Connected Vehicle Pilot Deployment Program Independent Evaluation

Mobility Impact Assessment—New York City

www.its.dot.gov/index.htm

Final Report—April 7, 2022
FHWA-JPO-22-935

U.S. Department of Transportation

Produced by the Texas A&M Transportation Institute, Texas A&M University System
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
Intelligent Transportation Systems (ITS) Joint Program Office
Federal Highway Administration

Cover photo courtesy of ITS Joint Program Office Module 13 ePrimer Presentation (Connected Vehicles)

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-22-935		

4. Title and Subtitle	5. Report Date
Connected Vehicle Pilot Deployment Independent Evaluation Program Mobility Impact Assessment —New York City	April 7, 2022
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Balke, K. and C. Simek	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas A&M Transportation Institute The Texas A&M University System 3135 TAMU College Station, TX. 77843-3135	11. Contract or Grant No. DTFH6116D00045/0003
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
ITS-Joint Program Office 1200 New Jersey Avenue, S.E., Washington, DC 20590	Research Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Work Performed for: Tom Kearney, Federal Highway Administration (FHWA) and Walter During, FHWA

16. Abstract

In September 2015, the U.S. Department of Transportation's 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 represented 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 mobility 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 mobility 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.

17. Keywords	18. Distribution Statement
Connected Vehicle, Connect Vehicle Pilot Deployment, Independent Evaluation, New York City, Mobility Impact Assessment	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		70	

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

Acknowledgements

The authors would like to thank the following individuals for their assistance in developing this plan in support of the independent evaluation of the Connected Vehicle Pilot Deployment Program:

- Walter During, Federal Highway Administration (FHWA)
- Tom Kearney, FHWA
- Kate Hartman, Intelligent Transportation Systems Joint Program Office (ITS JPO)
- Jonathan Walker, ITS JPO
- Govindarajan Vadakpat, FHWA
- Douglas Laird, FHWA
- Neil Spiller, FHWA
- James Colyar, FHWA
- James Sturrock, FHWA
- Volker Fessmann, FHWA
- Margaret Petrella, Volpe National Transportation Systems Center
- Wassim Najm, Volpe Center
- Karl Wunderlich, Noblis
- Meenakshy Vasudevan, Noblis
- Sampson Asare, Noblis
- Kathy Thompson, Noblis
- Peiwei Wang, Noblis
- Claire Silverstein, Noblis

Table of Contents

List of Tables

List of Figures

Executive Summary

On September 14, 2015, the U.S. Department of Transportation's Intelligent Transportation Systems Joint Program Office (ITS JPO) launched the Connected Vehicle Pilot Deployment (CVPD) Program.(1) ITS JPO selected New York City (NYC) as one of three locations to serve as 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 primary objective of the NYC CVPD was to develop and demonstrate the use of vehicle-to-vehicle (V2V), vehicle-to-infrastructure, and infrastructure-to-pedestrian communications to improve safety, 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 a total of 3,000 city-owned fleet vehicles with aftermarket safety devices running the following applications as part of its NYC CVPD:

- Speed Compliance (SPDCOMP).
- Curve Sped Compliance (CSPDCOMP).
- Speed Compliance in Work Zone (SPDCOMPWZ).
- Forward Collision Warning (FCW).
- Emergency Electronic Brake Light Warning (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 Signalized Crosswalk Warning (PEDINXWALK)
- Mobile Pedestrian Signal System (PED-SIG)
- Oversized Vehicle Compliance (OVC)
- Emergency Communications and Evaluation Information (EVAC)
- CV Data for Intelligent Transportation Signal System (I-SIGCVDATA)

The NYC CVPD Team also installed 457 roadside units at intersections in Manhattan and the Brooklyn Bridge and along Franklin D. Roosevelt Parkway on the east side of Manhattan. United Parcel Service (UPS) was an enlisted as an original participant in the early stages of the project but disengaged prior to the deployment phase.

The NYC CVPD Team collected pre- and post-deployment performance data which they 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.

Using the data provided by the NYC CVPD Team, the Texas A&M Transportation Institute (TTI) conducted a qualitative assessment of the impacts of the NYC CVPD on mobility. Because the NYC CVPD focused primarily on improving safety, no applications directly impacted mobility (i.e., reductions in travel time, reductions in delay, improvements in travel time reliability, etc.). Furthermore, because of deployment issues and challenges, the NYC CVPD Team had to change the fleet of vehicles on which to deploy the applications from taxis to city fleet vehicles. Government-owned vehicles use the transportation network differently than traditional commuter-type travelers.

Based on the performance measures originally planned by the NYC CVPD Team, TTI identified the following deployed applications as having the potential to impact mobility:

- SPDCOMP.
- PED-SIG.
- EVAC.

Using the performance data provided by the NYC CVPD Team, the TTI Team assessed the impact of these applications on mobility in the deployment area and concluded the following:

- While the data showed that the SPDCOMP application successfully reduced the number of speed limit violations in the deployment fleet, the NYC CVPD Team did not have sufficient data available to allow a direct assessment of this application on mobility because of limited sample sizes and the change in the deployment fleet from vehicle-for-hire to city-owned fleet vehicles.
- Field studies of the PED-SIG application showed that average wait time for sight-impaired pedestrians was 31.0 seconds, and the average crossing speed of these individuals was 3.6 feet per second, slightly above the 3.5 feet per second walking speed recommended by the *Manual on Uniform Traffic Control Devices*. The NYC CVPD Team based this finding on a limited number of sight-impaired individuals with a limited number of sample crossings. Furthermore, no pre-deployment data were available for comparison purposes.
- The NYC CVPD Team collected data from the EVAC applications only for test purposes. To avoid driver confusion, the NYC CVPD never activated the application under live operating conditions. As a result, the impacts of this application on mobility remain untested.

The TTI Team also assessed the indirect impacts on mobility of some applications. Indirect mobility impacts are those produced by the application even though the primary focus of the application was to address another issue. (An example of an indirect mobility impact would be reductions in congestion due to fewer collisions.) TTI identified the following applications as having potential indirect impacts on mobility:

- CSPDCOMP.
- RLVW.
- V2V Safety applications (including FCW, EEBL, BSW, LCW, and IMA).

Using the data provided by the NYC CVPD Team, the TTI Team concluded the following about the indirect impacts of the NYC CVPD on mobility:

- The NYC CVPD Team indicated that compliance with curve advisory speed limits increased after fleet vehicles started issuing CSPDCOMP alerts. Better speed compliance in curves may result in smoother flow and less turbulence at curve speed entry points. Reductions in turbulence could potentially have indirect impacts on mobility.
- The NYC CVPD Team reported that likely red-light violations reduced by 152 per 1,000 events after the fleet vehicles began issuing RLVW alerts. Although the NYC CVPD Team could not link this reduction to actual red-light violation warnings directly, it does suggest that the application has some potential to indirectly impact mobility. Fewer red-light violations may contribute to fewer right-angle collisions and reduce start-up delays for cross-street traffic at signalized intersections.
- The NYC CVPD Team reported that rear-end collisions declined by approximately 5 and 9 percent, respectively, after FCW and EEBL warnings became active in the fleet vehicles. Simulation experiments conducted by the NYC CVPD Team also indicated that both applications had a positive effect on reducing conflict risks. This finding suggests that these applications might have the potential to have an indirect impact on mobility if deployment fleet vehicles have the same crash exposure as the general vehicle traffic in NYC.
- The NYC CVPD Team indicated that injury and property damage-only sideswipe collisions reduced by 1.5 and 15 percent, respectively, after the fleet vehicles started receiving BSW and LCW alerts. While there is no evidence that these applications were directly responsible for these reductions, it does suggest that these applications could potentially generate indirect mobility benefits through reduced crash potential.
- Because of limited sample sizes, the NYC CVPD Team was unable to assess if the IMA application had an impact on potential crash experiences. Therefore, the TTI Team was unable to assess if this application had any indirect impact on mobility.

The following provides a summary of the lessons learned as reported by the NYC CVPD Team:

- The level of maturity of some of the applications were not as advertised. Some of the applications were not sufficiently developed and tested for deployment purposes and required more development work than expected by the NYC CVPD Team to get the applications ready for deployment.
- The level of market penetration, even with 3,000 equipped vehicles, was insufficient to provide a robust enough data set to allow evaluation of some applications. Limitations in data collection, inconsistencies between anticipated data sources, and external factors all impacted the data sample sizes of some applications.
- The FCW and the SPDCOMP applications produced over 75 percent of all vehicle alerts and warnings. NYC CVPD Team's analysis showed that drivers responded to those alerts and tended to reduce their speeds after hearing an alert.
- The differences in perspective between the research/evaluation and deployment were an on-going dilemma throughout the project required for the NYC CVPD. These caused the NYC CVPD Team to review several decisions made as the project progressed, primarily centered around data collection. The NYC CVPD Team suggested that data collection processes include more detailed investigation about locations and site-specific factors that may have impacted driver decisions (while still retaining privacy protection measures). The NYC CVPD Team suggested including the aftermarket safety device's (ASD's) time-to-collision estimations for the V2V events and the intersections identification approach for the RLVW events to the data collection processes for these applications.
- The NYC CVPD Team cited the Federal Communication Commission's (FCC's) changes to the communications spectrum reserved for Dedicated Short-Range Communication (DSRC) created significant challenges for the deployment. The FCC licensing "freeze" affected numerous pending

license applications, delaying completion of the deployment until well into the post-deployment evaluation process.

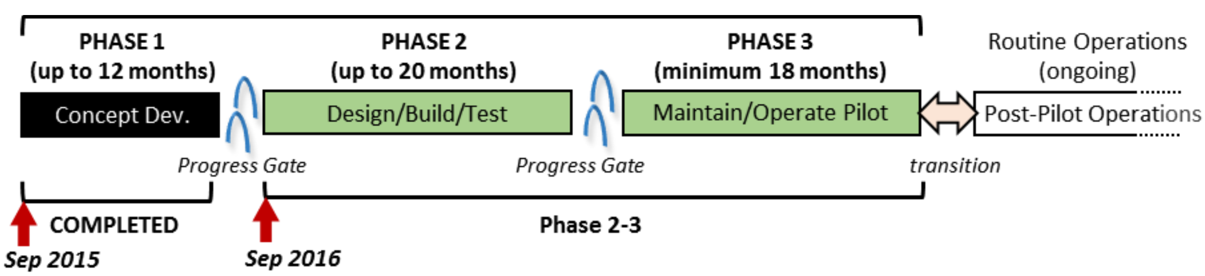
- The NYC CVPD Team was unable to collect the quantity of data originally anticipated due to the change in the targeted fleet. The original concept of operations envisioned equipping taxis as the deployment fleet. This fleet, operating heavily in Manhattan and the airports, would have extremely high hours of operation (24 x 7 hours each week) and vehicle miles of travel (200+ average miles per vehicle per day). Because of changes in the vehicle-for-hire market, the NYC CVPD Team transitioned to using NYC government vehicles as the deployment vehicle. Because government fleet vehicles operate differently from vehicle-for-hire vehicles, longer data retention on the fleet vehicles (changed from 48-hours to 10-days) would address fewer daily vehicle intersections with locations providing data collection services.

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 the connected vehicle technology, 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.
- 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 Program.(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 their 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 (I2P) 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) As part of their deployment, NYCDOT installed onboard units (OBUs) with embedded safety applications in approximately 3,000 city vehicles. The original concept included equipping United Parcel Service (UPS) vehicles; however, UPS disengaged prior to the deployment phase. 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 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.(3)

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 would 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.
- The best way 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 mobility impacts assessment (MIA) associated with the NYC CVPD. Because of delays in the deployment and unforeseen external factors (e.g., 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 was 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 the NYC CVDPD Team.

This report focuses solely on the MIA 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. It discusses NYC's goals and objectives associated with their 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 provides a summary of sources and availability of evaluation data. Specifically, this chapter describes the data generated by the NYC CVPD Team to evaluate each use case. It also describes some of the major influencing and confounding factors impacting the deployment.
- Chapter 4 reports the results of the assessment of the deployment's impacts on mobility in the deployment area. This chapter includes both results of the analysis of direct measures of mobility collected by the deployment team as well as indirect improvement associated with reported safety benefits. This chapter also provides a summary of simulation-generated mobility performance measures.
- Chapter 5 contains a summary of the results of the User Acceptance survey conducted by the NYC CVPD.
- Chapter 6 provides a summary of the lessons learned from the deployment.

Chapter 2. New York City Deployment

This chapter provides a summary of the following for the NYC CVPD:

- 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 the infrastructure components (i.e., RSUs) used in the deployment.

For more information on the types of technologies used in the deployment, the reader should review the following references:

- *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City (NYC).*[3]
- *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 focused 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 mobility. Fewer crashes would result in less crash-related delays. Likewise, fewer stops may result in fewer crashes, particularly rear-end crashes.[3]

The NYC CVPD Team identified seven use cases targeting NYCDOT's goals for the deployment. Table 1 provides a summary of the use cases identified for the NYC CVPD. Table 2 provides a brief description of 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: • Speed Compliance (SPDCOMP). • Curve Speed Compliance (CSPDOMP). • Speed Compliance in Work Zones (SPCOMPWZ).
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: • V2V applications including the following: ○ Forward Collision Warning (FCW). ○ Emergency Electronic Brake Light Warning (EEBL). ○ Blind Spot Warning (BSW)/Lane Change Warning (LCW). ○ Intersection Movement Assist (IMA). • Red-Light Violation Warning (RLVW). • Vehicle turning right in front of bus 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: • Pedestrian in Signalized Crosswalk Warning (PEDINXWALK). • Mobile 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 oversized 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 Communication and Evaluation 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 CV Data for Intelligent Traffic Signal System (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 3, 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 Sped 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 Collision 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.
Electronic Emergency Brake Light Warning	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/ 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 Signalized 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 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.
Oversized 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

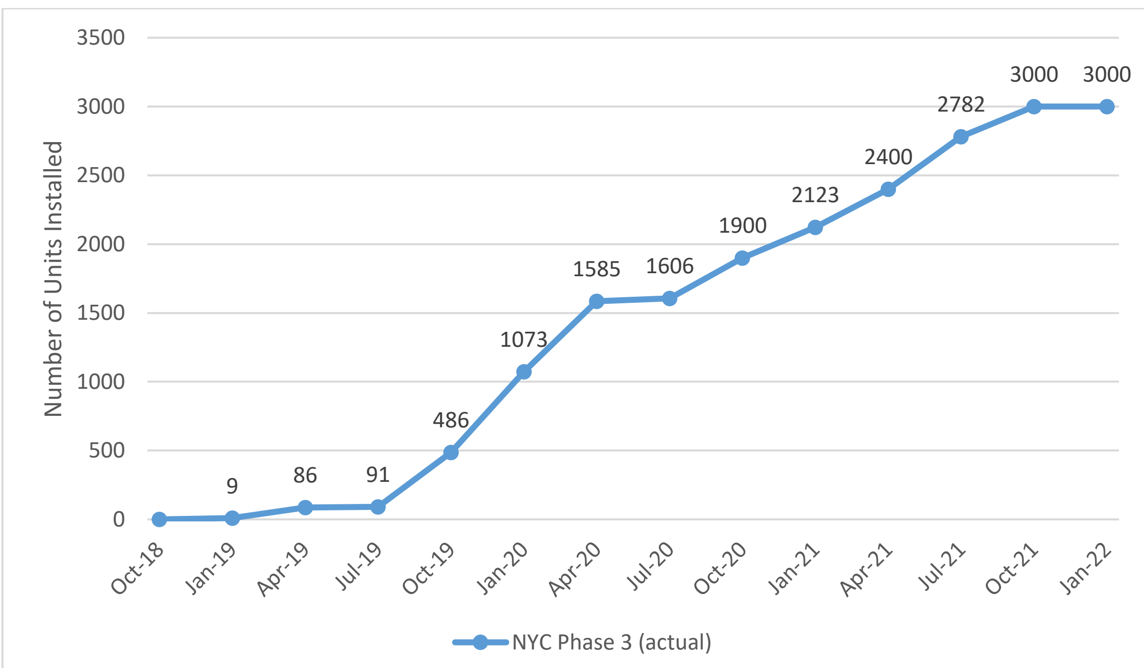
Application	Use Case	Description
		drivers when it entered the region of a potential bridge-strike. (This application was deployed in limited conditions during the pilot.)
Emergency Communications and Evacuation Information	5	This application was deployed to help transmit information from NYC's Office of Emergency Management (OEM) and NYCDOT's Office of Emergency Response 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.)
CV Data for Intelligent Transportation Signal System	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 3, 2022.

Deployment Fleet

For this deployment, the NYC CVPD Team equipped a total of 3,000 city-owned fleet vehicles with aftermarket safety devices.(3) Originally, the NYC CVPD Team planned to deploy ASDs in pay-for-hire taxi cabs (yellow cabs) that traverse the midtown area, but delays in deployment due to privacy concerns and the changing pay-for-hire rideshare market in the midtown area did not make this a viable option. The NYC CVPD Team also enlisted the United Parcel Service (UPS) as an original participant in the early stages of the project, but they also disengaged prior to the deployment phase. As a result, the NYC CVPD switched their 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 while other drivers were required to follow fixed routes. Table 3 shows the types of vehicles where the NYC CVPD Team deployed onboard devices.

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.(7) 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, ITS Joint Programs Office, 2022.

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

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

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.

As noted above, the NYC CVPD Team equipped city fleet vehicles operated by city personnel for their 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 Modes

NYC's experimental plan required the equipped vehicle to operate in either a silent or active warning. 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 two 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. Another key reason for having active and silent warning vehicles operating in the post-deployment period was to control for confounding factors which typically occurs with before/after experimental design.

According to 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 vehicle transitioned to the active mode. The NYC CVPD Team used over-the-air messaging to initiate the switching of the vehicles from the silent mode to the 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) were switched from silent to active mode shortly after the over-the-air 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 periods. Vehicles never transitioned from an active to a silent mode.

For more information on NYC CVPD Team's experimental design, the reader should consult *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation—New York City (NYC) Phase 3 Evaluation Report*.[3]

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 three-week period from September 13 to October 3, 2021. The NYC CVPD Team aggregated trips occurring during this period into the following five categories:

- 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.

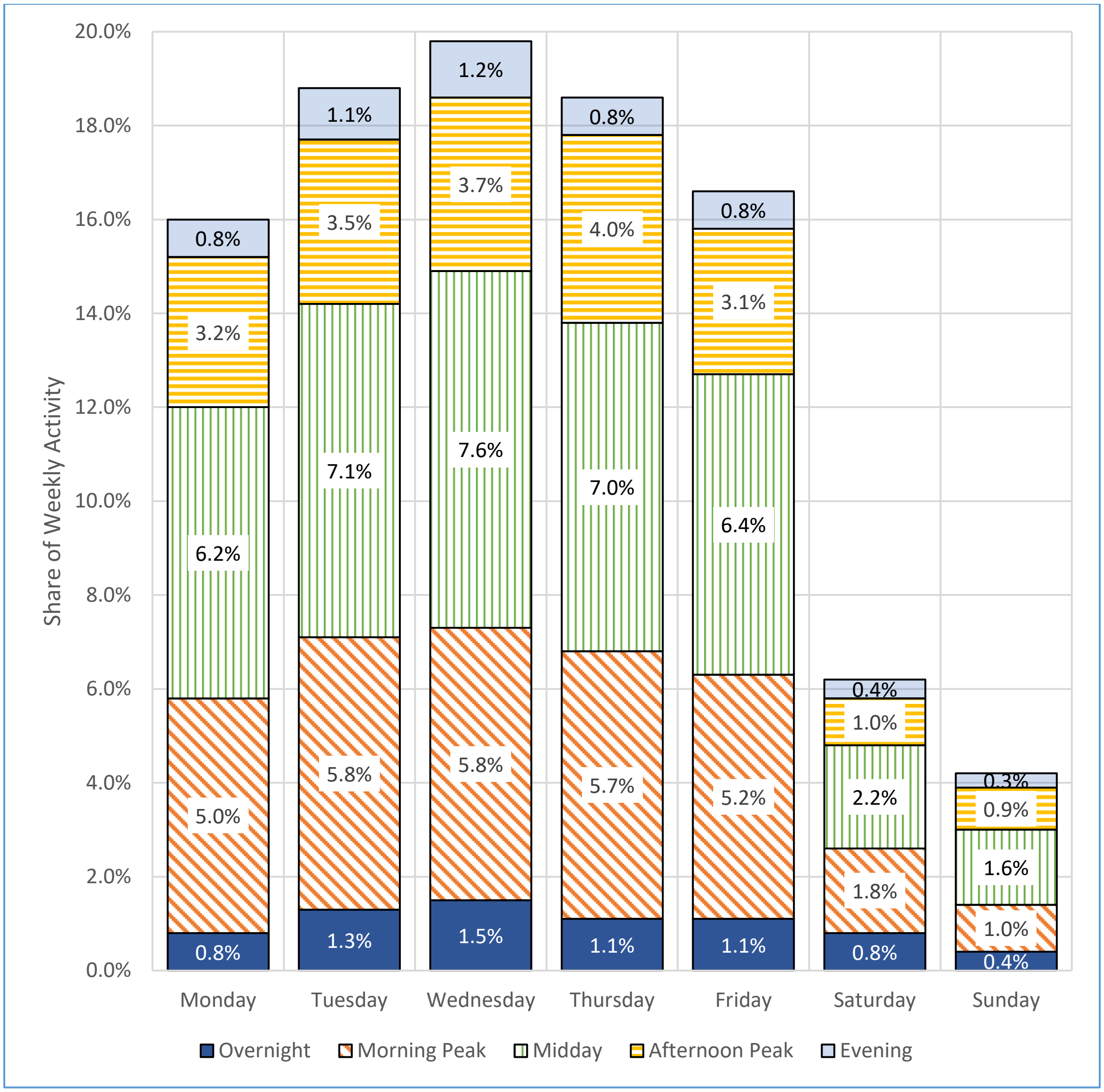
From this figure, the NYC CVPD team made the following observations about the distribution of fleet activity in the deployment network:

- 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 Morning Peak and Midday periods experienced the greatest share of fleet activity in the network, followed closely by the Evening period. Few trips occurred during the Evening and Overnight periods.

Roadside Units

The NYC CVPD Team installed 457 RSUs at intersections in Manhattan and the Brooklyn Bridge and along FDR on the east side of Manhattan.[7] The RSUs were the point of communication between the infrastructure and the vehicles and other mobile devices. The RSUs also communicated with the traffic signal controller as necessary to obtain information or to provide input to the traffic signal controller at signalized intersections. The NYC CVPD Team's RSU specifications[8] 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 the pedestrian presence in the roadway as measured by pedestrian detection devices.



Source: New York City Department of Transportation, 2021.

Figure 4. Chart. Typical Travel Patterns of NYC Fleet Vehicles by Time of Day and Day of Week.[3]

In addition, each RSU had the capability of collecting raw basic safety message (BSM) data from nearby ASDs (called "sightings'). This data was 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 over-the-air (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 one-year pre-deployment and one-year post-deployment evaluation periods.[3] 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.

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 will 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, FCC’s decision to reallocate the DRSC bandwidth, delays encountered throughout the deployment, and limited sample sizes, the NYC CVPD Team was unable to use all these performance measures in their 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.

Table 4. Identified Performance Metrics by CV Application.[3,4]

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). • Speeds (average and distribution measures). • Emissions. • Reduction in speed limit violations. • Speed variation. • Vehicle throughput (average and distribution measures). • 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? 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. • Vehicle speeds at curve entry. • Lateral acceleration in the curve. • Driver actions and/or impact on actions in response to issues warnings. • 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/ Work Zone	1	• Speed in work zones (average and distribution measures). • Speed variation (distribution) at work zone. • Number of vehicle speed limit violations in variable speed zone areas. • 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 EEBL BSW LCW IMA	2	• Fatality crash counts. • Injury crash counts. • Property damage-only (PDO) crash counts. • 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. • Time to collision (vehicle to cross vehicle path) at the intersection. • 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 in Front of Bus Warning	2	• Right-turning related conflicts. • Time to collision (vehicle-to-bus). • Number of warnings generated. • 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 Signalized Crosswalk Warning	3	• Pedestrian-related crash counts, by severity. • Number of warnings generated. • Pedestrian-related conflicts/hard braking events. • Time to collision (vehicle-to-pedestrian). • 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. • Pedestrian crossing speed and crossing travel time. • Times out of crosswalk. • 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	Oversized Vehicle Compliance	4	• Number of warnings generated. • 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 Connected Vehicle Data	6	• Segment speed (average and distribution measures) from CV compared to legacy detection systems. • 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.[3]

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

Application	Performance Measure	Data Sources	Included by NYC CVPD Team in Site Evaluation	Reason for Not Evaluating
EVAC	**Number of vehicles receiving information when generated**	**SD**	**Yes**	**NA**
I-SIGCVDATA	**Segment speed (average and distribution) from CV compared to legacy detection systems**	**SD, MS**	**Yes**	**Analysis only completed based on system data and not simulation**

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.

As stated previously, the primary goal of the NYC CVPD was to demonstrate the impacts of using CV technologies to improve safety. As a result, the NYC CVPD Team used performance measures that focused on managing speeds and reducing the number of crashes and severity as their primary measures of effectiveness. Although reducing crashes and incidents that disrupt travel can generate ancillary mobility and reliability benefits, the NYC CVPD Team did not plan to measure the impacts of the deployment on mobility (such as reductions in travel times, travel time reliability, vehicle throughput, and extent of congestion measures) directly, but instead planned to use microsimulation to evaluate mobility benefits. The NYC CVPD Team also did not measure other improvements (such as environmental benefits) directly but estimated them indirectly from mobility improvements or via simulation.(4)

Data Sources and Availability

Table 5 also shows the sources of data used by the NYC CVPD Team to generate their performance measures, including action logs, field data, system data, and survey data. The following sections describe the data sources that the NYC CVPD Team had available to conduct their assessment. The *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation —New York City Phase 3 Evaluation*(3) 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. For more information on the content of these data logs, readers should consult the following references:

- *CVPD 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.*(3)

Action Data Logs

The primary source of data logs used by the NYC CVPD Team to assess the performance of the applications were vehicle action logs. Each ASD logged relevant information surrounding a triggered event. These records included the following data:(3)

- Details regarding which CV application generated the warning, including firmware version and application parameters.
- BSMs 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 TIMs.

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 (SSL)—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.
- OTA 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 ASD heard by the RSU.(3)

RF Sightings of ASDs

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. Th reader should consult NYCDOT’s *Connected Vehicle Pilot*

Deployment Program Phase 2 Performance Measurement and Evaluation Support Plan—New York City. for more information on the process for computing travel times between RSUs. [4]

The NYC CVPD Team compared this method of collecting traffic time data to a similar travel time measurement system (radio-frequency identification (RFID) readers of electronic toll tags) already in use. NYC's evaluation assessed if a CV-based travel time measurement approach provided similar data inputs in near real-time to feed the Midtown in Motion (MIM) 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.[3] Field data include any field measured data collected from non-CV data sources, including the following:

- Accident Data.
- Weather Data.
- Traffic Count Data.
- Transportation Operations Coordinating Committee (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.

Microscopic Simulation

Instead of direct field measurements, the NYC CVPD Team used simulation modeling as the primary means of assessing mobility benefits associated with the safety applications.[3] The NYC CVPD Team used the Manhattan Traffic Model, an Aimsun-based microscopic model covering midtown Manhattan, to simulate the operational conditions in the study area network both with and without CV app deployments. The NYC CVPD Team simulated scenarios of different crashes to assess the overall potential benefits to mobility and general user costs associated with a prevented crash. While this would not identify the specific benefits of the true CV deployment, it would identify a cost associated with crashes in midtown Manhattan and could help identify the range of benefits to the system of prevented crashes.[3] Chapter 4 provides more information on how the NYC CVPD used the microscopic simulation model to assess potential mobility benefits.

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." [3] The system data included general statistics about the deployment (e.g., number of devices installed, number of alerts and warnings produced, etc.) and health monitoring statistics (e.g., uptime of RSU, number of active OBUs, etc.).

User Surveys

In addition, the NYC CVPD Team surveyed users to collect perception data on the effectiveness of the deployed application. Currently, the NYC CVPD Team have conducted three sets of user surveys:(3)

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

Appendix D of the *CVPD Phase 2 Performance Measurement and Evaluation Support Plan—New York City*(4) shows a draft of the survey instrument the NYC CVPD Team plans 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.(3) 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.(3) The NYC CVPD Team noted that because of the small sample size associated with the pedestrian survey, they were 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 collected and reported information on factors that can influence the performance of the applications. The following sections highlight some of the influencing factors the NYC CVPD identified as potentially impacting the results of their evaluation.

Operational Conditions

The NYC CVPD Team identified several operational conditions which could influence the impacts of the deployment.(3) 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 include 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.[3,4] According to *CVPD 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.[3]

False Alarms and Missed Alarms

False and missed 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 and missed alarms are still likely to occur. During Phase 3, the NYC CVPD Team plans to use vehicle operator feedback to solicit input into the operations and efficacy of the CV applications. The NYC CVPD Team intends 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.

Data Processing and Cleaning

The NYC CVPD Team developed extensive processes and procedures for processing and cleaning the CV data before uploading it into the Secure Data Commons (SDC) or ITS Data Hub. This section provides a brief description of the process that had the most significant effect on the evaluation data. For a more comprehensive description of the data processing and cleaning procedures, the reader should consult the following references:

- *Connected Vehicle Pilot Deployment Program Phase 2 Performance Measurement and Evaluation Support Plan.*(4)
- *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation.*(3)
- *Connected Vehicle Pilot Deploy Program Phase 2 Data Management Plan—New York City.*(9)
- *Connected Vehicle Pilot Deploy Program Phase 2 Data Privacy Plan—New York City.*(10)

Data Fusion

The NYC CVPD Team developed a process whereby the TMC fused relevant external data with observed action log data collected on the equipped vehicles. The non-CV data provided contextual information about the network and environmental operating conditions that existed at the time the vehicle generated an action log. The NYC CVPD Team believed this process was important because it provided insight into circumstances surrounding the generation of driver alerts. This data fusion process occurred daily in the TMC prior to the TMC uploading the action logs into the SDC and the ITS Data Hub. The type of non-CV data fused with the action logs included the following:(3)

- National Weather Service Current Conditions data.
- NYCDOT's snowplow data.
- TRANSCOM Link Condition data.
- TRANSCOM Event data.

For more information on the NYC's data fusion process, the reader should consult the references listed above in Data Processing and Cleaning.

Data Obfuscation

NYC's data obfuscation process had the greatest impact of the availability of useful evaluation data. Citing the need to "lessen the likelihood of using time and place specifics to marry CV Pilot performance evaluation data to other existing data sources and databases which do contain PII [Personally Identified Information], such as crash records," the NYC CVPD Team developed an extensive process of obfuscating ASD event log data. NYC's data obfuscation process focused on three record components: vehicle data, time data, and location data. The obfuscation process focused on removing the following types of data:(3)

- Any data that tied a specific ASD device to a specific vehicle.
- Any information about the precise time element of the moment a warning was issued in the host vehicle.
- Any detailed latitude, longitude, and elevation data recorded in any of the CV messages contained in the action logs.

This data obfuscation process made it difficult to link any specific performance measures to specific time and location bins.

For more information on the data obfuscation process implemented by the NYC CVPD Team, the reader should consult *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation—New York City (NYC) Phase 3 Evaluation Report*.(3).

Data Cleaning and Filtering

In generating evaluation performance metrics, the NYC CVPD Team also implemented two different processes for cleaning and filtering the event records: one for V2I applications and another for the V2V application action logs. For the V2I applications (i.e., SPDCOMP, CSPDCOMP, SPDCOMWZ, RLVW, PEDINXWALK, and OVC), the data cleaning process consisted of the following steps:(3)

- Removing events with incorrect triggering locations.
- Removing events with incorrect pre-warning and post-warning report times.
- Removing events with observed speed values greater than 60 mph.
- Removing events with warnings triggered above the speed limit threshold for SPDCOMP, CSPDCOMP, and SPDCOMPWZ.

After applying these data cleaning rules, the NYC CVPD Team removed between 12 to 28 percent of the V2I events.(3) The NYC CVPD Team removed a considerable proportion of the CSPDCOMP events for having incorrect triggering locations.

For the action logs associated with the V2V applications, the data cleaning process consisted of the following steps:(3)

- Removing events where a substantial elevation difference existed between the host and remote vehicles.
- Removing events where both the host and remote vehicles were stationary.
- Removing events where the trajectory of the host or remote vehicles were discontinuous or unreasonable.
- Removing events where the host and remote vehicle were not in the same lane or were too far apart from each other (used with FCW events only).
- Removing events with incorrect pre-warning or post-warning record times.
- Removing events where the observed speed values were greater than 60 mph.
- Recalculating speed values based on GPS coordinates where recorded speed values were all zero but the trajectory data showed the vehicle to be in motion.
- Removing events where recorded speed values for an event were partially zero but the trajectory data showed the vehicles to be in motion.
- Removing events where the recorded speed values during an event were equal to a non-zero constant but the trajectory data indicated a non-constant movement.
- Recalculating speed values based on GPS coordinates were the ratio of the calculated speed to the recorded speed were not clustered around one.

Table 6 shows the percentages of V2V events removed from the dataset after the NYC CVPD applied the data cleaning rules.

Table 6. Percentage of Event Removed after Applying V2V Data Cleaning Rules.[3]

V2V Application	Percentage of Events Removed
FCW	26 percent
EEBL	43 percent
IMA	32 percent
BSW	27 percent
LCW	28 percent
VTRW	0 percent

Source: Texas A&M Transportation Institute based on information in reference 3, 2022.

Chapter 4. Mobility Impact Assessment

Because the primary focus of the NYC CVPD was to improve safety in support of NYCDOT's *Vision Zero* goal, TTI did not expect many of the applications deployed by the NYC CVPD Team to have a direct impact on mobility. Table 7 lists the performance measures TTI selected to include in the MIA.

Table 7. Mobility Analysis Supported by NYC CVPD Performance Measures.

CV Application	Performance Measure	Mobility
Speed Compliance	Number of stops (average and distribution)	Direct
	Speed (average and distribution)	Direct
	Emissions	NA
	Reduction in speed limit violations	Direct
	Speed variation	Direct
	Vehicle throughput (average and distribution)	Direct
	Driver actions in response to issued warnings	NA
Curve Speed Compliance	Speed-related crash counts, by the severity of crashes	NA
	Vehicle speeds at curve entry	Indirect
	Lateral acceleration in the curve	NA
	Driver actions in response to issued warnings	NA
	Number of curve speed violations	NA
Speed Compliance in Work Zone	Speed in work zones (average and distribution)	Indirect
	Speed variation in work zones	Indirect
	Number of vehicle speed limit violations	NA
	Driver actions in response to issued warnings	NA
V2V Safety Warning Applications*	Fatality crash counts	Indirect
	Injury crash counts	Indirect
	PDO crash counts	Indirect
	Time to collision (V2V)	NA
Red-Light Violation Warning	Red-light violation counts	Indirect
	Time to collision (V2V)	NA
	Driver actions in response to issued warnings	NA
	Right-turning related conflicts	NA

CV Application	Performance Measure	Mobility
Vehicle Turning Right in Front of Bus	Time to collision (vehicle-to-bus)	NA
	Number of warnings generated	NA
	Driver actions in response to issued warnings	NA
Pedestrian in Signalized Crosswalk Warning	Pedestrian-related crash counts, by severity	Indirect
	Number of warnings generated	NA
	Pedestrian-related conflicts/hard braking events	NA
	Time to collision (vehicle-to-pedestrian)	NA
	Driver actions in response to issued warnings	NA
Mobile Accessible Pedestrian Signal System	Qualitative operator feedback	NA
	Pedestrian crossing speed and crossing travel times	NA
	Times out of crosswalk	NA
	Waiting time at the intersection for crossing pedestrians	NA
Oversized Vehicle Compliance	Number of warnings generated	NA
	Number of truck route violations	NA
Emergency Communications and Evacuation Information	Number of vehicles receiving information when generated	Direct
Intelligent Traffic Signal System Connected Vehicle Data	Segment speed (avg. and distribution) from CV compared to legacy detection systems	NA
	Travel time (average and distribution measures) from CV compared to legacy detection systems	NA
System Performance Monitoring	System performance statistics (system activity, downtime, radio frequency monitoring range on ASD's and RSUs, number of warnings by app)	NA

NA = not applicable.
*V2V Safety Applications include EEBL, FCW, IMA, BSW, and LCW

Direct Impact on Mobility

TTI identified the following three applications as having the potential to directly assess the mobility impact associated with deployment:

- SPDCOMP.
- PED-SIG.
- EVAC.

Table 8 shows the performance measures that the NYC CVPD had selected to assess the direct impacts of the deployment on mobility. Unfortunately, low sample rates prevented the NYC CVPD from producing the speed, speed variation, and vehicle throughput performance measures.[3]

Table 8. Performance Measures Selected by TTI Team to Assess Direct Mobility Impacts.

Performance Measure	Application	Included in Evaluation by NYC CVPD Team	Reason for Not Evaluating
Number of stops (average and distribution)	SPDCOMP	No	NA
Speed (average and distribution)	SPDCOMP	No	Low sample rates in the CV Travel Time system
Speed variation	SPDCOMP	No	Low measured mobility impacts negated the potential speed variation benefits
Vehicle throughput (average and distribution)	SPDCOMP	No	Low measured mobility impacts negated the potential for throughput benefits
Reduction in speed limit violations	SPDCOMP	Yes	NA
Pedestrian crossing speed and crossing travel times	PED-SIG	Yes	NA
Times out of crosswalk	PED-SIG	Yes	NA
Waiting time at the intersection for crossing pedestrians	PED-SIG	Yes	NA
Number of vehicles receiving information when generated	EVAC	Yes	NA

NA = not applicable.

Speed Compliance

The TTI Team identified the SPDCOMP application as having the potential to impact mobility in the deployment area both directly and indirectly. The purpose of the Speed Compliance application was to notify drivers when their speed exceeded the posted speed limits. The hypothesis was that better compliance with the posted speed limits would provide a smoother trip and limit speed turbulence.

Because of low sample rates, the NYC CVPD Team was unable to produce the speed, speed variation, and vehicle throughput performance measures that TTI had planned to use to assess the mobility benefits. The NYC CVPD Team did examine the extent to which the application was able to reduce the number of speed limit violations.[3] The NYC CVPD Team's evaluation of over 40,000 speed compliance events showed a reduction in approximately 47.7 speed limit violations per 1,000 events after drivers in the treatment group began receiving alerts. The NYC CVPD Team deemed this reduction in speed limit violation rates to be statistically significant at a 95 percent confidence interval. Based on this analysis, the NYC CVPD Team concluded that drivers tend to comply better to posted speed limits after being issued a speed compliance alert.

The NYC CVPD Team examined how weather impacted the speed limit compliance to alerts as well. The NYC CVPD Team examined reductions in speed limit violation per 1,000 events in three categories of weather conditions (clear, cloudy, and rain). The NYC CVPD Team reported the following reductions in the speed limit violation rate under different weather conditions:[3]

- During clear weather conditions, the NYC CVPD Team reported a reduction of 4.7 speed limit violations per 1,000 events by the treatment group drivers (compared to the control group). The NYC CVPD Team determined this reduction in speed limit violations to be statistically insignificant.
- The NYC CVPD observed that there was a reduction of 38.1 speed limit violations per 1,000 events by drivers receiving alerts compared to drivers not receiving alerts during cloudy conditions. The NYC CVPD Team determined that this reduction was statistically significant at a 95 percent confidence level.
- The NYC CVPD team also indicated that there was a reduction of 203.8 speed limit violations per 1,000 events because of drivers receiving speed compliance alerts during rainy conditions. The NYC CVPD Team determined this reduction to be statistically significant at a 95 percent confidence level.

The NYC CVPD Team noted that the application was set to have a 0 mph tolerance for vehicles driving over the speed limit,[3] which may not be practical in other situations. The NYC CVPD Team suggested that different speed limit values higher than the actual speed limit may be more appropriate to limit the frequency that a single driver received alerts.

Mobile Accessible Pedestrian Signal System

TTI also identified the PED-SIG application as having the potential of directly impacting mobility in the deployment area. The NYC CVPD Team conducted field studies to assess the efficacy of the application in assisting individuals with limited sight cross a series of signalized intersections in Manhattan. These field tests involved providing the PED-SIG application to 24 pedestrians with low or no vision to test the application on six predefined routes, each made up of two crosswalk crossings.[3] The crossings were located on roadways with relatively low traffic volumes and no or very low vehicle turning movements. The test intersections included Pacific Street and Bond Street, Pacific Street and Hoyt Street, and State Street and Hoyt Street in Brooklyn.

Because of difficulties in developing both iOS and Android versions of the application at same time, the NYC CVDP Team developed the application to operate on five personal information devices (PID) using the iOS platform. In the field studies, each participant carried and interacted with a PID device augmented with a GPS device connected via Bluetooth. The GPS device was necessary to enhance the GPS accuracy of the PID.

In terms of data collection, the NYC CVPD Team asked each participant to answer pre- and post-experiment surveys to obtain user feedback on the applications. Also, the NYC CVPD Team collected operation data logs from each user during the field tests. The PID's cell phone transmitted all raw log data to a secure, IRB-approved server at New York University via the PID's cell phone, where it was processed to remove all personally identifiable information.

Participants completed approximately 170 total runs, each made up of two crosswalk crossings. Using the application's operations logs, the NYC CVPD Team computed the following mobility related crossing performance measures:

- Pedestrian crossing speed and crossing travel time.
- Waiting time at intersection crossing.
- Time outside of designed crosswalk area.

The NYC CVPD Team reported the following impacts associated with the PED-SIG application on pedestrian mobility:[3]

- The average wait time per intersection was 31.0 seconds with a standard deviation of 15.9 seconds. Several individuals started crossing immediately after receiving the "WALK SIGNAL IS ON" message from the application. A few test participants waited until the red signal indication. One individual indicated that they always waited multiple signal cycles before crossing the street to ensure that it was safe to do so.
- The average crossing time per crosswalk was 9.6 seconds with a standard deviation of 2.4 seconds. This equates to an average walking speed of 3.6 feet per second with a standard deviation of 0.9 feet per second. This walking speed is faster than the 3.5 feet per second value specified for normally sighted pedestrians, specified in the *Manual on Uniform Traffic Control Devices* (MUTCD).[11] The NYC CVPD Team reported that 54 percent of the test participants crossed the street with speeds greater than 3.5 feet per second.
- Participants crossed out of the crosswalk 1.4 times per crossing on average, with a standard deviation of 1.4 times. The NYC CVPD Team reported that 63 percent of the participants veered out of the crosswalk at least one time during the field tests.

Due to time constraints, the NYC CVPD Team collected only post-deployment data (i.e., with the application active).[3] No pre-deployment (i.e., without the device active) data were available to assess the extent to which the application *improved* pedestrian mobility.

Emergency Communications and Evacuation Information

The NYC CVPD Team designed the EVAC application to provide emergency information via TIM to drivers within a geofenced area of concern.[3] The purpose of the message was to alert drivers of emergency situations near or within affected areas during defined incidents and events. The NYC CVPD Team activated the application only under test conditions and never activated messages during a true emergency event.[3] As a result, the NYC CVPD Team did not report any mobility benefits associated with this application.

Indirect Impacts on Mobility

TTI identified several applications that could potentially have an indirect impact on mobility. An indirect impact on mobility might be one where the designed application addressed other operational issues (i.e., safety) but, if successful, might also marginally impact mobility in a circuitous manner. An example of an indirect mobility impact would be the elimination of congestion because an application prevented a crash. TTI identified the following applications as potentially having an indirect impact on mobility:

- Curve Speed Compliance.
- Speed Compliance in Work Zones.
- All the V2V Safety applications (FCW, EEBL, BSW, LCW and IMA).
- Red-Light Violation Warning.

- Vehicle Turning Right Warning.
- Pedestrian Warning in Crosswalk Warning.

Table 9 shows the performance measures that the TTI Team had selected to use to assess the indirect impacts of these applications on mobility. Unfortunately, the NYC CVPD Team did not include many of these performance measures in their analysis due to data limitations.

The following provides an assessment of those applications where the NYC CVPD Team provided data.

Curve Speed Compliance

TTI identified the curve speed warning application as having a potential indirect impact on mobility. Like the speed compliance application, TTI's rationale for considering the curve speed compliance application as potentially impacting mobility has to do with maintaining uniformity of speeds in the traffic stream. Ensuring speed uniformity reduces variability in the traffic stream. Speed variability causes disturbances and turbulence in the traffic stream. Considering the low posted speed limits on the roadways in the NYC area and the limited number of curves in the network, TTI did not expect this application to significantly impact mobility.

Table 9. Performance Measures Used by TTI Team to Assess Indirect Mobility Impacts.

Performance Measure	Application	Included in Evaluation by NYC CVPD Team	Reason for Not Evaluating
Speed related crash counts, by the severity of crashes	CSPDCOMP	No	Limited crash data prevented meaningful analysis
Vehicle speeds at curve entry	CSPDCOMP	Yes	NA
Speed in work zones (average and distribution)	SPDCOMPWZ	No	Low sample rates in the CV Travel Time system (FD + SD)
Speed variation in work zones	SPDCOMPWZ	No	Low sample rates in the CV Travel Time system (FD + SD)
Fatality crash counts	V2V Safety*	Yes	As crash data permitted
Injury crash counts	V2V Safety*	Yes	As crash data permitted
PDO crash counts	V2V Safety*	Yes	As crash data permitted
Red-light violation counts	RLVW	Yes	NA
Right-turning related conflicts	VTRW	No	Extremely limited number of collected VTRW event records prevented meaningful analysis and evaluation
Pedestrian-related crash counts, by severity	PEDINXWALK	No	Too many confounding factors (including those related to signal timing variations by deployment site) prevented meaningful crash analysis

NA = not applicable.
*This is a combination of applications including FCW, EEBL, BSW, LCW and IMA.

After cleaning and filtering the vehicle event records, the NYC CVPD Team found only 27 curve speed compliance events in the treatment group and 1 comparable event in the control group.(3) Because of the small number of events, the NYC CVPD Team was unable to assess how curve speed compliance varied under different weather conditions.

To obtain the vehicle's speed at the curve entry, the NYC CVPD Team manually identified the curve entry point based on the shape of the vehicle trajectory information as it traversed the curve.(3) Once the entry point was determined, the NYC CVPD Team then extracted the speed of the vehicle at that point from the event data. The NYC CVPD Team then compared the average speed at curve entry before the application started issuing alerts to the average speed at curve entry after vehicles started receiving alerts. The NYC CVPD Team reported that average curve entry speeds reduced by approximately 8.75 mph after vehicles received alerts. The NYC CVPD Team deemed this reduction to be statistically significant at a 95 percent confidence level. From this finding, the NYC CVPD Team concluded that drivers tended to reduce their speeds at curve entries after they started receiving curve speed compliance alerts.

Red-Light Violation Warnings

The TTI Team also identified the red-light violation warning application as having an indirect impact on mobility. The NYC CVPD Team designed the red-light violation warning application to provide equipped vehicles approaching a signalized intersection with an alert if the application determined that the vehicle, given its current speed and acceleration profile and time remaining in the current green signal indication, would be across the stop bar after the onset of a red signal indication. If a violation seemed likely, the application issued a warning to the driver. In addition to the obvious safety benefits, the rationale for TTI to identify this application as having an indirect impact on mobility has to do with reducing startup delays for traffic on cross-street approaches. If the application was successful at reducing the frequency of red-light violations, the cross-street traffic would not have to wait as long for vehicles to clear the intersection and could better utilize the green signal indication. Better utilization of green signal indications has the potential to increase vehicle throughput through the signal, albeit marginally.

Because of the data obfuscation process, the NYC CVPD Team reported difficulties in identifying whether a vehicle entered the intersection with a red signal indication.(3) Therefore, the NYC CVPD Team based their analysis on "likely red-light violations." The NYC CVPD Team defined a likely red-light violation to occur when the driver's speed was greater than 0 mph after a RLVW was issued.

The NYC CVPD Team reported that there were about 470 likely red-light warning events per month from June 2021 through September 2021.(3) The NYC CVPD Team reported that there were approximately 152 fewer likely red-light violation events per 1,000 when the application was enabled, compared to the silent warning period. Based on these findings, the NYC CVPD Team concluded that drivers were more likely to come to full stops instead of running red lights after red-light warning alerts were issued.

Vehicle to Vehicle (V2V) Safety Applications

Using a survival analysis model, the NYC CVPD Team conducted an analysis of the potential safety improvements associated with the V2V applications. Because of privacy issues, the NYC CVPD Team was unable to link crash records to instrumented vehicles directly; therefore, these reductions in crashes cannot to attributed to any CVPD application. In fact, the NYC CVPD Team suggests the following:(3)

> "*The impact of instrumented vehicles in terms of crashes is expected to be marginal compared to various other safety-related confounding factors that occurred simultaneously*

> *with the NYC CVPD, such as the COVID-19 pandemic, Vision Zero projects, planned special events, and so on. Thus, the results…should be interpreted as a combined treatment effect for all the potential safety-related 'treatments' that occurred simultaneously around NYC during the NYC CVPD implementation period and may not be solely due to the…applications."*

Based on their analysis, the NYC CVPD Team reported the following findings associated with safety impacts of the V2V safety applications:(3)

- The NYC CVPD Team used rear-end crashes to assess the combined safety effects of the FCW and EEBL application in the deployment area. During the evaluation period (January 2021 through September 2021), the NYC Police Department crash database contained a total 4,851 reported rear-end collisions in the study area. Based on their analysis of these crash records, the NYC CVPD Team estimated the crash medication factors (CMFs) of 0.947 (not statistically significant) and 0.906 in injury and PDO rear-end collisions, after accounting for increases in traffic volume. This finding suggests that compared to the before period, both injury and PDO rear-end collisions reduced by 5.3 percent and 9.4 percent, respectively, in the after period.
- For the BSW and LCW applications, the NYC CVPD Team examined side-swipe collisions occurring in the deployment area. During the evaluation period (January 2021 through September 2021), a total of 1,471 sideswipe crashed occurred in the deployment area. Two of those crashes resulted in fatalities. After accounting for the effect of exposure (i.e., traffic volumes), the NYC CVPD Team estimated the CMF for injury and PDO sideswipe crashes to be 0.985 (statistically insignificant) and 0.850 (statistically significant), respectively. This finding suggests that compared to the before period, both injury and PDO sideswipe crashes reduced by 1.5 percent and 15 percent, respectively, in the after period, after accounting for crash exposure.
- The NYC CVPD Team did not pursue a crash analysis for the IMA application because there was no clear contributing factor corresponding to accident types (left turn crossing and head-on crashes) targeting the IMA application.

For more information on the NYC CVDP Team's crash reduction analysis, the reader should consult *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation—New York City (NYC) Phase 3 Evaluation Report*.(3)

Modeling Mobility Impacts of Crash Reductions

The NYC CVPD Team used simulation to help assess if the deployment impacted mobility due to reducing or eliminating crashes in the deployment area. To assess the potential impacts of reducing crashes, the NYC CVPD Team used their existing Manhattan Traffic Model (MTM) simulation platform to investigate network impacts caused by lane blockages at select locations. Developed using the Aimsun platform, the MTM includes both regional mesoscopic components and a detailed microscopic model of Midtown Manhattan. Figure 5 shows the coverage area of the model.

The NYC CVPD Team modeled crashes as lane blockages using Aimsun's built-in traffic management condition tools, where the time, network section, and specific lanes to be closed were used to define a crash. At the time of the crash in the simulation, the lane(s) blockage closed the lanes to all simulated traffic for the programmed duration. Traffic was allowed to react to the new conditions created by the lane(s) blockage, including the potential for simulated drivers that became aware of current traffic conditions to change paths dynamically in response to the changing traffic conditions. The NYC CVPD Team did not allow the traffic signals to adjust their timings in response to the crash condition. Also, no traveler alerts were issued that would have caused drivers to avoid the area of the crash or change their travel plans.

The NYC CVPD Team developed four hypothetical crash scenarios (see Table 10). Each scenario involved simulating a 30-minute lane blockage, representing a crash. The NYC CVPD Team compared the result of these simulations to the results of simulating the same conditions except without a lane-blocking event. Figure 6 shows the location of the crash scenarios on the simulation network.

As part of their Phase 2 activities, the NYC CVPD Team updated and calibrated the model to 2018 pre-deployment (pre-pandemic) conditions for a typical weekday morning (6 to 9 a.m.) and afternoon (3 to 7 p.m.) peak period. The model included unequipped automobile, truck, and fixed-route, fixed-schedule transit vehicles, and included typical operating constraints (like parking restrictions, reversible lane operations at river crossings, reserved bus lanes, and pickup and drop-off zones for taxis and for hire vehicles) used by the NYCDOT to manage traffic in the Manhattan area.

The NYC CVPD Team simulated network performance with and without the lane-closing events. They assumed that normal network performance best represented operations if the CV technology could prevent crashes from occurring.[3] Therefore, by comparing network performance with and without these collision events, one might demonstrate, in part, secondary mobility benefits of CV technology. To account for the stochastic nature of the simulation model, the NYC CVPD Team simulated each condition using five different seeds and averaged the results from the five model runs to estimate network performance. The NYC CVPD Team used throughput, total vehicle delay, and average travel time measures of network performance. The NYC CVPD Team examined both the local (i.e., the area immediately at the point of the closure) and system level (i.e., 10 blocks upstream of the crash location and on the immediate connecting side streets) impacts on roadway performance.

Table 11 and Table 12 show the local impacts (as measured by throughput and average speeds) on the block where the crash occurred.[3] These tables show that depending on the roadways where the events occurred, a 30-minute blockage reduced throughput in the immediate vicinity of the blockage between 5 and 15 percent and speed by 2 to 41 percent. These metrics include the effects of any self-diverting drivers changing their path in response to the blockages.

Table 13, Table 14, and Table 15 show the impacts of the same 30-minute blockages on the same crashes at the system level.[3] These tables show the changes in vehicle miles traveled (VMT), vehicle hours traveled (VHT), and vehicle hours of delay (VHD) reported by the NYC CVPD Team. These tables show that under the crash scenarios, VMT decreased by as much as 30 percent, VHT increased by as much as 32 percent, and VHD increased by as much as 50 percent. The NYC CVPD Team did not offer an explanation of why VMT would decrease under the crash scenarios. One potential explanation for this is that the impacts of each crash scenario extended well beyond the 10 blocks upstream of the closure location and traffic that normally would have entered by network in that area diverted to alternate routes outside of the data collection area. Another possibility is that the simulation ended before all the impacted vehicles had cleared the impacted area.

Table 10. Crash Scenarios Analyzed Using Simulation by NYC CVPD Team. [(3)]

Simulated Crash	Location (Network Link)	Time of Crash	Lane Blockage Duration	Lanes Blocked	Direction of Flow	Total Number of Lanes
Crash 1	1st Avenue North of 63rd Street	16:30	30 minutes	1 Lane (lane #4)	Northbound	4 general purpose lanes with parking on the left and exclusive bus lane to the right
Crash 2	5th Avenue South of 55th Street	16:30	30 minutes	2 lanes (lanes #1 and #2)	Northbound	3 general purpose lanes with 2 exclusive bus lanes to the right
Crash 3	2nd Avenue South of 23rd Street	16:30	30 minutes	1 lane (lane #4)	Southbound	4 general purpose lanes with exclusive bus lane to the left
Crash 4	6th Avenue North of 47th Street	16:30	30 minutes	2 lanes (lanes #3 and #4)	Southbound	3 general purpose lanes with exclusive bus lane to the right and parking/bike lane to the left

Source: New York City Department of Transportation, 2022

Source: New York City Department of Transportation, 2017.

Figure 5. Map. Manhattan Traffic Model Microscopic Model Geographic Extent.(3)

Based on the results of this simulation, the NYC CVPD Team concluded that removing crashes from the network at these locations reduced total VHD by an average of 17.5 vehicle hours and by a maximum of 51.9 vehicle hours at one location.(3) While not all these delay savings can be attributed to the CV applications directly, this finding suggests that mobility benefits may be possible if it can be shown that CV technologies successfully reduce crashes in the Manhattan area. However, to determine the extent to which the applications deployed by in the NYC CVPD had a direct impact on crash reductions requires additional analyses.

Source: Texas A&M Transportation Institute, 2022.

Figure 6. Map. Location of Crash Scenarios on Simulation Network.

Table 11. Throughput at Crash Location during Crash.(3)

Simulated Crash	Location (Network Link)	No Crash Scenario Section Throughput (vph)	Crash Scenario Section Throughput (vph)	Change	Percent Change
Crash 1	1st Avenue North of 63rd Street	1217.8	1029.8	−188.0	−15
Crash 2	5th Avenue South of 55th Street	443.3	421.5	−21.8	−5
Crash 3	2nd Avenue South of 23rd Street	874.8	834.8	−40.0	−5
Crash 4	6th Avenue North of 47th Street	718.3	685.8	−32.5	−5

Source: New York City Department of Transportation, 2022.

Table 12. Average Speeds at Crash Location during Crash.(3)

Simulated Crash	Location (Network Link)	No Crash Scenario Section Speed (mph)	Crash Scenario Section Speed (mph)	Change	Percent Change
Crash 1	1st Avenue North of 63rd Street	19.4	12.1	−7.3	−38
Crash 2	5th Avenue South of 55th Street	24.2	14.3	−9.9	−41
Crash 3	2nd Avenue South of 23rd Street	17.2	16.9	−0.3	−2
Crash 4	6th Avenue North of 47th Street	25.3	22.6	−2.7	−11

Source: New York City Department of Transportation, 2021.

Table 13. System Impacts of Crash—Vehicle Miles Traveled.[3]

Simulated Crash	Location (Network Link)	No Crash Scenario VMT (veh–miles)	Crash Scenario VMT (veh–miles))	Change	Percent Change
Crash 1	1st Avenue North of 63rd Street	988.5	788.3	−200.3	−20
Crash 2	5th Avenue South of 55th Street	550.0	541.4	−8.6	−2
Crash 3	2nd Avenue South of 23rd Street	633.4	934.2	−0.8	0
Crash 4	6th Avenue North of 47th Street	808.6	774.2	−34.4	−4

Source: New York City Department of Transportation, 2021.

Table 14. System Impacts of Crash—Vehicle Hours Traveled.[3]

Simulated Crash	Location (Network Link)	No Crash Scenario VHT (veh–hours)	Crash Scenario VHT (veh–hours)	Change	Percent Change
Crash 1	1st Avenue North of 63rd Street	139.9	184.5	44.5	32
Crash 2	5th Avenue South of 55th Street	78.2	81.2	3.0	4
Crash 3	2nd Avenue South of 23rd Street	64.5	63.6	−0.9	−1
Crash 4	6th Avenue North of 47th Street	88.6	102.7	14.2	16

Source: New York City Department of Transportation, 2021.

Table 15. System Impacts of Crash—Vehicle Hours Delay.[3]

Simulated Crash	Location (Network Link)	No Crash Scenario VHD (veh–hours)	Crash Scenario VHD (veh–hours)	Change	Percent Change
Crash 1	1st Avenue North of 63rd Street	102.9	154.8	51.9	50
Crash 2	5th Avenue South of 55th Street	57.1	60.4	3.3	6
Crash 3	2nd Avenue South of 23rd Street	633.4	934.2	300.8	47
Crash 4	6th Avenue North of 47th Street	58.1	73.6	15.5	27

Source: New York City Department of Transportation, 2021.

Chapter 5. User Satisfaction

The NYC CVPD Team also collected user satisfaction survey data.(3) The NYC CVPD Team collected two sets of user satisfaction surveys. In the first set of user satisfaction surveys, the NYC CVPD Team collected qualitative feedback on the effectiveness and impact of the CV applications. The second set of user satisfaction survey data focused solely on the PED-SIG application, which targeted visually impaired individuals. This chapter summarizes the results of each survey.

Driver Perception Surveys

The NYC CVPD Team attempted to collect driver perception data at three periods: pre-deployment, early in the post-deployment period, and late in the post-deployment period.(3) The NYC CVPD Team encouraged drivers of the CV-equipped fleet vehicles to complete each of the three surveys. However, because there was no direct contact between the NYC CVPD Team and the participating drivers and participants did not received incentives to provide responses, the number of participants providing responses varied greatly. In terms of sample size, the NYC CVPD Team reported the following numbers of completed survey responses:(3)

- Eighty-three responses in the pre-deployment survey.
- Nineteen responses in early post-deployment survey.
- One hundred sixty-one responses in the late post deployment survey.

The NYC Team solicited feedback from vehicle operators on the following general areas:(3)

- Typical vehicle usage and driving patterns when driving for work in NYC.
- Perceptions and attitudes about CV technology and the safety of driving for work in NYC.
- Experiences with CV applications while driving (collected in the post-deployment period only).

Because there was no way for the NYC CVPD Team to ensure that the same individuals completed the survey, it was difficult to compare changes in perceptions and attitudes over time. Furthermore, the NYC CVPD Team was not able to correlate survey responses to the CV technology operating mode (active or silent) in the post-deployment survey.

For completeness, the NYC CVPD Team reported the following key findings from their user satisfaction surveys:(3)

- Half of respondents drive an average of 20 to 50 miles per day for work, about half drive 8 or more hours per day, and the majority drive at least 5 days per week.
- Among all respondents, 56 percent were familiar with CV technology. This proportion was higher among respondents in the late deployment stage.
- Eighty-four percent of the respondents felt moderately, very, or extremely safe driving in the city for work.

- The largest concerns about CV technology were regarding distractions, false alerts, and too many alerts with CV technology. The proportion of responses with these concerns was only slightly lower in the post-deployment surveys as compared to the pre-deployment surveys.
- The most useful alerts to improve safety were SPDCOMP and FCW. These were also the two alerts that the drivers reported hearing the most.
- Seventy-two percent of respondents found the alerts moderately, very, or extremely distracting.
- Twenty-three percent of respondents reported some level of satisfaction with the experienced CV technology, while 39 percent reported some level of dissatisfaction.
- Familiarity with CV technology was correlated with both anticipation of usefulness and overall satisfaction with the pilot.
- The NYC CVPD Team did not find any correlation between length of driving and likelihood of crash with pedestrian, vehicles, or infrastructure objects.
- Both the frequency and the perceived loudness of the alerts were highly correlated with the reported level of distraction from the alerts.
- The NYC CVPD Team did not find any correlation between the driver's assessment of their safety during driving for work and usefulness of the audible alerts.

The NYC CVPD Team did not report user perceptions of the effectiveness or the efficiency of the applications to improve mobility, public agency efficiency, and the environment.

User Perceptions of the Mobility Accessible Pedestrian Signal System

The CVPD Team also collected user feedback data on the PED-SIG application. The NYC CVPD Team collected field data and user perception data from 24 visually impaired participants.(3) The focus of this assessment was on ease-of-use, user experience, application functionality, and user perception of safety. Major findings from the survey of users of the PED-SIG application were as follows:(3)

- Eighty-three percent of the participants had a favorable impression ("Good," "Very Good," or "Excellent") of the PED-SIG application.
  - Ninety-six percent felt the application gave them sufficient time to cross the intersection.
  - Sixty-three percent of the participants felt they stayed oriented on the crosswalk when using the PED-SIG application.
- Ninety-two percent of the participants indicated that the application was easy to use.
- Seventy-one percent of the participants agreed that they felt more confident in their ability to cross a signalized intersection with the application compared with other assistive technologies. Only one participant expressed disagreement with this statement.
- Approximately 80 percent of the participants reported receiving timely alerts from the application.
- Seventy-one percent of the participants reported that reports were always or mostly accurate.
- Fifty percent of the participants reported feeling much safer using the PED-SIG application compared to not using it. Thirty-one percent reported feeling slightly safer, while 17 percent reported feeling just as safe using the application compared to not using it.

Chapter 6. Summary of Findings and Lesson Learned

This chapter provides a summary of the findings and lessons learned based on the data and information provided by the NYC CVPD Team in their *Connected Vehicle Pilot Deployment Program Performance Measures and Evaluation—New York City (NYC) Phase 3 Evaluation Report*.[3]

Summary of Findings

Using the data provided by the NYC CVPD Team, TTI assessed the impacts of the NYC CVPD on mobility. Because the NYC CVPD focused primarily on improving safety, no applications directly impacted mobility (i.e., reductions in travel time, reductions in delay, improvements in travel time reliability, etc.). Furthermore, because of deployment issues and challenges, the NYC CVPD Team had to change the fleet of vehicles in which to deploy the applications from taxis to city fleet vehicles. Government owned vehicles use the transportation network differently than traditional commuter-type travelers.

Based on the performance measures originally planned by the NYC CVPD Team, TTI identified the following deployed applications as having the potential to impact mobility:

- SPDCOMP.
- PED-SIG.
- EVAC.

Using the performance data provided by the NYC CVPD Team, the TTI Team assessed the impact of these applications on mobility in the deployment area and concluded the following:

- While the data showed that the SPDCOMP application successfully reduced the number of speed limit violations in the deployment fleet, the NYC CVPD Team did not have sufficient data available to allow a direct assessment of this application on mobility because of limited sample sizes and the change in the deployment fleet from vehicle-for-hire to city-owned fleet vehicles.
- Field studies of the PED-SIG application showed that average wait time for sight-impaired pedestrians was 31.0 seconds, and the average crossing speed of these individuals was 3.6 feet per second, slightly above the 3.5 feet per second walking speed recommended by the MUTCD. The NYC CVPD Team based this finding on a limited number of sight-impaired individuals with a limited number of sample crossings. Furthermore, no pre-deployment data were available for comparison purposes.
- The NYC CVPD Team collected data from the EVAC applications only for test purposes. To avoid driver confusion, the NYC CVPD never activated the application under live operating conditions. As a result, the impacts of this application on mobility remain untested.

The TTI Team also assessed the indirect impacts on mobility of some applications. Indirect mobility impacts are those produced by the application even though the primary focus of the application was to address another issue. (An example of an indirect mobility impact would be reductions in congestion due to fewer collisions.) TTI identified the following applications as having potential indirect impacts on mobility:

- CSPDCOMP.
- RLVW.
- V2V Safety applications (including FCW, EEBL, BSW, LCW, and IMA).

Using the data provided by the NYC CVPD Team, the TTI Team concluded the following about the indirect impacts of the NYC CVPD on mobility:

- The NYC CVPD Team indicated that compliance with curve advisory speed limits increased after fleet vehicles started issuing CSPDCOMP alerts. Better speed compliance in curves may result in smoother flow and less turbulence at curve speed entry points. Reductions in turbulence could potentially have indirect impacts on mobility.
- The NYC CVPD Team reported that likely red-light violations reduced by 152 per 1,000 events after the fleet vehicles began issuing RLVW alerts. Although the NYC CVPD Team could not link this reduction to actual red-light violation warnings directly, it does suggest that the application has some potential to indirectly impact mobility. Fewer red-light violations may contribute to fewer right-angle collisions and reduce start-up delays for cross-street traffic at signalized intersections.
- The NYC CVPD Team reported that rear-end collisions declined by approximately 5 and 9 percent, respectively, after FCW and EEBL warnings became active in the fleet vehicles. Simulation experiments conducted by the NYC CVPD Team also indicated that both applications had a positive effect on reducing conflict risks. This finding suggests that these applications might have the potential to have an indirect impact on mobility if deployment fleet vehicles have the same crash exposure as the general vehicle traffic in NYC.
- The NYC CVPD Team indicated that injury and PDO sideswipe collisions reduced by 1.5 and 15 percent respectively after the fleet vehicles started receiving BSW and LCW alerts. While there is no evidence that these applications were directly responsible for these reductions, it does suggest that these applications could potentially generate indirect mobility benefits through reduced crash potential.
- Because of limited sample sizes, the NYC CVPD Team was unable to assess if the IMA application had an impact on potential crash experiences. Therefore, the TTI Team was unable to assess if this application had any indirect impact on mobility.

Lessons Learned

The following provides a summary of the lessons learned reported by the NYC CVPD Team:

- The level of maturity of some of the applications were not as advertised. Some of the applications were not sufficiently developed and tested for deployment purposes and required more development work than expected by the NYC CVPD Team to get the applications ready for deployment.
- The level of market penetration, even with 3,000 equipped vehicles, was insufficient to provide a robust enough data set to allow for the evaluation of some applications. Limitations in data collection, inconsistencies between anticipated data sources, and external factors all impacted the data sample sizes of some applications.

- The FCW and SPDCOMP applications produced over 75 percent of all vehicle alerts and warnings. NYC CVPD Team's analysis showed that drivers responded to those alerts and tended to reduce their speeds after hearing an alert.
- The differences in perspective between the research/evaluation and deployment were an on-going dilemma throughout the NYC CVPD. These caused the NYC CVPD Team to review several decisions made as the project progressed, primarily centered around data collection. The NYC CVPD Team suggested that data collection processes include more detailed investigation about locations and site-specific factors that may have impacted driver decisions (while still retaining privacy protection measures). The NYC CVPD Team suggested including the ASD's time-to-collision estimations for the V2V events and the intersections identification and approach for the RLVW events to the data collection processes for these applications.
- The NYC CVPD Team cited the FCC's changes to the DSRC spectrum created significant challenges for the deployment. The FCC licensing "freeze" effected numerous pending license applications, delaying completion of the deployment until well into the post-deployment evaluation process.
- The NYC CVPD Team was unable to collect the quantity of data originally anticipated due to the change in the targeted fleet. The original concept of operations envisioned equipping taxis as the deployment fleet. This fleet, operating heavily in Manhattan and the airports, would have extremely high hours of operation (24 x 7 hours each week) and vehicle miles of travel (200+ average miles per vehicle per day). Because of changes in the vehicle-for-hire market, the NYC CVPD Team transitioned to using NYC government vehicles as the deployment vehicle. Because government fleet vehicles operate differently from vehicle-for-hire vehicles, longer data retention on the fleet vehicles (changed from 48-hours to 10-days) would address fewer daily vehicle intersections with locations providing data collection services.

References

1. Connected Vehicle Pilot Deployment Program. Intelligent Transportation Systems Joint Program Office. U.S. Department of Transportation. Available at https://www.its.dot.gov/pilots/overview.htm. Accessed April 6, 2022.
2. NYC Connected Vehicle Project for Safer Transportation. New York City Department of Transportation. Available at https://cvp.nyc/. Accessed April 6, 2022.
3. 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.
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, ITS Joint Program Office. Washington, DC. Revised April 15, 2021. Available at https://rosap.ntl.bts.gov/view/dot/61190.
6. Talas, H., K. Patton, D. Benevelli, R. Rausch, S Sim. *Connected Vehicle Pilot Deployment Program Phase 2, System Design—New York City*. FHWA-JPO-17-452. U.S. Department of Transportation, ITS Joint Program Office. Washington, DC. Revised April 15, 2021. Available at https://rosap.ntl.bts.gov/view/dot/61189.
7. CV Device Deployment Status. Connected Vehicle Pilot Deployment Program. Intelligent Transportation Systems Joint Program Office. Available at https://www.its.dot.gov/pilots/status.htm.
8. Talas, M., D. Benevelli, R. Rausch, S. Sim, N. Barhoum, and P. Bradley. *Connected Vehicle Pilot Deployment Program, Comprehensive Installation Plan—New York City*. FHWA-JPO-17-455. U.S. Department of Transportation, ITS Joint Program Office. May 2018. Available at https://rosap.ntl.bts.gov/view/dot/36389.
9. Van Duren, D., R. Rausch, D. Benevelli. *Connected Vehicle Pilot Deployment Program Phase 2, Data Management Plan*. FHWA-JPO-17454. U.S. Department of Transportation, ITS Joint Program Office. Washington, DC. October 2017. Available at https://rosap.ntl.bts.gov/view/dot/35363.
10. Van Duren, D.S. Cadzow, J. Petit, W. Whyte, and R. Rausch, D. *Connected Vehicle Pilot Deployment Program Phase 2, Data Privacy Plan*. FHWA-JPO-17-453. U.S. Department of Transportation, ITS Joint Program Office. Washington, DC. December 2017. Available at https://rosap.ntl.bts.gov/view/dot/32311.
11. Section 4E.06 Pedestrian Intervals and Signal Phases. Chapter 4E. Pedestrian Control Features. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration. 2009. Available at https://mutcd.fhwa.dot.gov/htm/2009/part4/part4e.htm.

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487

www.its.dot.gov

FHWA-JPO-22-935

U.S. Department of Transportation