropriately scoped to reduce technical risk, and consistent with the nature, quality, and quantity of underlying data. To complete the analysis, TTI used materials and information provided through published information and outcomes of other evaluation efforts, including the following:

- Performance measurement activity performed by the sites.
- The Volpe National Transportation Systems Center's safety impact assessments.
- Site-generated dashboards and lessons-learned logbooks.
- Survey and interview outputs from *Connected Vehicle Pilot Deployment Program Independent Evaluation Stakeholder and Use Acceptance Surveys—New York City*.

This report focuses solely on the PAEIA associated with the deployment. Other reports have been produced to summarize the independent evaluation of the safety, environmental, and public agency efficiency benefits of the deployment.

## Organization of Report

The organization of this report is as follows:

- Chapter 2 provides an overview of the NYC CVPD. The chapter discusses NYC's goals and objectives associated with its deployment and provides a brief overview of the architecture of the deployment. Chapter 2 also includes a description of the applications planned and deployed through Phase 3 of the deployment.
- Chapter 3 summarizes the sources and availability of evaluation data. Specifically, this chapter describes the data generated by the NYC CVPD Team to evaluate each use case. The chapter also describes some of the major confounding factors impacting the deployment.
- Chapter 4 reports the results of the assessment of the impacts of the deployment on public agency efficiency.
- Chapter 5 summarizes the findings and conclusions associated with the impact of the deployment on public agency efficiency.

# Chapter 2. New York City Deployment

This chapter provides the following for the NYC CVPD:

- A summary of the goals, objectives, and use cases for the deployment.
- A summary of the vehicle fleet where the CV technologies were deployed.
- A brief overview of infrastructure components (RSUs) used in the deployment.

More information on the types of technologies used in the deployment is available in the following references:

- *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation.*(2)
- *Connected Vehicle Pilot Deployment Program Phase 2 Performance Measurement and Evaluation Support Plan—New York City.*(4)
- *Connected Vehicle Pilot Deployment Program Phase 2: System Architecture—New York City*.(5)
- *Connected Vehicle Pilot Deployment Program Phase 2: System Design—New York City*.(6)

## Deployment Goal, Objectives, and Use Cases

The primary goal of the NYC CVPD was to demonstrate how CV technologies and applications could potentially help NYCDOT advance its Vision Zero Program to "eliminate traffic related deaths and reduce crash related injuries and damage to both vehicles and infrastructure."(2) As a result, the NYC CVPD focuses on applications targeted to improve safety. The NYC CVPD Team identified mobility as a secondary but intertwined goal of the deployment. The NYC CVPD Team hypothesized that reducing the number of crashes (and their severity). and managing speeds could also improve safety and mobility. Fewer crashes would result in fewer crash-related delays. Likewise, fewer stops could result in fewer crashes, particularly rear-end crashes.(2)

The NYC CVPD Team identified seven use cases targeting NYCDOT's goals for the deployment. Table 1 summarizes the use cases identified for the NYC CVPD. Table 2 briefly describes the applications deployed in each use case.

**Table 1. Use Case Descriptions for the NYC CVPD.**

| Use Case Number | Use Case | Use Case Focus | Description |
|---|---|---|---|
| 1 | Manage Speed | Safety and Mobility | Because excessive speed is a contributing factor in many crashes and fatalities, NYCDOT identified managing speeds to operate within safe limits to improve on the safe operations of the city's roadways. The NYC CVPD Team deployed three different applications aimed at managing the operating speed of equipped vehicles under different conditions:<br>• Speed Compliance (SPDCOMP).<br>• Curve Speed Compliance (CSPDCOMP).<br>• Speed Compliance in Work Zone (SPDCOMPWZ). |
| 2 | Reduce V2V Crashes | Safety | The goal of NYCDOT's *Vision Zero* program is to reduce the number of fatalities and injuries on roadways, including V2V crashes. To reduce V2V crashes, the NYC CVPD Team deployed the following applications:<br>• V2V applications including the following:<br>o Forward Crash Warning (FCW).<br>o Emergency Electric Brake Light (EEBL).<br>o Blind Spot Warning (BSW)/Lane Change Warning (LCW).<br>o Intersection Movement Assist (IMA).<br>• Red Light Violation Warning (RLVW).<br>• Vehicle Turning Right Warning (VTRW). |
| 3 | Reduce Vehicle-to-Pedestrian Crashes | Safety | Because of NYC's heavy pedestrian and bicycle environment and its history of frequent vehicle-to-pedestrian collisions, many of which result in fatalities, NYCDOT wanted to assess CV technologies as a potential strategy for assisting and protecting pedestrians at intersection crossings. As part of the deployment, the NYC CVPD Team deployed two different pedestrian-oriented applications:<br>• Pedestrian in Crosswalk Warning (PEDINXWALK).<br>• Mobile Accessible Pedestrian Signal System (PED-SIG). |
| 4 | Reduce V2I Crashes | Safety | Because of the frequency and costs associated with vehicle strikes to bridges, NYCDOT identified a need to reduce the potential for V2I crashes. The NYC CVPD identified the Oversize Vehicle Compliance (OVC) application to address low clearance issues for oversize vehicles and enforce related truck route restrictions. |

| Use Case Number | Use Case | Use Case Focus | Description |
|---|---|---|---|
| 5 | Inform Drivers of Serious Incidents | Mobility | As the traffic manager and roadway infrastructure owner, NYCDOT needs to provide notification to drivers of areas to avoid and why. The NYC CVPD Team developed the Emergency Communications and Evacuation Information (EVAC) application to inform drivers of serious incidents. |
| 6 | Provide Mobility Information | Mobility | NYCDOT identified a need to develop reliable alternatives for providing travel time data for use in the adaptive traffic signal system. The NYC CVPD Team identified the Intelligent Traffic Signal System Data (I-SIGCVDATA) application to augment NYC's existing toll tag technology for producing linked travel time information. |
| 7 | Manage System Operation | | NYCDOT identified a need to manage and track the performance and operations of the deployed CV technologies. The NYC CVPD Team developed a series of system reports, databases, and management tools to support the day-to-day management and assessment of CV system operations. |

*Source: Texas A&M Transportation Institute based on information contained in reference 2, 2022.*

**Table 2. Summary Description of NYC CVPD Applications.**

| Application | Use Case | Description |
|---|---|---|
| Speed Compliance | 1 | This application notified drivers when their speed exceeded the posted speed limits. Using a zero-tolerance approach, any travel speed above the posted speed limit triggered a warning to the driver to reduce their speed to the posted speed limit. The speed limits were transmitted to the vehicle's after-market safety device (ASD) via MAP messages broadcast from the system RSUs along all study corridors. The city's default regulatory speed limit was 25 mph. |
| Curve Speed Compliance | 1 | This application was deployed to inform connected vehicles that they were approaching a sharp curve with a reduced advisory speed limit, thereby allowing the drivers to reduce vehicle speeds prior to the curve. The advisory curve speed limit was delivered to the vehicle's ASD via a Traveler Information Message (TIM) broadcast from nearby RSUs for a predefined geofenced area approaching the curve. The application was deployed along selected on-ramps to the Franklin D. Roosevelt (FDR) Parkway in Manhattan. |
| Speed Compliance in Work Zone | 1 | This application was deployed to provide connected vehicles that were approaching a reduced speed work zone with information on the zone's reduced speed limit and warn the drivers if their speed was above the work zone's speed limit. The geofenced work zone area and its reduced speed limit were delivered to the vehicle's ASD via TIMs broadcast from nearby RSUs. In all cases deployed in Phase 3, the defined work zone speed limit was set to 15 mph, 10 mph below the default regulatory citywide 25 mph speed limit. |
| Forward Crash Warning | 2 | This application warned the driver of the host vehicle of an impending rear-end collision with a remote vehicle ahead in traffic in the same lane and direction of travel. |
| Emergency Electric Brake Light | 2 | This application enabled equipped vehicles to broadcast a self-generated emergency brake event to other surrounding connected vehicles. Upon receiving such event information, the host vehicle receiving that message determined the relevance of the event and provided a warning to the driver, if appropriate. |
| Blind Spot Warning/<br>Lane Change Warning | 2 | These two related applications aimed to warn the driver of the host vehicle during a lane change attempt if the blind spot zone into which the host vehicle intended to switch was (or would soon be) occupied by another connected vehicle traveling in the same direction. |
| Intersection Movement Assist | 2 | This application warned the driver of a host vehicle when it was not safe to enter an intersection due to a high probability of collision with other remote connected vehicles (usually at stop sign–controlled or uncontrolled intersections). |

| Application | Use Case | Description |
|---|---|---|
| Red Light Violation Warning | 2 | This application was deployed to warn drivers of potential red-light violations. The application enabled a connected vehicle approaching an RSU-equipped signalized intersection to receive information regarding the signal timing and geometry of the intersection. The application used the speed and acceleration profiles of the host vehicle along with current signal timing and geometry information to determine if it appeared likely that the vehicle would enter the intersection in violation of a red traffic signal. If the violation seemed likely to occur, the application provided a warning to the driver. The application operated on the host vehicle's ASD by processing received MAP and SPaT messages broadcast from RSUs connected to signalized intersections. |
| Vehicle Turning Right Warning | 2 | This application was deployed to determine the movement of connected vehicles near a host transit vehicle stopped at a transit stop. The application provided an indication to the transit vehicle operator that a nearby connected vehicle was pulling in front of the transit vehicle. The application was intended to help transit vehicle operators determine if the area in front of the vehicle was occupied before it pulled away from the transit stop. (This application was deployed in limited conditions and primarily under testing conditions.) |
| Pedestrian in Crosswalk Warning | 3 | This application was deployed using pedestrian detection equipment (dedicated field-mounted infrared camera) to inform RSUs at equipped intersections of the presence of pedestrians within a defined crosswalk at signalized intersections. When pedestrians were detected, nearby connected vehicles were notified via RSU broadcasted SPaT (to define active pedestrian detection) and MAP messages (to define geometry and crosswalk details). Using this information, the host vehicle's ASD warned the driver of the pedestrian presence as appropriate given the vehicle's trajectory. |
| Mobile Accessible Pedestrian Signal System | 3 | This custom smartphone application provided pedestrians with information regarding the geometry conditions and active signal state of the pedestrian signals (WALK/DON'T WALK) at signalized intersections. The application functioned by receiving both MAP and SPaT messages via a cloud-based infrastructure and a location augmentation device to provide more detailed location data than that provided by the native smartphone platform. |
| Oversize Vehicle Compliance | 4 | This application was deployed to inform drivers of connected trucks and other commercial vehicles of pending low clearance conditions based on the height of the equipped vehicle. The application functioned on the host vehicle's ADS by receiving TIMs broadcast from nearby RSUs that defined a geofenced region ahead of low-height clearance conditions and warned drivers when it entered the region of a potential bridge-strike. (This application was deployed in limited conditions during the pilot.) |

| Application | Use Case | Description |
|---|---|---|
| Emergency Communications and Evacuation Information | 5 | This application was deployed to help transmit information from NYC's Office of Emergency Management (OEM) and NYCDOT's Office of Emergency Response (OER) to connected vehicles near or within affected areas during defined incidents and events. The vehicle's ASD warned drivers of events with a custom message upon entering a geofenced area of concern, as defined by a TIM broadcast from a nearby RSU. (This application was deployed under test conditions only with test messages during the deployment. No true emergency messages were broadcast during the evaluation period.) |
| Intelligent Traffic Signal System Data | 6 | This application used data from RSUs to monitor connected vehicle movements to provide RSU-to-RSU travel time data for use in other NYCDOT systems (specifically, the Midtown-In-Motion adaptive traffic signal system). The intent of this application was to determine if CV technology could provide comparable travel times to existing toll tag technology used by NYCDOT's Adaptive Control Decision Support System. The RSUs monitored and reported when equipped vehicles entered defined areas (usually the intersection "box") and reported those individual sightings back to NYCDOT's Traffic Management Center (TMC). Additional software in the TMC then matched the sightings received from different RSUs to compute RSU-to-RSU travel link travel times. |

*Source: Texas A&M Transportation Institute based on information contained in reference 2, 2022.*

# Deployment Fleet

For this deployment, the NYC CVPD Team equipped 3,000 city-owned fleet vehicles with aftermarket safety devices.(2) Originally, the NYC CVPD Team planned to deploy ASDs in pay-for-hire taxi cabs (yellow cabs) and United Parcel Service (UPS) vehicles that traverse the midtown area; however, both disengaged prior to the deployment phase. As a result, the NYC CVPD Team switched the deployment to city-owned fleet vehicles. Various agencies use these vehicles to conduct the daily business of the city. Some equipped vehicles were pool vehicles available to agency staff on an as-needed basis, while other vehicles were assigned to individual staff members. While some users could use their vehicles to commute to and from work, most participants used their vehicles for work-related trips. In most cases, drivers used the vehicles to make point-to-point, work-related trips, but other drivers were required to follow fixed routes. Table 3 shows the types of vehicles in which the NYC CVPD Team deployed onboard devices.

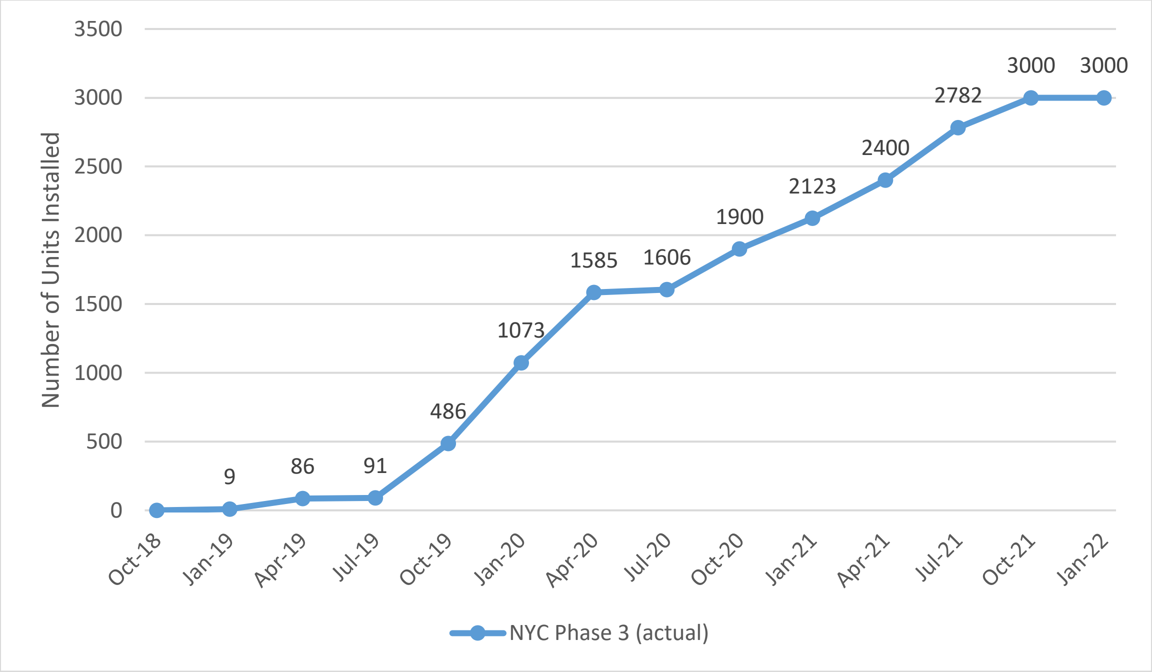
**Table 3. ASD Deployment by Agency and Vehicle Type.(2)**

| Agency | Passenger Cars | Pickup and Trucks | Vans | Buses | Vehicle Installations |
|---|---|---|---|---|---|
| NYC Dept. of Transportation | Yes | Yes | Yes | No | 1,238 |
| NYC Dept. of Parks and Recreation | Yes | Yes | Yes | No | 511 |
| NYC Dept of Corrections | Yes | Yes | Yes | Yes | 259 |
| NYC Dept. of Environmental Protection | Yes | Yes | Yes | No | 159 |
| NYC Dept. of Homeless Services | Yes | No | Yes | No | 100 |
| NYC Taxi and Limousine Commission | Yes | Yes | Yes | No | 98 |
| NYC Human Resources Administration | Yes | No | Yes | No | 86 |
| NYC Dept. of Citywide Administrative Services Fleet | Yes | No | No | No | 78 |
| NYC Dept. of Education | Yes | Yes | Yes | No | 78 |
| NYC Dept. of Buildings | Yes | No | No | No | 69 |
| NYC Administration for Children’s Services | Yes | Yes | Yes | No | 65 |
| NYC Det. Of Housing, Preservation, and Development | Yes | No | No | No | 48 |
| NYC Dept. of Health and Mental Hygiene | Yes | Yes | Yes | No | 45 |
| NYC Dept. of Design and Construction | Yes | No | No | No | 38 |
| NYC Office of Chief Medical Examiner | Yes | Yes | Yes | No | 29 |
| Metropolitan Transit Authority Bus & New York City Transit | No | No | No | Yes | 14 |
| NYC Emergency Management | Yes | No | No | No | 12 |
| NYC Dept. of Consumer Affairs | Yes | Yes | No | No | 12 |

| | | | | | |
|---|---|---|---|---|---|
| Anheuser-Busch InBev | No | No | Yes | No | 10 |
| NYC Dept. of Information Technology and Telecommunications | Yes | No | No | No | 9 |
| NYC Dept. of Probation | Yes | No | No | No | 6 |
| NYC CVPD Team Vehicle | No | Yes | No | No | 1 |
| Taxi Limousine Commission (Yellow Cabs) | Yes | No | No | No | 1 |
| **Totals** | **1,662** | **967** | **269** | **102** | **3,000** |

*Source: New York City Department of Transportation, 2021.*

Because of NYC's response to the COVID-19 pandemic in 2020, the NYC CVPD Team experienced significant delays in reaching the full deployment of 3,000 vehicles. Figure 3 shows the deployment history of the number of equipped vehicles per quarter for the NYC CVPD.(1) At the start of 2021, the beginning of the post-deployment evaluation period, the NYC CVPD Team had equipped over 2,150 vehicles. Installations in the remaining vehicles continued to occur well into the evaluation period. The NYC CVPD Team did not achieve full deployment until August 17, 2021.



*Source: U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office, 2022*

**Figure 3. Graph. Installation and Operational Readiness Summary—OBUs.**

As noted previously, the NYC CVPD Team equipped city fleet vehicles operated by city personnel for the deployment. The NYC CVPD Team noted that drivers operating city fleet vehicles may not necessarily operate their vehicle in the same manner as drivers of privately owned vehicles. The NYC CVPD Team noted that fleet vehicle operators, especially NYC fleet vehicle operators, log more vehicle miles traveled and spend more time driving the road network compared to normal, non-fleet vehicle operators. Also, because deployment operators are driving for work using a city-owned vehicle, they drive differently in the deployment vehicles compared to their own personal vehicles. Furthermore, because most of the NYC fleet vehicles are equipped with fleet management technologies that are routinely used to monitor speeding and aggressive driving, among other things, fleet vehicle operators exhibit different driving behaviors than drivers who are not routinely monitored. While these differences in driver behavior may not necessarily make fleet operators ideal surrogates for drivers from the general population, the NYC CVPD achieved the highest level of deployment of all three of the CVPDs.

## Operating Mode

NYC's experimental plan required the equipped vehicle to operate in either a silent or active warning mode. The CV applications functioned the same in both operating modes, including logging all application input data and all recommended alert messages. The only difference between vehicles operating in the different modes was that silent mode vehicles did not issue audible alerts to the drivers, while vehicles operating in the active mode did. This allowed the NYC CVPD Team to capture and examine the difference between driver behaviors, with and without CV technologies, using the same performance measures.

According to the NYC CVPD's experimental plan, all equipped vehicles operated in the silent mode from January 1, 2021, to May 19, 2021 (a total of 139 days), after which about 95 percent of the vehicles transitioned to the active mode. The NYC CVPD Team used over-the-air (OTA) messaging to initiate the switching of the vehicles from silent mode to active mode. This transition period from silent to active mode ran from May 20, 2021, to May 31, 2021. The NYC CVPD Team reported a sizable portion of the vehicles (90 percent) switched from silent to active mode shortly after the OTA message was first issued. However, because receiving the switching message required a vehicle to pass near an RSU and some vehicles were less active in the network than others, the NYC CVPD Team reported that a small portion of vehicles did not complete their switch to the active mode until well into the post-deployment evaluation period.

Once a vehicle transitioned to the active mode, it remained in the active mode for the duration of the post-deployment evaluation period. Vehicles never transitioned from an active to a silent mode.

## Control versus Treatment Vehicles

The NYC CVPD purposely did not allow all vehicles to transition to the active mode. The NYC CVPD purposely did not transition 150 vehicles (5 percent of the total deployment fleet) to the active mode. These vehicles remained in the silent mode throughout the duration of the after period. The vehicles served as control samples in the vehicle fleet. To minimize driver confusion and to ensure that drivers experienced consistent exposure from the applications, vehicles assigned to the control group were NYCDOT vehicles. In assigning vehicles to the control group, the NYC CVPD Team tried to select vehicles that NYCDOT personnel used as frequently and in a consistent manner as those in the treatment group.

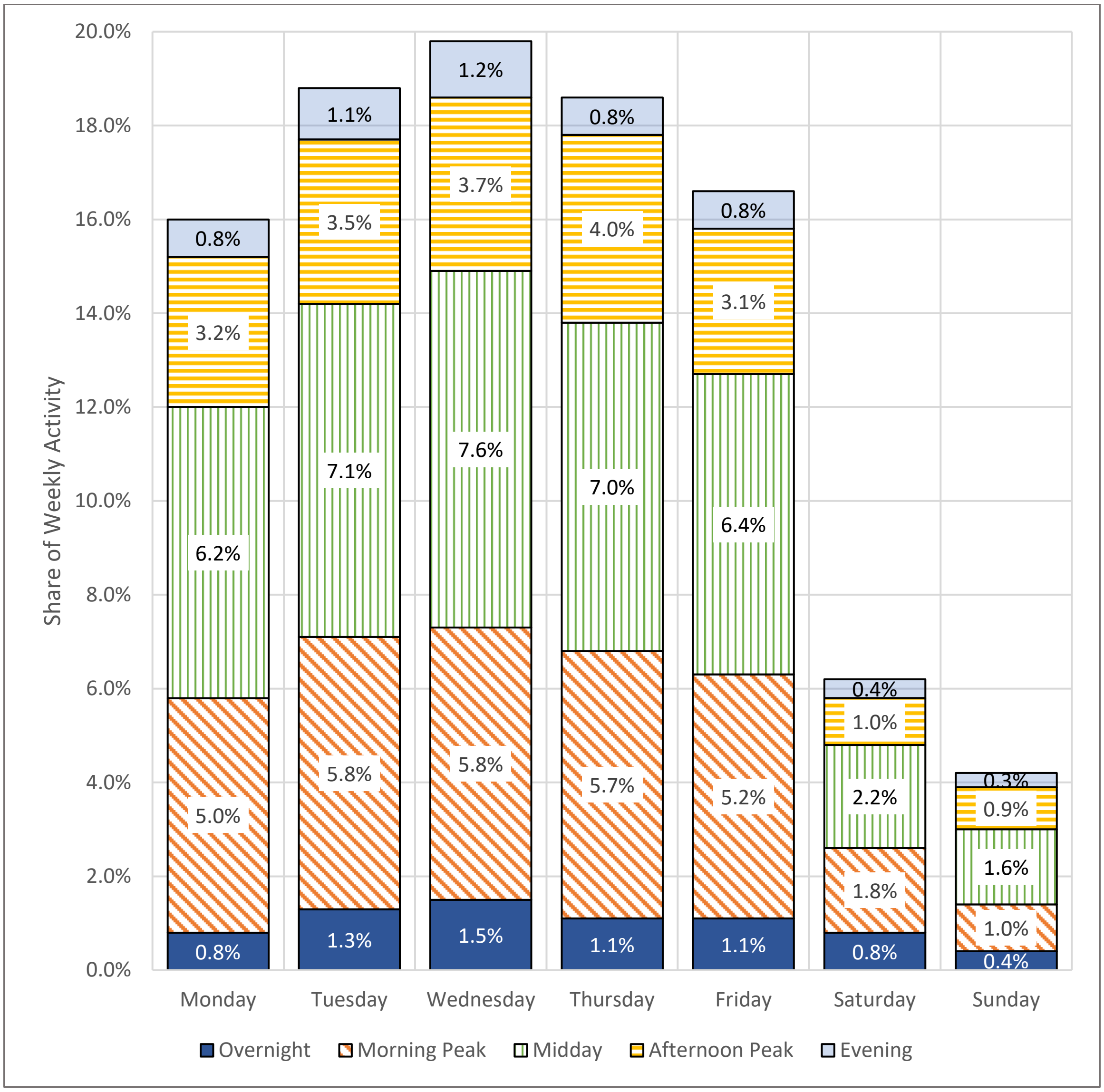
## Typical Fleet Activity

As part of the evaluation process, the NYC CVPD Team examined the typical hours of operations of the fleet vehicles by time of day and day of week. Figure 4 shows the percentage of weekly activities of the equipped vehicles for a 3-week period from September 13 to October 3, 2021. The NYC CVPD Team aggregated trips occurring during this period into the following five bins:

- Overnight (NT)—midnight to 6 a.m.
- Morning peak (AM)—6 a.m. to 10 a.m.
- Midday (MD)—10 a.m. to 3 p.m.
- Afternoon peak (PM)—3 p.m. to 8 p.m.
- Evening (EV)—8 p.m. to midnight

From this figure, the NYC CVPD Team made the following observations about the distribution of fleet activity in the deployment network:

- Approximately 90 percent of the trips occurred on weekdays, while the remaining 10 percent occurred on the weekend.
- Most fleet vehicle activity occurred Tuesday through Thursday.
- The AM and MD periods experienced the greatest share of fleet activity in the network, followed closely by the PM period. Few trips occurred during the EV and NT periods.



*Source: New York City Department of Transportation*

**Figure 4. Chart. Typical Travel Patterns of NYC Fleet Vehicles by Time of Day and Day of Week.**(2)

## Roadside Units

The NYC CVPD Team installed 457 RSUs at intersections in Manhattan, at the Brooklyn Bridge, and along FDR Parkway on the east side of Manhattan.(1) The RSUs were the point of communication between the infrastructure and the vehicles/other mobile devices. The RSUs also communicated with the traffic signal controller as necessary to obtain the information necessary or to provide input to the traffic signal controller at signalized intersections. The NYC CVPD Team's RSU specifications(2) indicated that each RSU should have the following capabilities:

- Broadcasting SPaT and map data to equipped vehicles using the Society of Automotive Engineers Dedicated Short-Range Communication (J2735) message set.
- Broadcasting the roadway's clearance height and restrictions.
- Broadcasting the roadway geometry for the speed zone, curve speed warning, and vehicle restriction applications.
- Receiving personal safety messages from surrounding pedestrians and determining when pedestrians were in specific crosswalks.
- Indicating pedestrian presence in the roadway as measured by pedestrian detection devices.

In addition, each RSU had the capability of collecting raw basic safety message (BSM) data from nearby ASDs (called "sightings"). These data were transmitted to the NYC TMC for use in computing RSU-to-RSU travel times. After transmitting the data to the TMC, the RSU purged this information.

The RSU also had the capability of performing OTA updates for managing and updating ASD firmware, configuration parameters, and application software. The ASD communicated with the RSU to verify its firmware version against the advertised available version. If the ASD firmware was out of date, the ASD initiated a request from the RSU to download the latest version over the air.

# Chapter 3. Evaluation Data and Data Availability

The NYC CVPD Team used a before-and-after study design with the inclusion of a control group to assess the performance of the NYC CVPD. The NYC CVPD Team selected this study approach to "maximize the likelihood of preventing or reducing the severity of accidents after the ASDs were switched into active mode."(4)

The NYC CVPD Team compressed both the pre- and post-deployment evaluation periods instead of the 1-year pre-deployment and 1-year post-deployment evaluation periods.(2) The NYC CVPD Team defined the before period to be from January 1, 2021, through May 19, 2021 (a total of 139 days). During this period, all vehicles operated in the silent mode (the applications were operational, but no alerts were issued). The after (or post-deployment) period ran from June 1, 2021, to December 31, 2021 (a total of 222 days). During this period, vehicles assigned to the treatment group issued alerts to drivers, while vehicles assigned to the control group continued operating in the silent mode. The NYC CVPD Team used the period between May 20, 2021, and May 31, 2021, to transition treatment vehicles from the silent mode to the active mode. It should be noted that even through some vehicles transitioned from silent to active mode well into June and July, 2021, 90 percent of the vehicles had transited to the active mode by May 31, allowing the NYC CVPD to initially define June 1, 2021 as the start of the post-deployment evaluation period. For more information, on the NYC CVPD Team's experimental design and the use of control and treatment vehicles in the deployment, the reader should consult NYCDOT's *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation.*(2

The NYC CVPD Team did collect initial performance data during Phase 2 to support the build-out and testing of the equipment; and to test the data collection, cleaning, and obfuscation method. However, since the testing and changing parameters represent an additional confounding factor in the evaluation data sets, the NYC CVPD Team did not use the data from the Phase 2 testing period in the performance assessment.(4)

## Evaluation Performance Measures

The NYC CVPD Team used a host of performance measures to assess the safety and mobility benefits associated with the deployment. Table 4 shows the original performance measures that the NYC CVPD Team used to assess the benefits of the deployment. However, because of issues encountered throughout the deployment—including the COVID-19 pandemic, the Federal Communications Commission's (FCC's) decision to reallocate the dedicated short-range communications (DSRC) bandwidth, delays encountered throughout the deployment, and limited sample sizes—the NYC CVPD Team was unable to use all these performance measures in its final assessment. In the end, of the total 42 performance measures identified in Table 4, the NYC CVPD Team assessed only 28, the majority of which were safety-related performance measures. Table 5 shows the performance measures that the

NYC CVPD Team computed as part of their assessment. The performance measures that the NYC CVPD Team computed are highlight in bold text in Table 5.

**Table 4. Identified Performance Metrics by CV Application.**[2,4]

| User Need | Category | NYCDOT Needs | CV Applications | Use Case No. | Performance Measure Metrics | Questions for Evaluation |
|---|---|---|---|---|---|---|
| Manage Speeds | Safety, Mobility | Discourage Spot Speeding | Speed Compliance | 1 | • Number of stops (average and distribution measures).<br>• Speeds (average and distribution measures).<br>• Emissions.<br>• Reduction in speed limit violations.<br>• Speed variation.<br>• Vehicle throughput (average and distribution measures).<br>• Driver actions and/or impact on actions in response to issues warnings. | Does speed limit adherence increase and speed variability decrease within the vehicle fleet on a given study roadway segment for a given time (cycle length basis) from the Before period to the Pilot period and from the control group to the treatment group?<br>Is this accompanied by an overall increase, decrease, or no change in average segment speed? |
| Manage Speeds | Safety | Improve Truck Safety | Curve Speed Compliance | 1 | • Speed-related crash counts, by severity.<br>• Vehicle speeds at curve entry.<br>• Lateral acceleration in the curve.<br>• Driver actions and/or impact on actions in response to issues warnings.<br>• Number of curve speed violations at each instrumented location. | Do the number of curve speed violations on each applicable roadway segment decrease from the Before and Pilot periods and from the control to the treatment groups? |

| User Need | Category | NYCDOT Needs | CV Applications | Use Case No. | Performance Measure Metrics | Questions for Evaluation |
|---|---|---|---|---|---|---|
| Manage Speeds | Safety | Improve Work Zone Safety | Speed Compliance in Work Zone | 1 | • Speed in work zones (average and distribution measures).<br>• Speed variation (distribution) at work zone.<br>• Number of vehicle speed limit violations in variable speed zone areas.<br>• Driver actions and/or impact on actions in response to issued warnings. | Do the number of work-zone speed violations on each applicable roadway type decrease from the Before period to the Pilot period and from the control group to the treatment group? |
| Reduce V2V Crashes | Safety | Reduce V2V Accidents | FCW<br>EEBL<br>BSW<br>LCW<br>IMA | 2 | • Fatality crash counts.<br>• Injury crash counts.<br>• Property damage-only (PDO) crash counts.<br>• Time to collision (V2V). | Do the number of reportable crashes decrease from the Before period to the Pilot period and from the control group to the treatment group? |
| Reduce V2V Crashes | Safety | Reduce Accidents at High Incident Intersections | Red Light Violation Warning | 2 | • Red-light violation counts.<br>• Time to collision (vehicle to cross vehicle path) at the intersection.<br>• Driver actions and/or impact on actions in response to issued warnings. | Does the severity of red-light violations at each studied intersection decrease from the Before period to the Pilot period and from the control group to the treatment group? |
| Reduce V2V Crashes | Safety | Reduce Bus Incidents, Improve Safety | Vehicle Turning Right Warning | 2 | • Right-turning related conflicts.<br>• Time to collision (vehicle-to-bus).<br>• Number of warnings generated.<br>• Driver actions and/or impact on actions in response to issued warnings. | Do the number of bus/right turn vehicle crashes decrease from the Before period to the Pilot period and from the control group to the treatment group? |

| User Need | Category | NYCDOT Needs | CV Applications | Use Case No. | Performance Measure Metrics | Questions for Evaluation |
|---|---|---|---|---|---|---|
| Reduce Vehicle to Pedestrian Crashes | Safety | Improve Pedestrian Safety on Heavily Traveled Bus Routes | Pedestrian in Crosswalk Warning | 3 | • Pedestrian-related crash counts, by severity.<br>• Number of warnings generated.<br>• Pedestrian-related conflicts/hard braking events.<br>• Time to collision (vehicle-to-pedestrian).<br>• Driver actions and/or impact on actions in response to issued warnings. | 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? |
| Reduce Vehicle to Pedestrian Crashes | Safety | Improve Safety of Visually- and Auditory-Impaired Pedestrians | Mobile Accessible Pedestrian Signal System | 3 | • Qualitative operator feedback.<br>• Pedestrian crossing speed and crossing travel time.<br>• Times out of crosswalk.<br>• Waiting time at the intersection for crossing. | Does the mobile app improve participants' perceived safety when crossing signalized intersections? |
| Reduce V2I Crashes | Safety | Address Bridge Low Clearance Issues/Enforce Truck Route Restriction | Oversize Vehicle Compliance | 4 | • Number of warnings generated.<br>• Number of truck route violations. | Do the number of low clearance violations decrease from the Before period to the Pilot period and from the control group to the treatment group? |
| Inform Drivers of Serious Incidents | Mobility | Inform Drivers | Emergency Communications and Evacuation Information | 5 | • Number of vehicles receiving information when generated. | Do CV vehicles receive the information warnings when generated? |

| User Need | Category | NYCDOT Needs | CV Applications | Use Case No. | Performance Measure Metrics | Questions for Evaluation |
|---|---|---|---|---|---|---|
| Provide Mobility Information | Mobility | Replace Legacy Measurements | Intelligent Traffic Signal System Data | 6 | • Segment speed (average and distribution measures) from CV compared to legacy detection systems.<br>• Travel time (average and distribution measures) from CV compared to legacy detection systems. | Do the CV-based mobility metrics compare favorably to legacy detection systems to provide better information? |
| Manage System Operations | System Operations | Ensure Operations of the CV Deployment | NA | NA | • System performance statistics (system activity, downtime, radio frequency monitoring range on ASD's and RSU's, number of event warnings by app). | Does the system operate reliably? |

NA = not applicable.

*Source: New York City Department of Transportation, 2021.*

**Table 5. Performance Measured included in the NYC CVPD Team Site Evaluation.(2)**

| Application | Performance Measure | Data Sources | Included by NYC CVPD Team in Site Evaluation | Reason for Not Evaluating |
|---|---|---|---|---|
| SPDCOMP | Number of stops (average and distribution) | AL, MS | No | NA |
| SPDCOMP | Speed (average and distribution) | FD, SD, MS | No | Low sample rates in the CV Travel Time system |
| SPDCOMP | Emissions | MS | No | Low measured mobility impacts negated the potential of emissions benefits |
| **SPDCOMP** | **Reduction in speed limit violations** | **AL, MS** | **Yes** | **NA** |
| SPDCOMP | Speed variation | FD, SD | No | Low measured mobility impacts negated the potential speed variation benefits |
| SPDCOMP | Vehicle throughput (average and distribution) | FD, MS | No | Low measured mobility impacts negated the potential for throughput benefits |
| **SPDCOMP** | **Driver actions in response to issued warnings** | **AL** | **Yes** | **NA** |
| CSPDCOMP | Speed related crash counts, by the severity of crashes | FD | No | Limited crash data prevented meaningful analysis |
| **CSPDCOMP** | **Vehicle speeds at curve entry** | **AL** | **Yes** | **NA** |
| **CSPDCOMP** | **Lateral acceleration in the curve** | **AL** | **Yes** | **NA** |
| **CSPDCOMP** | **Driver actions in response to issued warnings** | **AL** | **Yes** | **NA** |
| **CSPDCOMP** | **Number of curve speed violations** | **AL** | **Yes** | **NA** |
| SPDCOMPWZ | Speed in work zones (average and distribution) | FD, AL | No | Low sample rates in the CV Travel Time system (FD + SD) |
| SPDCOMPWZ | Speed variation in work zones | FD, AL | No | Low sample rates in the CV Travel Time system (FD + SD) |

| Application | Performance Measure | Data Sources | Included by NYC CVPD Team in Site Evaluation | Reason for Not Evaluating |
|---|---|---|---|---|
| **SPDCOMPWZ** | **Number of vehicle speed limit violations** | **FD, AL** | **Yes** | **NA** |
| **SPDCOMPWZ** | **Driver actions in response to issued warnings** | **AL** | **Yes** | **NA** |
| **V2V Safety** | **Fatality crash counts** | **FD** | **Yes** | **As crash data permitted** |
| **V2V Safety** | **Injury crash counts** | **FD** | **Yes** | **As crash data permitted** |
| **V2V Safety** | **PDO crash counts** | **FD** | **Yes** | **As crash data permitted** |
| **V2V Safety** | **Time to collision (V2V)** | **AL, MS** | **Yes** | **NA** |
| **RLVW** | **Red-light violation counts** | **FD, AL** | **Yes** | **NA** |
| RLVW | Time to collision (V2V) | AL, MS | No | ASD-based TTC analysis for RLVW not possible because ASDs did not record vehicle trajectories crossing the host vehicles |
| **RLVW** | **Driver actions in response to issued warnings** | **AL** | **Yes** | **NA** |
| VTRW | Right-turning related conflicts | FD | No | Extremely limited number of collected VTRW events records prevented meaningful analysis and evaluation |
| VTRW | Time to collision (vehicle-to-bus) | AL, MS | No | Extremely limited number of collected VTRW events records prevented meaningful analysis and evaluation |
| VTRW | Number of warnings generated | SD | No | Extremely limited number of collected VTRW events records prevented meaningful analysis and evaluation |
| VTRW | Driver actions in response to issued warnings | AL | No | Extremely limited number of collected VTRW events records prevented meaningful analysis and evaluation |

| Application | Performance Measure | Data Sources | Included by NYC CVPD Team in Site Evaluation | Reason for Not Evaluating |
|---|---|---|---|---|
| PEDINXWALK | Pedestrian-related crash counts, by severity | FD | No | Too many confounding factors (including those related to signal timing variations by deployment site) prevented meaningful crash analysis |
| **PEDINXWALK** | **Number of warnings generated** | **SD** | **Yes** | **NA** |
| **PEDINXWALK** | **Pedestrian-related conflicts/hard braking events** | **AL** | **Yes** | **NA** |
| **PEDINXWALK** | **Time to collision (vehicle-to-pedestrian)** | **AL, MS** | **Yes** | **Simulated only as field data did not exist** |
| **PEDINXWALK** | **Driver actions in response to issued warnings** | **AL** | **Yes** | **NA** |
| **PED-SIG** | **Qualitative operator feedback** | **SV** | **Yes** | **NA** |
| **PED-SIG** | **Pedestrian crossing speed and crossing travel times** | **AL** | **Yes** | **NA** |
| **PED-SIG** | **Times out of crosswalk** | **AL** | **Yes** | **NA** |
| **PED-SIG** | **Waiting time at the intersection for crossing pedestrians** | **AL** | **Yes** | **NA** |
| **OVC** | **Number of warnings generated** | **SD** | **Yes** | **NA** |
| OVC | Number of truck route violations | FD | No | The NYC CVPD Team did not implement OVC TIM messages on truck restricted routes as originally planned, only at low bridge clearances |

AL=Action logs, FD= Field Data, SD=System Data, MS=Microscopic Simulation, NA = not applicable.
*V2V Safety Applications include EEBL, FCW, IMA, BSW, and LCW.

# Data Sources

The following sections describe the data sources that the NYC CVPD Team had available to conduct its assessment. The *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation*(2) describes how the NYC CVPD Team generated these performance measures from these data sources.

## Connected Vehicle Data Logs

The NYC CVPD generated several vehicle-based data logs used to assess the performance of the applications deployed in the equipped vehicles. The following provides a brief description of these data logs. More information on the content of these data logs is available in the following references:

- *Connected Vehicle Pilot Deployment Program Phase 2 Performance Measurement and Evaluation Support Plan—New York City*.(4)
- *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation.*(2)

### *Action Data Logs*

The primary source of data logs used by the NYC CVPD Team to assess the performance of the applications was vehicle action logs. Each ASD logged relevant information surrounding a triggered event. These records included the following data:(2)

- Details regarding which CV application generated the warning, including firmware version and application parameters.
- BSMs that transmitted message content of the subject or host vehicle.
- BSM content received from other CV-equipped vehicles within a configurable range of the host vehicle.
- SPaT, MAP, and TIM messages received from RSUs within a configurable range of the subject vehicle, dependent on the type of warning:
  - RLVW and PEDINXWALK will collect heard SPaT and MAP messages.
  - EVACINO and OVCCLEARANCELIMIT will collect TIM messages.

The NYC Evaluation Team fused these action logs with other field data, such as weather and traffic condition data, to evaluate driver responses under different operating conditions. The resulting fused data provided context information under which the various applications produced alerts.

### *Breadcrumb Data Logs*

Each ASD also collected breadcrumb data. These logs are less detailed than the action logs associated with CV safety application warnings. The breadcrumb data logs include BSM data collected by the vehicle over a defined interval. The data collection intervals were configurable based on distance, time, or both. These data logs only contain information from the host vehicle.

### *Other Vehicle-Based Data Logs*

The NYC CVPD Team also configured each vehicle to collect other data for use in troubleshooting and evaluating system operations. These other data logs included the following:

- Radio frequency (RF) data files—These data files contain the V2V and V2I sightings by the equipped vehicle. The NYC CVPD Team used data in these files to assess RF radiation issues for specific vehicles.
- System status logs (SSLs)—These logs provide information regarding the health of the ASD. The SSL consists of messages that describe the ASD's operational status including any errors and/or failures.
- Over-the-air messages—The NYC CVPD Team used OTA messaging for managing and operating the ASD. This log contains copies of the OTA messages received by the ASD. The NYC CVPD Team used these messages to update the configuration parameters for each application and to upgrade application software.

## Infrastructure-Based System Logs

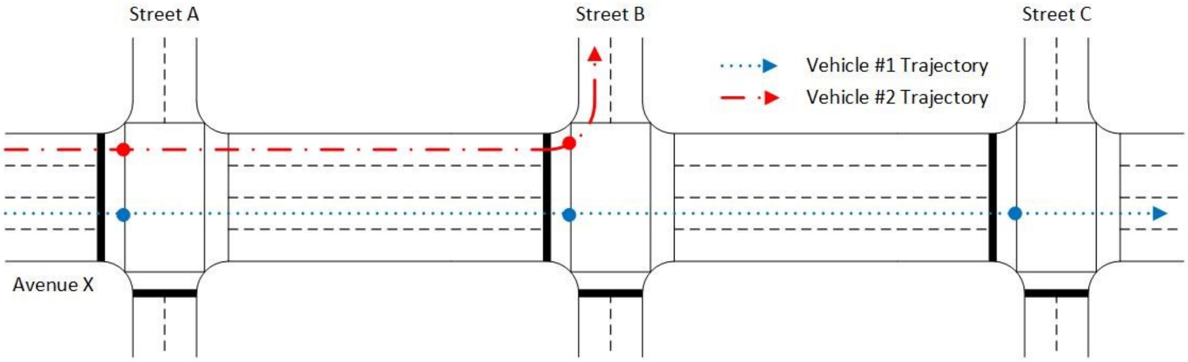
The NYC CVPD Team also produced two data sets recorded by the RSUs. Both sets include sighting information of ASDs heard by the RSU.(2)

### *Radio Frequency Sightings of Aftermarket Safety Devices*

Each RSU generated a log of each BSM broadcast it received. This log contained only the first and last BSM heard from each equipped vehicle within an established time window. The NYC CVPD Team used this information to establish the RF footprint and communication range of each RSU.

### *RSU-Based Travel Time Reporting System*

The NYC CVPD Team used sighting data from select RSUs along 1st and 2nd Avenues in Manhattan and along Flatbush Avenue in Brooklyn to collect travel time data from equipped vehicles. The sighting data recorded the temporary ID of each equipped vehicle and a time stamp of when the sighting occurred. Each RSU transmitted these data to NYCDOT's TMC. Using the temporary IDs from the vehicles, software in the TMC matched RSU-ASD sightings to produce an RSU-to-RSU travel time. A filtering algorithm removed travel time outliers (e.g., vehicles that have abnormally long travel times) and assigned a confidence score based on the number of samples and the standard deviation of the travel time samples within the aggregation period. Figure 5 shows how the NYC CVPD Team computed travel times between RSUs.



RSU X&A sends to TMC:
$\text{BSM}_{\text{Veh\#1 at X\&A}}$
$\text{BSM}_{\text{Veh\#2 at X\&A}}$

RSU X&B sends to TMC:
$\text{BSM}_{\text{Veh\#1 at X\&B}}$
$\text{BSM}_{\text{Veh\#2 at X\&B}}$

RSU X&C sends to TMC:
$\text{BSM}_{\text{Veh\#1 at X\&C}}$

Process at TMC:
$\text{TT}_{\text{Veh\#1 from A to B}} = \text{BSM}_{\text{Veh\#1 at X\&B}} - \text{BSM}_{\text{Veh\#1 at X\&A}}$
$\text{TT}_{\text{Veh\#2 from A to B}} = \text{BSM}_{\text{Veh\#2 at X\&B}} - \text{BSM}_{\text{Veh\#2 at X\&A}}$
$\text{TT}_{\text{Veh\#1 from B to C}} = \text{BSM}_{\text{Veh\#1 at X\&C}} - \text{BSM}_{\text{Veh\#1 at X\&D}}$

Store Each Observance in TMC Mobility Database (Time Binned)
$\text{TT}_{\text{Veh\#1 from A to B}}$
$\text{TT}_{\text{Veh\#2 from A to B}}$
$\text{TT}_{\text{Veh\#1 from B to C}}$

*Source: New York City Department of Transportation, 2021*

**Figure 5. Diagram. Process for Calculating Travel Times from RSU Data.**[(4)]

The NYC CVPD Team compared this method of collecting traffic time data to a similar travel time measurement system (radio frequency identification readers of electronic toll tags) already in use. NYC's evaluation assessed whether a CV-based travel time measurement approach can provide similar data inputs in near real time to feed the Midtown-In-Motion adaptive signal system.

## Field Data

The NYC CVPD Team also collected and retained more traditional, non-CV-based field data for use in the evaluation. The NYC CVPD Team called "any field observed or measured data which is not contained as part of the ASD action log" field data.(2) Field data include any field-measured data collected from non-CV data sources, including the following:

- Accident data.
- Weather data.
- Traffic count data.
- Transcom event and link condition data.

- Taxi and for-hire vehicle data.
- NYC Street Improvement Project information.

Field data are independent of the CV technology deployed and represent the entire vehicle population (equipped and unequipped) operating on the roadways.

## System Performance Data

To the NYC CVPD Team, *system data* referred to "any data that is produced or extracted from the CV Technology but is not directly related to the detailed ASD Action Log (1/10 sec) data."(2) The system data included general statistics about the deployment (e.g., number of devices installed and number of alerts and warnings produced) and health-monitoring statistics (e.g., uptime of RSU and number of active OBUs).

## User Surveys

In addition, the NYC CVPD Team surveyed users to collect perception data on the effectiveness of the deployed application. The NYC CVPD Team has conducted three sets of user surveys:(2)

- Pre-deployment Survey—The purpose of this survey was to measure end-user expectations and collect demographic data.
- Early-Stage, Post-Deployment Survey—The purpose of this survey was to collect feedback on the initial use of the applications in the deployment
- Post-deployment Survey—The purpose of this survey was to gather information about whether the pilot deployment attained its goals and objectives from the user's perspective.

Appendix D of the *Connected Vehicle Pilot Deployment Program Phase 2 Performance Measurement and Evaluation Support Plan—New York City*(4) shows a draft of the survey instrument the NYC CVPD Team planned to use to collect user perception information.

The NYC CVPD Team did not conduct interviews with individual drivers. Instead, the NYC CVPD Team used a web-based survey to collect user acceptance data. In addition, the NYC CVPD Team did not collect longitudinal perception changes from individual users because of anonymity and privacy concerns and the high likelihood that multiple operators would drive the same equipped vehicles.(2) Instead, the NYC CVPD Team provided only general changes in perception information for the driver population.

The NYC CVPD Team also conducted a survey of visually impaired pedestrians to measure the changes in users' experiences with the PED-SIG application, their satisfaction with the technology, and its perceived impact on their safety and mobility.(2) The NYC CVPD Team noted that because of the small sample size associated with the pedestrian survey, the team was not able to conduct a robust statistical analysis. The NYC CVPD Team tested this application between October 29, 2021, and November 18, 2021.

# Influencing Factors

The NYC CVPD Team also planned to collect and report information on factors that can confound the performance of the applications. The following sections highlight some of the confounding factors the NYC CVPD identified as potentially impacting the results of its evaluation.

## Operational Factors

The NYC CVPD Team identified several traditional factors that could have impacted of the deployment.(2) These factors include the following:

- Traffic demand variations.
- Weather.
- Accidents and incidents.
- Traffic signal timing updates.
- Short-term or unplanned work zones.
- Planned special events.

## Confounding Factors

The NYC CVPD Team identified several factors which could confound the impacts of the deployment. These factors included the following:

- Economic conditions.
- Fuel prices.
- E-hail and for-hire vehicle services.
- Citi bike.
- Transit service changes.
- Vision Zero improvement projects.

## COVID-19 Pandemic

In addition to these impacts, the COVID-19 pandemic has dramatically impacted overall travel demands and the nature of travel in New York City.(4) According to *Connected Vehicle Pilot Deployment Program Phase 2 Performance Measurement and Evaluation Support Plan—New York City:*(4)

> *"Lingering impacts are still readily evident now in 2021 as restrictions are still in place and are likely to remain in place until a significant number of vaccinations are completed. Additionally, a true return to pre-COVID conditions may not ever be seen, as changes to telecommuting and other changes in travel behaviors are speculated to be permanently altered, at least to some degree."*

Details of the overall impacts of COVID-19 and the ongoing effects on transportation in the NYC region are available at https://c2smart.engineering.nyu.edu/covid-19-dashboard.

## False Alarms and Missed Alarms

Missed and false alarms can significantly alter actual and user perceptions of the performance of the applications. While the NYC CVPD Team took steps in Phase 2 to improve locational accuracy (a significant source of false and missed alarms)(4), false alarms and missed alarms still occurred. During Phase 3, the NYC CVPD Team used vehicle operator feedback to solicit input into the operations and efficacy of the CV applications. The NYC CVPD Team intended to obtain this input through informal input from the vehicle operators to the fleet managers and more formalized anonymous driver surveys conducted through a web-based survey tool.

# Chapter 4. Public Agency Efficiency Impact Assessment

For evaluation purposes, the TTI Evaluation Team defines *public agency efficiency* as any activity or response that impacts the agency's ability to respond to changing travel conditions or unexpected events in the deployment area faster with fewer resources or improve the agency's ability to manage its infrastructure assets better or more effectively. Examples of public agency efficiencies include the following:

- Changes in incident response times.
- Changes in signal timing plans.
- Prevention of events that may create nonrecurring congestion conditions or need for unplanned operational changes.
- Better compliance to regulatory or advisory signage by the traveling public.

Agencies can measure changes in public agency efficiency directly (e.g., changes in response time for emergency vehicles) or indirectly through secondary measures (e.g., the timeliness and accuracy of alerts or notifications about potentially hazardous conditions) or stakeholder perceptions. Public agency efficiency may also include freeing up human resources to work on other things as a result of the introduction of new technology.

Table 6 lists the performance measures TTI identified to include in its impact assessment as part of PAEIA. However, due to issues associated with the deployment, the NYC CVPD Team was unable to provide all its planned performance measures. Table 6 also shows whether the NYC CVPD Team was able to produce the planned performance measure for each application. The performance measures shown in bold represent those planned PAEIA performance measures produced by the NYC CVPD Team. TTI's PAEIA focused on those performance measures listed in bold.

**Table 6. Potential Analysis Supported by NYC CVPD Performance Measures.**

| CV Application | Performance Measure | Potential Public Agency Efficiency Impact | Data Available from NYC CVPD Evaluation$^{(2)}$ |
|---|---|---|---|
| Speed Compliance | Number of stops (average and distribution) | NA | No |
| | Speed (average and distribution) | Secondary | No |
| | Emissions | NA | No |
| | **Reduction in speed limit violations** | **Primary** | **Yes** |
| | Speed variation | Primary | No |
| | Vehicle throughput (average and distribution) | NA | No |
| | Driver actions in response to issued warnings | NA | No |
| Curve Speed Compliance | Speed-related crash counts, by the severity of crashes | NA | No |
| | Vehicle speeds and vehicle speeds at curve entry | NA | Yes |
| | Lateral acceleration in the curve | NA | Yes |
| | Driver actions in response to issued warnings | NA | Yes |
| | **Number of curve speed violations** | **Primary** | **Yes** |
| Speed Compliance in Work Zone | Speed in work zones (average and distribution) | Secondary | No |
| | Speed variation in work zones | Secondary | No |
| | **Number of vehicle speed limit violations** | **Primary** | **Yes** |
| | Driver actions in response to issued warnings | NA | Yes |
| V2V safety warning applications* | Fatality crash counts | NA | Yes |
| | Injury crash counts | NA | Yes |
| | Property damage only crash counts | NA | Yes |
| | Time to collision (vehicle-vehicle) | NA | Yes |
| Red Light Violation Warning | Red-light violation counts | NA | Yes |
| | Time to collision (vehicle-vehicle) | NA | No |
| | Driver actions in response to issued warnings | NA | Yes |
| Vehicle Turning Right Warning | Right-turning related conflicts | NA | No |
| | Time to collision (vehicle-bus) | NA | No |
| | Number of warnings generated | NA | No |
| | Driver actions in response to issued warnings | NA | No |
| | Pedestrian-related crash counts, by severity | NA | Yes |

| CV Application | Performance Measure | Potential Public Agency Efficiency Impact | Data Available from NYC CVPD Evaluation[(2)] |
|---|---|---|---|
| Pedestrian in Crosswalk Warning | Number of warnings generated | NA | Yes |
| | Pedestrian-related conflicts/hard braking events | NA | Yes |
| | Time to collision (vehicle to pedestrian) | NA | Yes |
| | Driver actions in response to issued warnings | NA | Yes |
| Mobile Accessible Pedestrian Signal System | Qualitative operator feedback | NA | Yes |
| | Pedestrian crossing speed and crossing travel times | NA | Yes |
| | Times out of crosswalk | NA | Yes |
| | Waiting time at the intersection for crossing pedestrians | NA | Yes |
| Oversize Vehicle Compliance | **Number of warnings generated** | **Primary** | **Yes** |
| | Number of truck route violations | Primary | No |
| Emergency Communications and Evacuation Information | **Number of vehicles receiving information when generated** | **Primary** | **Yes** |
| Intelligent Traffic Signal System Data | **Segment speed (average and distribution) from CVs compared to legacy detection systems** | **Primary** | **Yes** |
| | **Travel time (average and distribution measures) from CVs compared to legacy detection systems** | **Primary** | **Yes** |
| System Performance Monitoring | System performance statistics (system activity, downtime, radio frequency monitoring range on ASDs and RSUs, and number of warnings by app) | NA | Yes |

* V2V safety warning applications include EEBL, FCW, IMA, BSW, and LCW.
NA = not applicable.

# Improved Compliance

To address safety issues, NYCDOT wanted to demonstrate the potential to improve compliance to regulatory and advisory speed limits within the deployment area. The NYC CVPD Team deployed four different applications aimed at achieving better compliance by the equipped vehicles. The following provides a summary of the public agency benefits associated with these deployments.

## Reductions in Speed Limit Violations

NYCDOT cited compliance with regulatory speed limits as a contributing factor to safety and mobility issues in NYC.(2) To address speed limit compliance, the NYC CVPD Team developed a speed compliance application. The application notified drivers when their speed exceeded the regulatory speed limit. In the deployment area, the regulatory speed limit is 25 mph. For the deployment, the NYC CVPD Team used a zero-tolerance strategy whereby speed above the speed limit would trigger an alert message. The application was intended to promote voluntary compliance with the citywide speed limit on the assumption that slower speeds would provide drivers with more time to react to traffic conditions and to avoid pedestrians and bicycles. As part of their Vision Zero campaign, NYCDOT has retimed the traffic signals to accommodate slower travel speeds in the network.

The NYC CVPD Team investigated over 40,635 speed compliance events associated with equipped vehicles over a period from January 2021 through September 2021.(2) The NYC CVPD Team declared a speed violation when the drivers did not reduce their speed to or below the speed limit after a speed compliance alert was issued by the application. The NYC CVPD Team compared the difference in speed limit violations between the treatment and the control group from the before and after periods. Although the NYC CVPD Team did not report the measured before-and-after compliance rates for both groups, the NYC CVPD reported a reduction of 47.7 speed limit violations per 1,000 events after the speed compliance alerts were enabled. The NYC CVPD concluded that this estimated reduction in speed limit violations between the control and treatment groups was statistically significant at a 95 percent confidence level.

The NYC CVPD Team also examined speed limit compliance under different weather conditions (clear, cloudy, or rainy) and reported the following:(2)

- During clear weather conditions, vehicles receiving alerts (i.e., the treatment group) experienced 4.687 fewer speed limit violations per 1,000 events than those that did not receive the alerts (i.e., the control group). The NYC CVPD Team found that this difference was not statistically significant at a 95 percent confidence level.
- Speed limit violations reduced by 38.071 violations per 1,000 events for drivers receiving alerts compared to those that did not receive alerts during cloudy conditions The NYC CVPD Team determined that this reduction was statistically significant at a 95 percent confidence level.
- During rainy conditions, the number of speed limit violations decreased by 203.833 violations per 1,000 events. The NYC CVPD Team found this reduction to be statistically significant at a 95 percent confidence level.

The NYC CVPD Team also examined the differences in deceleration and the time duration to slow down to the speed limit as part of its evaluation. Based on an analysis of the data, the NYC CVPD Team reported the following:(2)

- During clear and cloudy conditions, vehicles receiving the alerts had a higher difference in deceleration than those that did not receive the alerts. This implies that vehicles receiving alerts reacted more aggressively to reach the speed limit than those that did not receive alerts. Vehicles receiving alerts during rainy conditions did not show significant differences in deceleration, compared to vehicles not receiving alerts.
- Equipped vehicles traveling during clear and cloudy conditions demonstrated greater reduction in time to slow down to the speed limit after receiving alerts (i.e., they slowed down faster) than those that did not receive the alert.

## Reduction in Curve Speed Violations

TTI also identified the CSPDCOMP application as having the potential to improve compliance with speed regulations and advisories. In its assessment of performance, the NYC CVPD Team reported on the extent to which the CSPDCOMP application improved compliance with curve speed advisories along select on-ramps to the FDR Parkway in Manhattan.(2) Increasing curve speed compliance reduces the potential for rollover and run-of-the-road type collisions at these ramps and helps the NYCDOT better manage traffic flow efficiency onto the FDR.

During the evaluation period (January 2021 to September 2021), the NYC CVPD Team reported only 27 curve speed compliance events and only one curve speed compliance event in the control group. Based on the data for all the curve speed compliance events, the NYC CVPD Team found the following in terms of the performance of the CSPDCOMP application:(2)

- There was an 8.75-mph reduction in curve entry speed after drivers received a curve speed compliance alert. The NYC CVPD Team deemed this reduction in curve entry speed to be statistically significant at a 95 percent confidence level. Based on this finding, the NYC CVPD Team concluded that the alerts produced by the application caused drivers to reduce their speed at the curve entry.
- Based on all the curve speed compliance events, there was a reduction in lateral acceleration in the curve of approximately 0.681 $m/s^2$. The NYC CVPD Team concluded that this estimated reduction was statistically significant at a 95 percent confidence level. The NYC CVPD Team concluded the alerts produced by the application caused drivers to reduce their lateral acceleration in the curve entry.

The NYC CVPD Team also explored how the application impacted curve speed warning violations.(2) To assess performance, the NYC CVPD Team defined a curve speed violation to be when the driver's speed did not reduce to or below the advisory speed after being issued a curve speed compliance alert.

The NYC CVPD reported that none of the vehicles receiving a curve speed violation alert reduced their speed to the advisory speed limit (the advisory speed for the instrumented location was 15 mph).(2) The NYC CVPD Team attributed this finding to the small sample size of the curve speed compliance events. Another potential explanation for this observation might be that the recommended advisory speed (15 mph) may represent an appropriate speed (based on a ball-bank indicator or similar measuring devices used to measure speeds in curves). Regardless, the TTI Team concluded that based on findings reported by the NYC CVPD Team, there was insufficient evidence to confirm that the curve speed advisory application generated conclusive reductions in curve speed violations.

## Improved Speed Compliance in Work Zones

The NYC CVPD Team deployed the SPDCOMPWZ application to provide CVs approaching a reduced-speed work zone with information on the zone's reduced speed limit, and to warn drivers if their speeds were greater than the work zone's speed limit. Better compliance with reduced speeds in work zones helps to improve worker safety in and around lane closures and capacity restrictions. For this deployment, the defined work zone speed limit was set to 15 mph, 10 mph below the default regulatory citywide speed limit.

During the evaluation period, the NYC CVPD Team reported a total of 2,665 work zone speed compliance events.(2) The NYC CVPD Team reported a significant drop in the number of events for the period from April 2021 to June 2021. The NYC CVPD Team reported that terminating the SPDCOMPWZ test messages used in the before period caused this dip. During the after period, TTI estimates that fewer than 400 SPDCOMPWZ alerts occurred during the after period.

Regrettably, the NYC CVPD Team did not report on the effectiveness of the application to improve compliance with work zones speed limits; however, the NYC CVPD Team provided the following assessment of the application's performance based on the ASD data:(2)

- The NYC CVPD Team reported an increase in deceleration difference of approximately 0.427 $m/s^2$ after the drivers started receiving SPDCOMPWZ alerts. The NYC CVPD Team deemed this increase in deceleration difference to be statistically significant at a 95 percent confidence level and concluded that drivers tend to decelerate more after receiving SPDCOMPWZ alerts.
- The NYC CVPD Team reported a 2.2-second reduction in the time to slow down to the speed limit after receiving alerts. The NYC CVPD Team found this reduction to be statistically significant at a 95 percent confidence level and concluded that drivers tend to reduce their speeds to the speed limit faster when issued a SPDCOMPWZ alert.

## Oversize Vehicle Compliance

TTI also considered the OVC application as a final application that might help NYCDOT's operational efficiency. NYCDOT identified this application to address low-clearance issues for oversize vehicle and enforcing related truck route restrictions. The NYC CVPD Team deployed this application to provide alerts to drivers of connected city-owned and commercial fleet vehicles with alerts of pending low-clearance conditions based on the height of the equipped vehicle.(2) An RSU near the bridge would broadcast the height clearance information. The vehicle would then alert the driver of an impending bridge-strike condition, based on the height of the vehicle. The NYC CVPD Team deployed the OVC application at only one location throughout the evaluation period.

For the deployment location, the clearance height was set artificially low to 78 inches (6.5 feet) to test the performance of the application.(2) The NYC CVPD Team reported a total of 446 OVC alerts throughout the post-deployment period.(2) Because the clearance was set to an artificially low clearance threshold and there was never a true potential for a bridge strike to occur, the NYC CVPD Team indicated that it could not form any meaningful conclusion or evaluation on the efficacies of the application's ability to changing vehicle motions or driver behaviors.

# Improved Information Dissemination and Situational Awareness

The NYC CVPD included two applications that had the potential to allow NYCDOT to better manage the roadway network using CV data. These applications include the EVAC and I-SIGCVDATA applications. The potential impacts of these two applications on public agency efficiency are discussed as follows.

## Emergency Communications and Evacuation Information

The NYC CVPD Team developed the EVAC application to help transmit information from NYC's OEM and NYCDOT's OER to CVs near or within affected areas during defined incidents and events. The intent of this application was to provide custom TIMs to CVs when entering a geofence-defined area near an RSU. The intent of this application was to provide emergency response information such as evacuation orders, routing information, and areas to avoid to the vehicles through the RSEs by evacuation zones, resulting in improved traveler information dissemination to specific target audiences.

The NYC CVPD Team never needed to implement the EVAC for a true emergency condition throughout the deployment phase. Instead, the NYC CVPD Team activated EVAC test messages at a handful of locations during the initial stages of the before period and at one location throughout the entire before period.(2) The NYC CVPD Team stopped all EVAC test messages before beginning the after period to ensure that no vehicles received test messages during the post-deployment period.

Although the NYC CVPD Team did not conduct a direct analysis of driver responses to EVAC messages, the NYC CVPD Team did examine the communications range associated with disseminating the messages.(2) NYCDOT was concerned that the "urban canyon" effect caused by the high-rise buildings might prevent the effective dissemination EVAC messages in sufficient time to allow drivers to take appropriate action.

The NYC CVPD Team examined the effective range of a total of 1,666 EVAC messages.(2) Table 7 shows the effective range at which vehicles received EVAC messages, in relation to the center of the TIM alert zone. The table shows that most vehicles received alerts within 0 to 100 meters of the center of the alert zone. The table also shows that over 95 percent of the vehicles were able to receive EVAC alerts within 0 to 200 meters of the alert zone. The DSRC RSU specification (7) indicates that the RSU "shall transmit DSRC messages throughout a range of 1 m to 300 m" in an open field environment.

Table 7. EVAC Events Received by Radius from a TIM Broadcast Site.(2)

| Radius (m) | EVAC Messages | Percent of Total | Cumulative Percentage |
|---|---|---|---|
| 0–50 | 634 | 38.1 | 38.1 |
| 50–100 | 500 | 30.0 | 68.1 |
| 100–200 | 460 | 27.6 | 95.7 |
| 200–300 | 14 | 0.8 | 96.5 |
| 300–400 | 21 | 1.3 | 97.8 |
| 400–500 | 10 | 0.6 | 98.4 |
| 500–750 | 21 | 1.3 | 99.7 |
| 750–1,000 | 4 | 0.2 | 99.9 |
| 1,000–1,250 | 2 | 0.1 | 100.0 |
| **Total** | **1,666** | **100.0** | **100.0** |

*Source: New York City Department of Transportation, 2021*

## CV-Generated Travel Time Information (I-SIGCVDATA)

The NYC CVPD Team developed the I-SIGCVDATA application to test the feasibility of using CV data to monitor CV movements as an alternative technology for producing travel time data for use with the NYC CVPD's adaptive traffic signal system.(2) The purpose of evaluating this application was to investigate whether the data produced by CVs was comparable to those produced by NYCDOT's current travel time system data that uses electronic toll collection (ETC) technology. The NYC CVPD Team did not actually use the travel time data to adjust traffic signal parameters in the Midtown area. The intent of the project was to determine if the CV technology could provide input that is equivalent to the existing data collection mechanism used to allow more widespread deployment of the ACDSS adaptive control system with reduced infrastructure costs

As part of its evaluation, the NYC CVPD Team conducted an experiment comparing travel times produced by the two technologies for one segment of 2nd Avenue from 49th Street to 42nd Street for October 2021. The NYC CVPD Team intended this test to be a comparison of the different technologies to produce travel time data. The NYC CVPD Team reported the following findings associated with this comparison:(2)

- The current CV travel time system produced small sample sizes on any given day across the 24-hour period.
- Both technologies (the CV-based and ETC-based systems) produced similar average daily travel time and speed profiles at the 1-week and 1-month analysis period. The NYC CVPD Team reported significant differences observed for certain hours and attributed these differences to smaller sample sizes in the CV technology.
- In comparing 1-week and 1-month median travel times and speed, the CV technology tended to produce lower median travel times and speeds than the ETC system.

This analysis provides some insight to the potential value and issues associated with using city fleet vehicles to measure traffic operations in a network. Table 8 compares the average number of daily observations between the ETC travel time system and the CV travel time system for October 2021. The

CV system has significantly fewer observations for all segments. The NYC CVPD Team expected this difference in sample size because approximately 80 percent of the NYC vehicles have ETC equipment, compared to the less than 1 percent of vehicles equipped with CV technologies.(2)

**Table 8. High-Level Sample Size Comparison across All ETC Segments.(2)**

| ETC Segment | ETC Segment Description | ETC Sample Size | CV Sample Size |
|---|---|---|---|
| 45-102 | 1st Avenue from 23rd Street to 34th Street | 740 | 26 |
| 102-48 | 1st Avenue from 34th Street to 42nd Street | 115 | 10 |
| 48-40 | 1st Avenue from 42nd Street to 49th Street | 511 | 6 |
| 40-41 | 1st Avenue from 49th Street to 57th Street | 1,729 | 11 |
| 45-105 | 23rd Street from 1st Avenue to 2nd Avenue | 816 | 4 |
| 105-45 | 23rd Street from 2nd Avenue to 1st Avenue | 649 | 9 |
| 103-105 | 2nd Avenue from 34th Street to 23rd Street | 2,684 | 13 |
| 42-103 | 2nd Avenue from 42nd Street to 34th Street | 1,.660 | 14 |
| 46-42 | 2nd Avenue from 49th Street to 42nd Street | 2,098 | 14 |
| 55-46 | 2nd Avenue from 57th Street to 49th Street | 3,323 | 12 |
| 102-103 | 34th Street from 1st Avenue to 2nd Avenue | 93 | 3 |
| 103-102 | 34th Street from 2nd Avenue to 1st Avenue | 1,673 | 16 |
| 40-46 | 49th Street from 1st Avenue to 2nd Avenue | 1,252 | 3 |
| 41-55 | 57th Street from 1st Avenue to 2nd Avenue | 103 | 1 |
| 55-41 | 57th Street from 2nd Avenue to 1st Avenue | 434 | 1 |
| 71-70 | Flatbush Avenue from Atlantic Avenue to Willoughby Street | 4,745 | 6 |
| 73-70 | Flatbush Avenue from Tillary Street to Willoughby Street | 8,283 | 2 |
| 70-71 | Flatbush Avenue from Willoughby Street to Atlantic Avenue | 5, 105 | 2 |
| 70-73 | Flatbush Avenue from Willoughby Street to Tillary Street | 7, 642 | 4 |

*Source: New York City Department of Transportation, 2021*

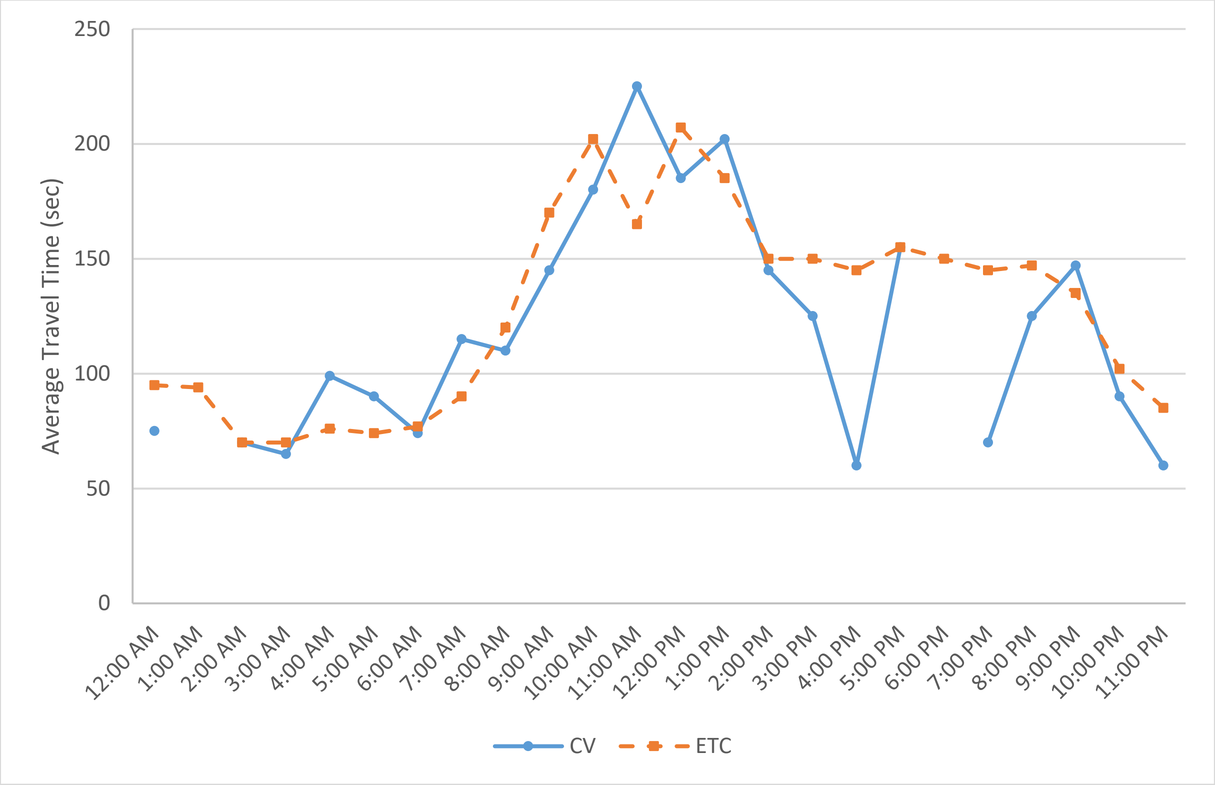
### *Comparison of Average and Median Travel Times and Speed*

The NYC CVPD Team compared the 1-week and 1-month average and median travel times and speed estimates produced by the two systems (the ETC and the CV systems).(2) Figure 6 through Figure 13 show the results of these comparisons. The NYC CVPD Team made the following observations between the travel times and speeds produced by these two systems:(2)

- The CVs generated similar average and median 24-hour travel time profiles compared to those produced by the ETC system.
- The CVs generated similar average speed 24-hour travel time profiles compared to those produced by the ETC system.

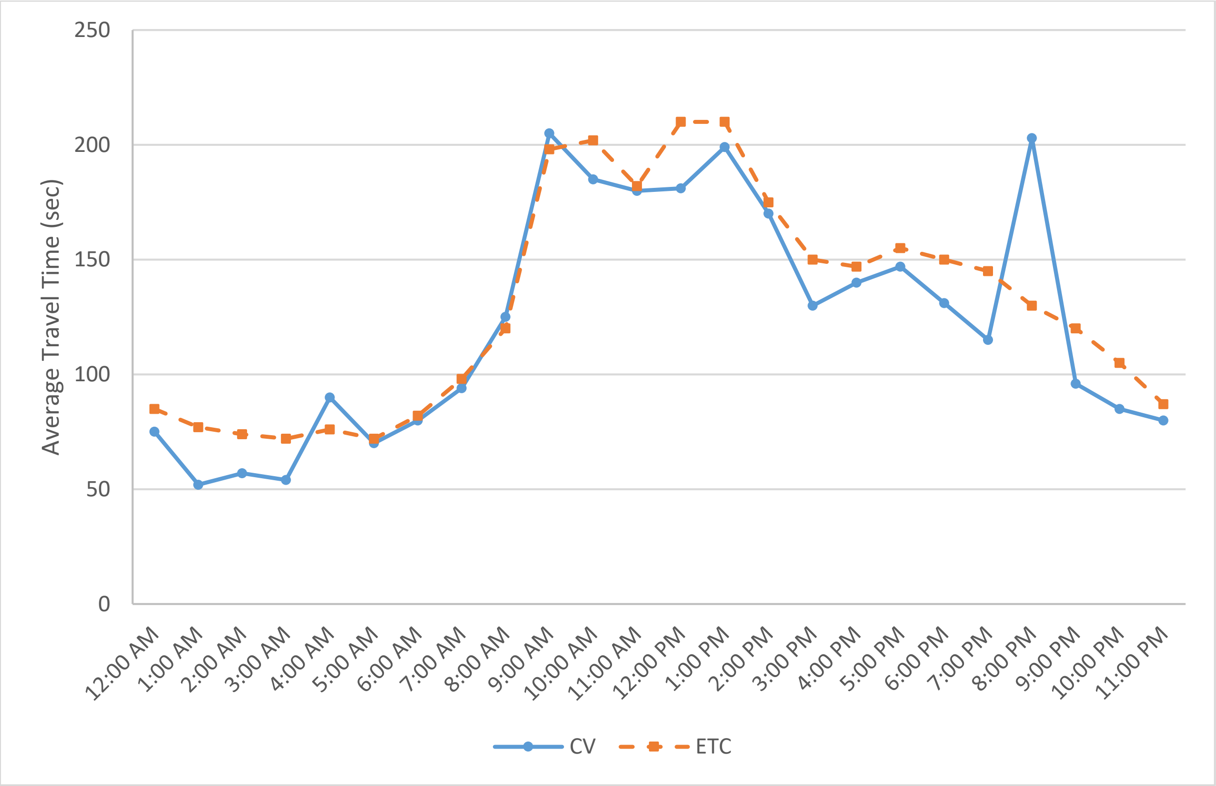
- There were hours of the day when the NYC CVPD Team observed significant differences in average travel times. The NYC CVPD Team attributed this finding to the few CVs traversing the network.

Based on this analysis, the NYC CVPD Team concluded the availability of CV travel time data block by block can help NYCDOT identify bottleneck conditions better than the ETC travel time data by understanding the spatial and temporal evolution of traffic patterns.(2) This is valuable for traffic management and traffic operations.



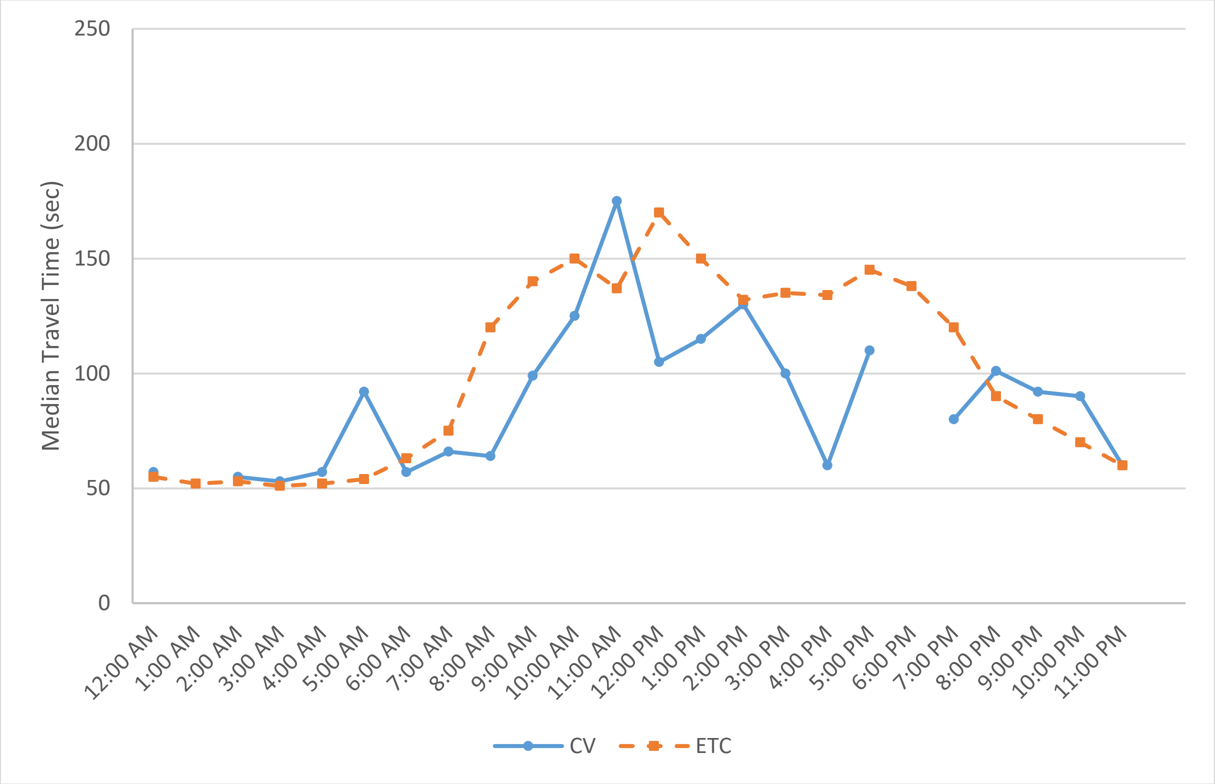
*Source: New York City Department of Transportation, 2021*

**Figure 6. Chart. Average Travel Time Comparison between CV and ETC for 1 Week (October 11, 2021, to October 15, 2021).(2)**



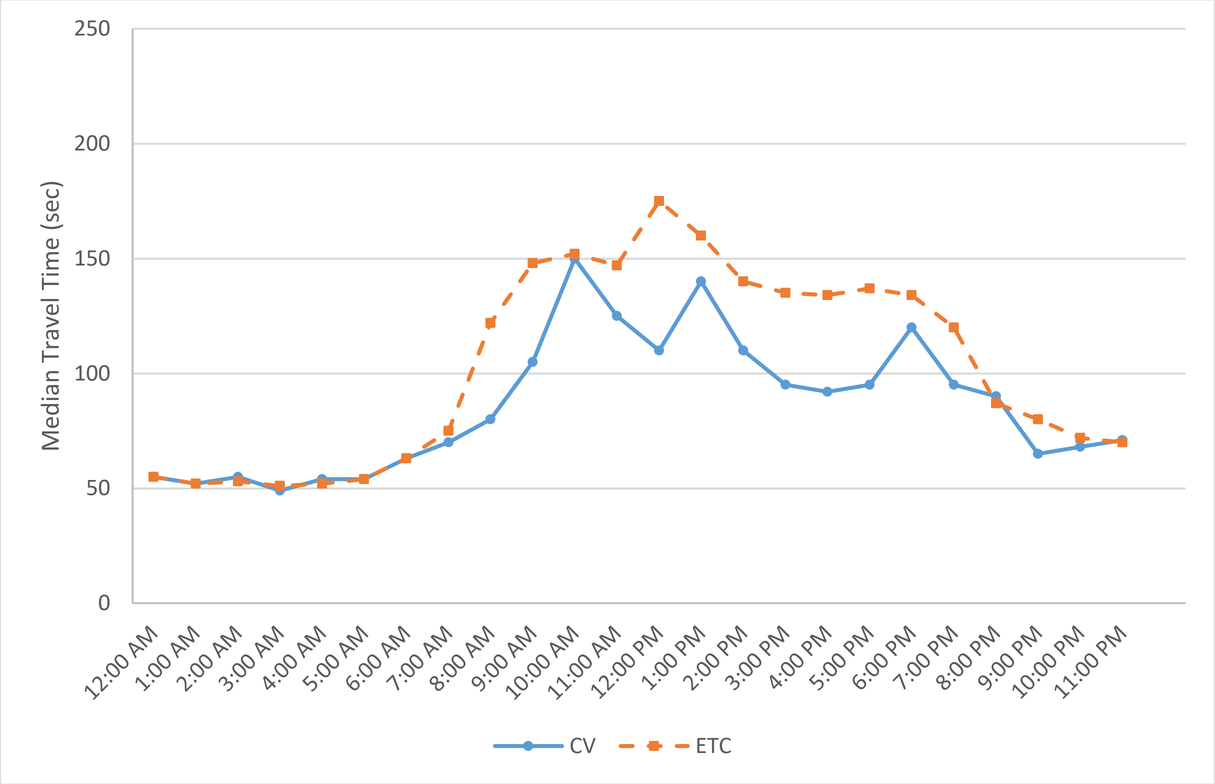
*Source: New York City Department of Transportation, 2021*

**Figure 7. Chart. Average Travel Time Comparison for 1 Month (October 2021).(2)**



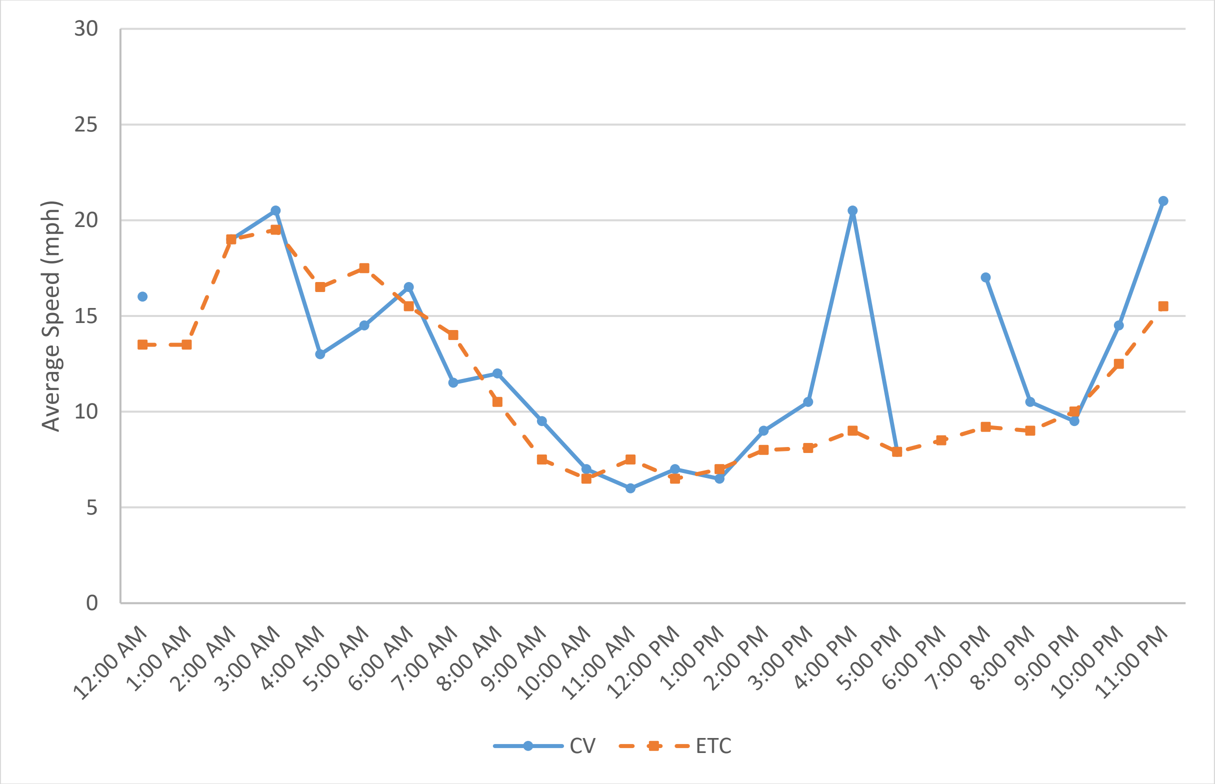
*Source: New York City Department of Transportation, 2021*

**Figure 8. Chart. Median Travel Time Comparison for 1 Week (October 11, 2021, to October 15, 2021).(2)**



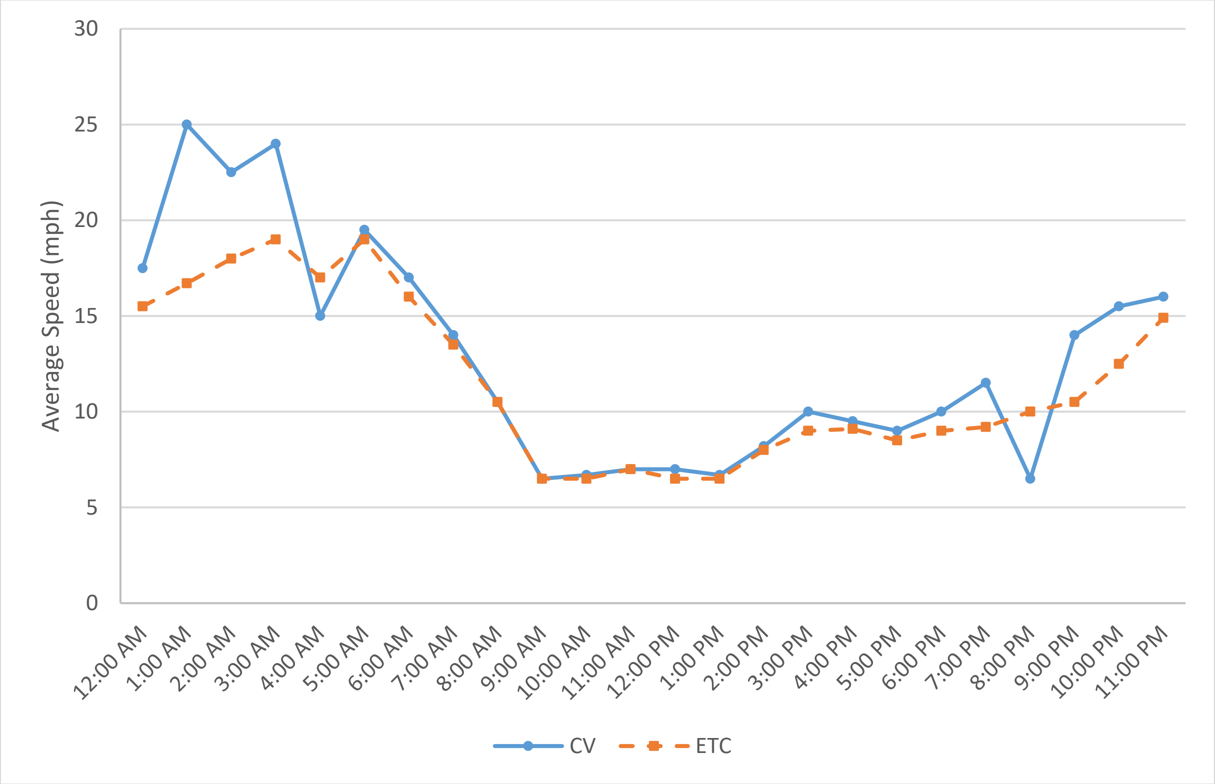
*Source: New York City Department of Transportation, 2021*

**Figure 9. Chart. Median Travel Time Comparison for 1 Month (October 2021).(2)**



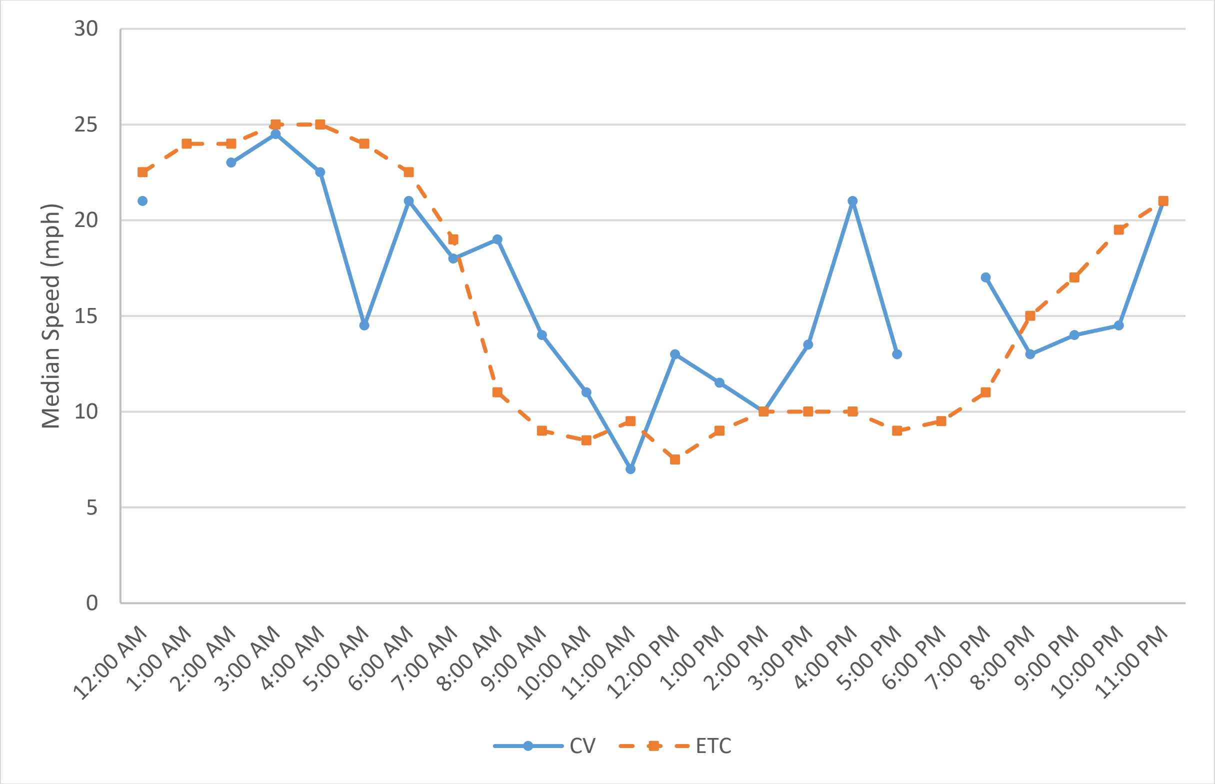
*Source: New York City Department of Transportation, 2021*

**Figure 10. Speed Based on Average Travel Time for 1 Week (October 11, 2021, to October 15, 2021).**(2)



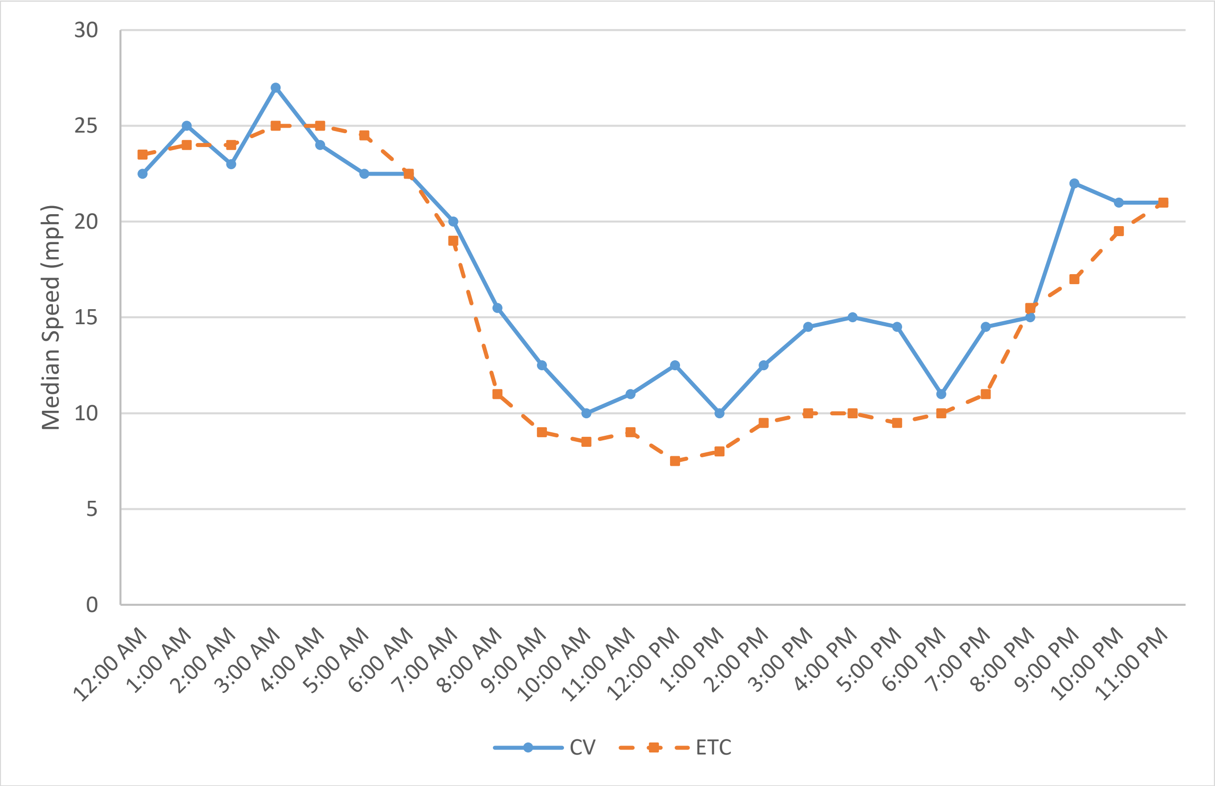
*Source: New York City Department of Transportation, 2021*

**Figure 11. Chart. Speed Based on Average Travel Time 1 Month (October 2021).(2)**



*Source: New York City Department of Transportation, 2021*

**Figure 12. Chart. Speed Based on Median Travel Time 1 Week (October 11, 2021, to October 15, 2021).(2)**



*Source: New York City Department of Transportation, 2021*

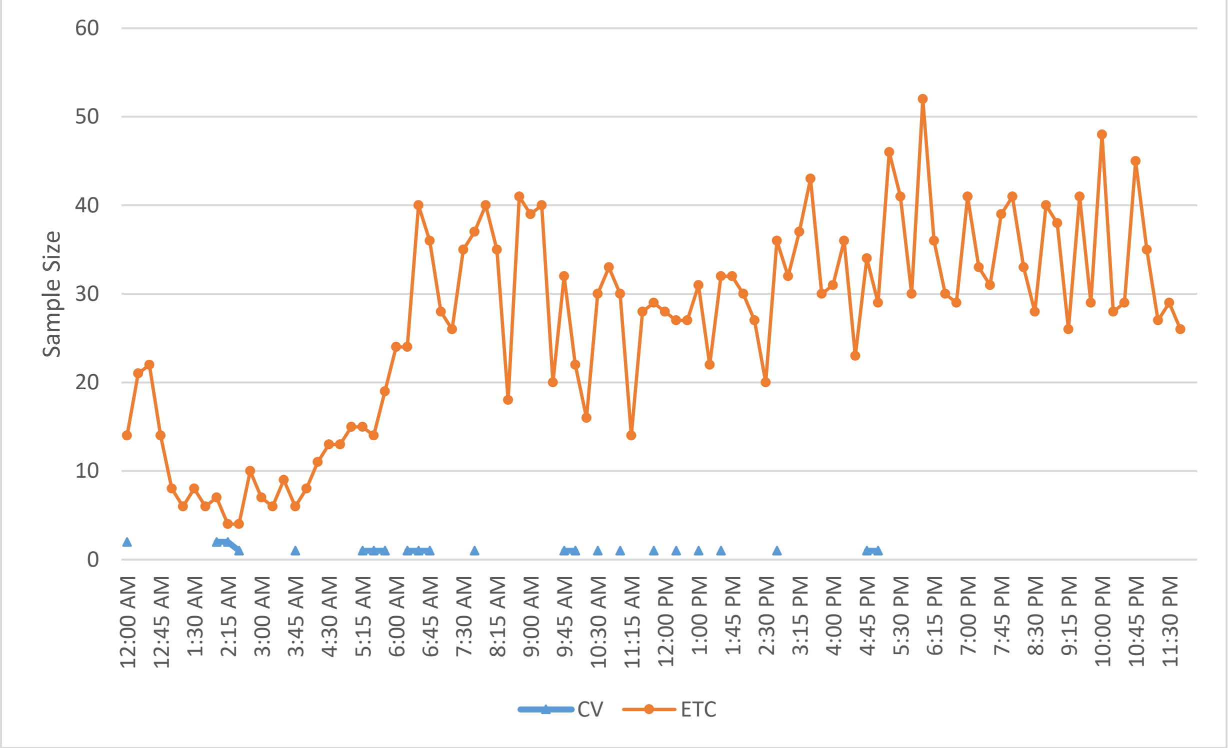
**Figure 13. Chart. Speed Based on Median Travel Time 1 Month (October 2021) Bottleneck Analysis.(2)**

***Feasibility of Using CV Travel Time Data for Real-Time Adaptive Control Systems***

The NYC CVPD Team examined the feasibility of using travel time data produced by the CV-equipped fleet vehicles to drive NYCDOT’s Midtown in Motion adaptive traffic signal control logic.(2) The system uses data in 15-minute intervals to make real-time changes to the traffic signal operations. The NYC CVPD Team reported that the ETC system requires a minimum sample size between 10 and 15 travel times to provide a good representation of traffic conditions. Figure 14 compares the 15-minute sample size for 1 day between the CV and the ETC travel time systems.

This figure shows that under the current deployment, there were not enough CVs traveling the network at any given time, particularly from approximately 3 p.m. to midnight, to produce good estimates of travel times for use in managing traffic signal timing. In most cases, only a single vehicle traversed the segment in each time. The NYC CVPD Team also reported significant gaps in time (4 p.m. to 5 p.m. and 7 p.m. to 8 p.m.) where no CVs were present to compute travel times. This level of market penetration and distribution of travel throughout the day may also speak to the limitation of using city-operated fleet vehicles as probes to collect or measure network performance.

The NYC CVPD Team also reported that “the availability of CV travel time data block-by-block can better help identify bottleneck conditions than the ETC travel time data by understanding the spatial and temporal evolution of traffic patterns."(2) TTI classifies this finding as a public agency efficiency benefit and has include it in its PAEIA.



*Source: New York City Department of Transportation, 2021*

**Figure 14. Chart. Comparison of CV and ETC 15-Minute Sample Size for a Single Day (October 13, 2021).(2)**

# Chapter 5. Summary of Findings and Conclusions

For evaluation purposes, the TTI Evaluation Team defines *public agency efficiency* as any activity or response that impacts the agency's ability to respond to changing conditions or unexpected events in the deployment area or improve their ability to manage the agency's infrastructure assets. Because of delays in the deployment and because of unforeseen external factors (e.g., the COVID-19 pandemic), FHWA revised TTI's evaluation scope to include only data collected by the sites during their evaluation. TTI did not perform an extensive quantitative analysis of the data collected by the NYC CVPD Team. Instead, TTI's evaluation is primarily qualitative in nature with some supporting explanatory quantitative analyses appropriately scoped to reduce technical risk, and consistent with the nature, quality, and quantity of underlying data.

TTI assessed the impacts of the deployment on the following two public agency efficiencies areas:

- Improved speed and regulatory compliance.
- Improved information dissemination and situational awareness.

The NYC CVPD Team deployed four different applications aimed to achieving better compliance by the equipped vehicles:

- SPDCOMP.
- CSPDCOMP.
- SPDCOMPWZ.
- OVC.

Better compliance with regulatory speed limits helps reduce speed variability and promote smoother flow in roadway networks. Better compliance with reduced speeds in work zones also helps to improve worker safety in and around lane closures and capacity restrictions.

Based on the data available, the NYC CVPD Team concluded the following, related to the effectiveness of these applications to achieve better speed compliance in the fleet vehicles.

- The SPDCOMP application was effective at achieving better speed limit compliance by the fleet vehicles. The NYC CVPD Team reported that the drivers receiving the alerts had a reduced number of speed limit violations compared to vehicles that did not receive alerts. Vehicles receiving SPDCOMP alerts decelerated faster and took less time to reach compliance than vehicles that did not receive alerts.
- Limited observations prevented the NYC CVPD Team from reaching a conclusive finding about the effectiveness of the CSPDCOMP and the SPDCOMPWZ applications to produce better compliance to curve speed advisories and work zone speed limits, respectively, within the deployment area.

- The NYC CVPD Team operated the OVC application in a test mode only. The NYC CVPD Team used an artificially low bridge height to generate compliance with the over-height compliance application. As a result, the NYC CVPD Team could not form any meaningful conclusion or evaluation on the efficacies of the application's ability to changing vehicle motions or driver behaviors.

The NYC CVPD included two applications that had the potential to allow NYCDOT to better manage the roadway network using CV data. These applications include EVAC and I-SIGCVDATA.

The NYC CVPD Team developed the EVAC application to help transmit information from NYC's OEM and NYCDOT's OER to CVs near or within affected areas during defined incidents and events. The intent of this application was to provide custom TIMs to CVs when entering a geofence-defined area near an RSU.

The NYC CVPD Team never needed to implement the EVAC application for a true emergency condition throughout the deployment phase. Instead, the NYC CVPD Team activated EVAC test messages at a handful of locations during the initial stages of the before period and at one location throughout the entire before period.(2) The NYC CVPD Team stopped all EVAC test messages before beginning the after period to ensure that no vehicles received test messages during the post-deployment period.

The NYC CVPD Team developed the I-SIGCVDATA application to test the feasibility of using CV data to monitor CV movements as an alternative technology for producing travel time data for use with the adaptive traffic signal system.(2) The purpose of evaluating this application was to investigate whether the data produced by CVs was comparable to those produced by NYCDOT's current travel time system data that uses ETC technology.

The NYC CVPD Team compared the 1-week and 1-month average and median travel times and speed estimates produced by the two systems (the ETC and the CV systems).(2) The NYC CVPD Team made the following observations between the travel times and speeds produced by these two systems:(2)

- The CVs generated similar average and median 24-hour travel time profiles compared to those produced by the ETC system.
- The CVs generated similar average speed 24-hour travel time profiles compared to those produced by the ETC system.
- There were hours of the day when the NYC CVPD Team observed significant differences in average travel times. The NYC CVPD Team attributed this finding to the few CVs traversing the network.

Based on data available, the NYC CVPD Team concluded the availability of block-by-block CV travel time data can help NYCDOT better identify bottleneck conditions than the ETC travel time data can. The CV data allowed operators to better understand the spatial and temporal evolution of traffic congestion patterns in the network.

**Better compliance with reduced speeds in work zones helps to improve worker safety in and around lane closures and capacity restrictions.**

# References

1. Intelligent Transportation Systems Joint Program Office. Connected Vehicle Pilot Deployment Program, Program Overview. U.S. Department of Transportation, Federal Highway Administration. Available at https://www.its.dot.gov/pilots/overview.htm. Accessed April 6, 2022.
2. Talas, M., K. Opie, J. Gao, K. Ozbay, D. Yang, R. Rausch, D. Benevelli, and S. Sim. *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation.* U.S. Department of Transportation, Federal Highway Administration. Washington, DC. December 2021.
3. New York City Department of Transportation. NYC Connected Vehicle Project for Safer Transportation. Available at https://cvp.nyc/. Accessed April 6, 2022.
4. Talas, M., K. Opie, J. Gao, K. Ozbay, D. Yang, R. Rausch, D. Benevelli, and S. Sim. *Connected Vehicle Pilot Deployment Program Phase 2 Performance Measurement and Evaluation Support Plan—New York City.* FHWA-JPO-16-302. U.S. Department of Transportation, Federal Highway Administration. Washington, DC. Updated March 31, 2021.
5. Talas, H., D. Benevelli, R. Rausch, and S. Sim. *Connected Vehicle Pilot Deployment Program Phase 2: System Architecture—New York City*. FHWA-JPO-17-451. U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office. Washington, DC. Revised April 15, 2021. Available at https://rosap.ntl.bts.gov/view/dot/61190. Accessed April 6, 2022.
6. Talas, H., K. Patton, D. Benevelli, R. Rausch, and S. Sim. *Connected Vehicle Pilot Deployment Program Phase 2: System Design—New York City*. FHWA-JPO-17-452. U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office. Washington, DC. Revised April 15, 2021. Available at https://rosap.ntl.bts.gov/view/dot/61189. Accessed April 6, 2022.
7. Perry, F., K. Raboy, E. Leslie, Z. Huang, and D. Van Duren. *Dedicated Short-Range Communications Roadside Unit Specifications.* FHWA-JPO-17-589. U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office. Washington, DC. April 28, 2017. Available at https://rosap.ntl.bts.gov/view/dot/3600. Accessed April 24, 2022.

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