Connected Vehicle Pilot Deployment Program Independent Evaluation

Environmental Impact Assessment—New York City

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Final Report—June 15, 2022
FHWA-JPO-22-938

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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 environmental 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 NYC CVPD Team conducted a simulation analysis of a 30-minute blockage at four intersections in the deployment area. From the modeling results, the Texas A&M Transportation Institute estimated that by preventing collisions at each of the four hypothetical crash locations, the NYC CVPD Team would save 144.8 gallons of gasoline and reduce greenhouse gas emissions by 1,287 Kg.

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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, NY, (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 NYC CVPD had the primary objective of developing and demonstrating the use of vehicle-to-vehicle, vehicle-to-infrastructure, and infrastructure-to-pedestrian communications to improve safety. The NYC CVPD was also part of NYCDOT's Vision Zero goal to eliminate traffic-related fatalities and reduce crash-related injuries and damage throughout the city.

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

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

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

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

Using the data provided by the NYC CVPD Team, the Texas A&M Transportation Institute (TTI) conducted a qualitative assessment of the environmental impacts of the NYC CVPD. Because the NYC CVPD focused primarily on improving safety, no applications directly impacted mobility (e.g., reductions in travel time, reductions in delay, or improvements in travel time reliability). 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.

This assessment examined the extent to which the NYC CVPD produced environmental benefits. This impact assessment was conducted using data and information produced by the NYC CVPD *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation.*[3]

Improving safety was the primary objective of the NYC CVPD Team. The NYC CVPD Team did not deploy any applications designed specifically to improve mobility or reduce emissions or fuel consumption. Therefore, the NYC CVPD Team did not collect any direct performance measures from which the TTI Team could perform an assessment of the environmental impacts. As a result, TTI conducted the assessment based on indirect measurements of the environmental impacts.

The TTI Team used the mobility simulation to provide a high-level estimate of the potential environmental impacts associated with improved safety through the deployment. The TTI Team theorized that the safety applications would reduce the number of crashes that occurred in the deployment area. Reducing the number of crashes would also reduce the amount of crash-related congestion and delays, which in turn could be used to estimate some of the environmental benefits associated with the deployment.

Using an existing microscopic simulation model of midtown Manhattan, the NYC CVPD Team conducted similar experiments to estimate the total system delay caused by four hypothetical crashes in the deployment network. Crashes were simulated by creating a 30-minute block at select locations. The NYC CVPD Team compared the results of these simulations to the results of simulating the same conditions except without a lane-blocking event. In the model, simulated drivers could dynamically alter their path to improve their travel times if an event existed. The NYC CVPD Team did not allow the model to adjust signal timings in response to crash conditions. Also, the model did not allow traveler alerts to be issued asking drivers to avoid the area of the crash.

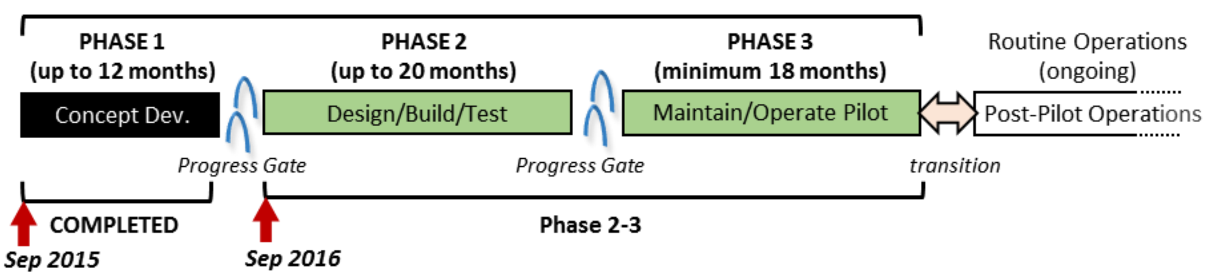
From the modeling results, TTI estimated that by preventing collisions at each of the four hypothetical crash locations, the NYC CVPD Team would save a combined total for all four collisions of 144.8 gallons of gasoline and reduce greenhouse gas emissions by 1,287 Kg.

Chapter 1. Introduction

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

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

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



Source: Federal Highway Administration, 2015

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

New York City Pilot Deployment

ITS JPO selected New York City (NYC) as one of three CVPDs. The New York City Department of Transportation (NYCDOT) led the deployment. Located primarily in the Manhattan area and along Flatbush Avenue in Brooklyn (see Figure 2), the NYC CVPD focused on developing applications using vehicle-to-vehicle, vehicle-to-infrastructure, and infrastructure-to-pedestrian communications to improve safety as part of its Vision Zero goal to eliminate traffic-related fatalities and reduce crash-related injuries and damage throughout the city.[(2)] As part of its deployment, NYCDOT installed onboard units (OBUs) with embedded safety applications in approximately 3,000 city vehicles. 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 environmental impacts assessment (EIA) associated with the NYC CVPD. Because of delays in the deployment and unforeseen external factors (e.g., the COVID-19 pandemic), the Federal Highway Administration revised TTI's evaluation scope to include only data collected by the sites during 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.
- Modeling results conducted by the sites.

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

Organization of Report

The organization of this report is as follows:

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

Chapter 2. New York City Deployment

This chapter provides the following for the NYC CVPD:

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

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

- *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation.*(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 fewer 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 summarizes 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 (CSPDCOMP). • Speed Compliance in Work Zone (SPDCOMPWZ).
2	Reduce vehicle-vehicle crashes	Safety	The goal of NYCDOT's Vision Zero Program is to reduce the number of fatalities and injuries on roadways, including vehicle-vehicle crashes. To reduce vehicle-vehicle crashes, the NYC CVPD Team deployed the following applications: • Vehicle-vehicle applications including the following: o Forward Crash Warning (FCW). o Emergency Electric Brake Light (EEBL). o Blind Spot Warning (BSW)/Lane Change Warning (LCW). o Intersection Movement Assist (IMA). • Red Light Violation Warning (RLVW). • Vehicle Turning Right Warning (VTRW).
3	Reduce vehicle-pedestrian crashes	Safety	Because of NYC's heavy pedestrian and bicycle environment and its history of frequent vehicle-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 Crosswalk Warning (PEDINXWALK). • Mobile Accessible Pedestrian Signal System (PED-SIG).
4	Reduce vehicle-infrastructure crashes	Safety	Because of the frequency and costs associated with vehicle strikes to bridges, NYCDOT identified a need to reduce the potential for vehicle-infrastructure crashes. The NYC CVPD identified the Oversize Vehicle Compliance (OVC) application to address low-clearance issues for oversize vehicles and enforce related truck route restrictions.

Use Case Number	Use Case	Use Case Focus	Description
5	Inform drivers of serious incidents	Mobility	As the traffic manager and roadway infrastructure owner, NYCDOT needs to provide notification to drivers of areas to avoid and why. The NYC CVPD Team developed the Emergency Communications and Evacuation Information (EVAC) application to inform drivers of serious incidents.
6	Provide mobility information	Mobility	NYCDOT identified a need to develop reliable alternatives for providing travel time data for use in the adaptive traffic signal system. The NYC CVPD Team identified the Intelligent Traffic Signal System Data (I-SIGCVDATA) application to augment NYC's existing toll tag technology for producing linked travel time information.
7	Manage system operation	Not Assigned	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 speed to the posted speed limit. The speed limits were transmitted to the vehicle's aftermarket safety device (ASD) via intersection geometry (MAP) messages broadcast from the system RSUs along all study corridors. The city's default regulatory speed limit was 25 mph.
Curve Speed Compliance	1	This application was deployed to inform CVs 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 CVs that were approaching a reduced speed work zone with information on the zone's reduced speed limit and warn the drivers if their speed was above the work zone's speed limit. The geofenced work zone area and its reduced speed limit were delivered to the vehicle's ASD via TIMs broadcast from nearby RSUs. In all cases deployed in Phase 3, the defined work zone speed limit was set to 15 mph, 10 mph below the default regulatory citywide 25-mph speed limit.
Forward Crash Warning	2	This application warned the driver of the host vehicle of an impending rear-end collision with a remote vehicle ahead in traffic in the same lane and direction of travel.
Emergency Electric Brake Light	2	This application enabled equipped vehicles to broadcast a self-generated emergency brake event to other surrounding CVs. 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 CV 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 CVs (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 CV 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 CVs near a host transit vehicle stopped at a transit stop. The application provided an indication to the transit vehicle operator that a nearby CV was pulling in front of the transit vehicle. The application was intended to help transit vehicle operators determine if the area in front of the vehicle was occupied before it pulled away from the transit stop. (This application was deployed in limited conditions and primarily under testing conditions.)
Pedestrian in Crosswalk Warning	3	This application was deployed using pedestrian detection equipment (a 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 CVs were notified via RSU-broadcasted SPaT (to define active pedestrian detection) and MAP messages (to define geometry and crosswalk details). Using this information, the host vehicle's ASD warned the driver of the pedestrian presence as appropriate given the vehicle's trajectory.
Mobile Accessible Pedestrian Signal System	3	This custom smartphone application provided pedestrians with information regarding the geometry conditions and active signal state of the pedestrian signals (WALK/DON'T WALK) at signalized intersections. The application functioned by receiving both MAP and SPaT messages via a cloud-based infrastructure and a location augmentation device to provide more detailed location data than those provided by the native smartphone platform.
Oversize Vehicle Compliance	4	This application was deployed to inform drivers of connected trucks and other commercial vehicles of pending low-clearance conditions based on the height of the equipped vehicle. The application functioned on the host vehicle's ADS by receiving TIMs broadcast from nearby RSUs that defined a geofenced region ahead of low-height clearance conditions and warned drivers when the vehicle entered the region of a potential bridge strike. (This application was deployed in limited conditions during the pilot.)

Application	Use Case	Description
Emergency Communications and Evacuation Information	5	This application was deployed to help transmit information from NYC's Office of Emergency Management and NYCDOT's Office of Emergency Response to CVs near or within affected areas during defined incidents and events. The vehicle's ASD warned drivers of events with a custom message upon entering a geofenced area of concern, as defined by a TIM broadcast from a nearby RSU. (This application was deployed under test conditions only with test messages during the deployment. No true emergency messages were broadcast during the evaluation period.)
Intelligent Traffic Signal System Data	6	This application used data from RSUs to monitor CV 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 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 3,000 city-owned fleet vehicles with ASDs.[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 UPS disengaged prior to the deployment phase. As a result, the NYC CVPD switched its 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.

Table 3. ASD Deployment by Agency and Vehicle Type.[3]

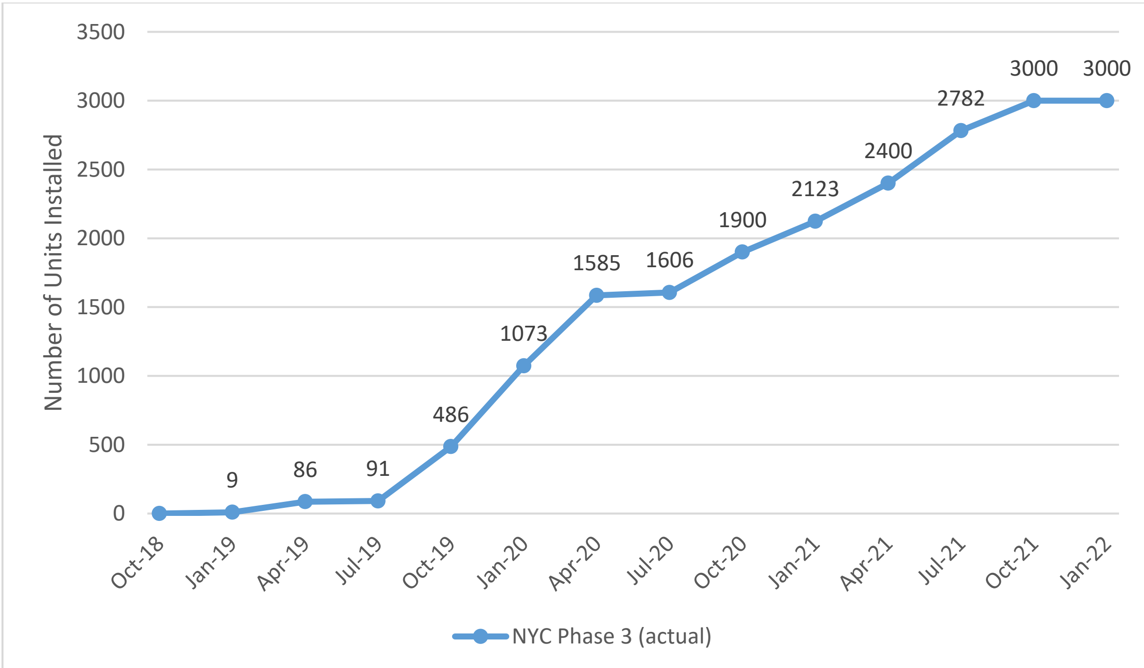
Agency	Passenger Cars	Pickups and Trucks	Vans	Buses	Vehicle Installations
NYC Department of Transportation	Yes	Yes	Yes	No	1,238
NYC Department of Parks and Recreation	Yes	Yes	Yes	No	511
NYC Department of Corrections	Yes	Yes	Yes	Yes	259
NYC Department of Environmental Protection	Yes	Yes	Yes	No	159
NYC Department 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 Department of Citywide Administrative Services Fleet	Yes	No	No	No	78
NYC Department of Education	Yes	Yes	Yes	No	78
NYC Department of Buildings	Yes	No	No	No	69
NYC Administration for Children’s Services	Yes	Yes	Yes	No	65
NYC Department of Housing, Preservation, and Development	Yes	No	No	No	48
NYC Department of Health and Mental Hygiene	Yes	Yes	Yes	No	45
NYC Department of Design and Construction	Yes	No	No	No	38
NYC Office of Chief Medical Examiner	Yes	Yes	Yes	No	29

Agency	Passenger Cars	Pickups and Trucks	Vans	Buses	Vehicle Installations
Metropolitan Transit Authority Bus and New York City Transit	No	No	No	Yes	14
NYC Emergency Management	Yes	No	No	No	12
NYC Department of Consumer Affairs	Yes	Yes	No	No	12
Anheuser-Busch InBev	No	No	Yes	No	10
NYC Department of Information Technology and Telecommunications	Yes	No	No	No	9
NYC Department of Probation	Yes	No	No	No	6
NYC CVPD Team Vehicle	No	Yes	No	No	1
Taxi Limousine Commission (yellow cabs)	Yes	No	No	No	1
Totals	**1,662**	**967**	**269**	**102**	**3,000**

Source: New York City Department of Transportation, 2021

Because of NYC's response to the COVID-19 pandemic in 2020, the NYC CVPD Team experienced significant delays in reaching the full deployment of 3,000 vehicles. Figure 3 shows the deployment history of the number of equipped vehicles per quarter for the NYC CVPD.(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.

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



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

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

Operating Modes

NYC's experimental plan required the equipped vehicles to operate in either a silent or active warning mode. The CV applications functioned the same in both operating modes, including logging all application input data and all recommended alert messages. The only difference between vehicles operating in the 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 occur with before/after experimental design.

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

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

More information on the NYC CVPD Team's experimental design is available in *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation*.[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.

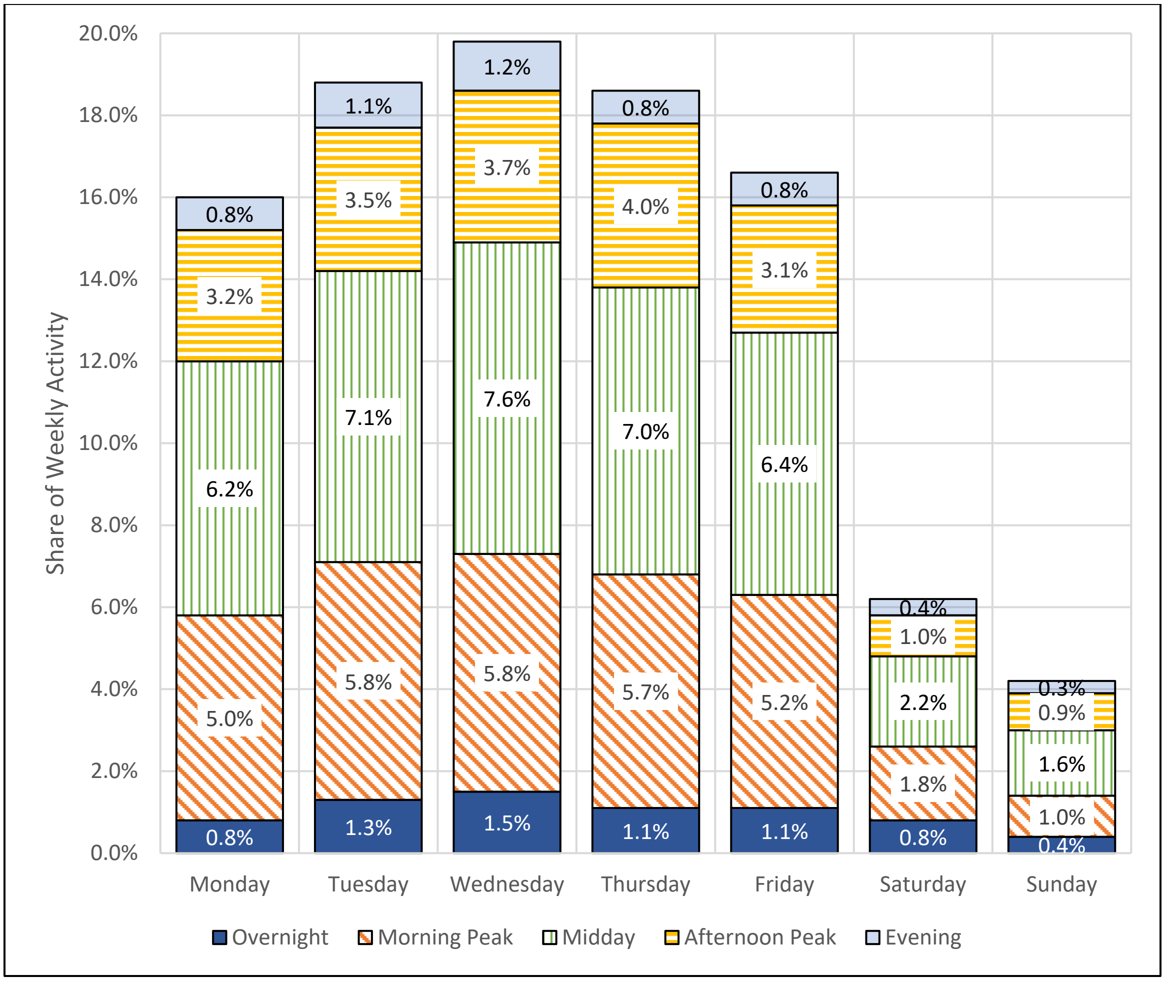
Typical Fleet Activity

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 3-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 during the work week, with Tuesdays through Thursdays each accounting for slightly over 18 percent of the total weekly activity and Mondays and Fridays each accounting for approximately 16 percent of the total weekly activity.
- The AM and MD periods experienced the greatest share of fleet activity in the network, followed closely by the PM period. Few trips occurred during the EV and NT periods.



Source: New York City Department of Transportation, 2021

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

Roadside Units

The NYC CVPD Team installed 457 RSUs at intersections in Manhattan and Brooklyn and along FDR Parkway 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] indicate that each RSU should have the following capabilities:

- Broadcasting SPaT and MAP data to equipped vehicles using the Society of Automotive Engineers Dedicated Short-Range Communication (J2735) message set.
- Broadcasting the roadway's clearance height and restrictions.
- Broadcasting the roadway geometry for the speed zone, curve speed warning, and vehicle restriction applications.

- Receiving personal safety messages from surrounding pedestrians and determining when pedestrians were in specific crosswalks.
- Indicating pedestrian presence in the roadway as measured by pedestrian detection devices.

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

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

Chapter 3. Evaluation Data and Data Availability

The NYC CVPD Team conducted simulations using an existing Aimsun model of Midtown Manhattan to assess the potential mobility and environmental impacts associated with preventing crashes in the Manhattan area.[3]. The Midtown in Motion model is a microscopic simulation model of a sub-area from a larger mesoscopic dynamic traffic assignment model, which may cause vehicles to be rerouted outside the defined sub-area for the microscopic simulation. Figure 5 shows the coverage area of the model. As part of its 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 (e.g., 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 NYCDOT to manage traffic in the Manhattan area.

The NYC CVPD Team developed four hypothetical crash scenarios (see Table 4).[3] 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. In the model, simulated drivers could dynamically alter their path to improve their travel times if one existed. The NYC CVPD Team did not allow the model to adjust signal timings in response to crash conditions. Also, the model did not allow traveler alerts to be issued asking drivers to avoid the area of the crash. Figure 6 shows the location of the crash scenarios on the simulation network.

The NYC CVPD Team simulated network performance with and without the lane-closing events. The team 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, the CVPD might demonstrate, in part, secondary mobility and environmental 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-level (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 5 and Table 6 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 by 5 to 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.

Source: New York City Department of Transportation, 2017

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

Table 4. Crash Scenarios Analyzed Using Simulation by the NYC CVPD Team.

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 1 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 1 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 1 exclusive bus lane to the right and parking/bike lane to the left

Source: Texas A&M Transportation Institute, 2022

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

Table 5. 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	1,217.8	1,029.8	−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 6. 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 7, Table 8, and Table 9 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.. 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 the network in that area diverted to alternate routes outside the data collection area. Another possibility is that the simulation ended before all the impacted vehicles had cleared the impacted area.

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, determining the extent to which the applications deployed by the NYC CVPD had a direct impact on crash reductions requires additional analyses.

Table 7. System Impacts of Crash—Vehicle Miles Traveled.[3]

Simulated Crash	Location (Network Link)	No Crash Scenario VMT (Vehicle Miles)	Crash Scenario VMT (Vehicle 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 8. System Impacts of Crash—Vehicle Hours Traveled.[3]

Simulated Crash	Location (Network Link)	No Crash Scenario VHT (Vehicle Miles)	Crash Scenario VHT (Vehicle Miles)	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 9. System Impacts of Crash—Vehicle Hours of Delay.[3]

Simulated Crash	Location (Network Link)	No Crash Scenario VHD (Vehicle Miles)	Crash Scenario VHD (Vehicle Miles)	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 4. Environmental Impact Assessment

TTI used the results of the simulation analysis to estimate the potential fuel savings benefits associated with the deployment. In these simulations, the NYC CVPD Team modeled four hypothetical scenarios to estimate the secondary mobility impacts of preventing a crash in the network. The NYC CVPD Team did not specifically model any one particular CV application but assumed that the combination of CV applications, along with other improvements performed by NYCDOT, were effective at preventing collisions in the network. TTI used a method developed by the Argonne National Laboratory for estimating the amount of fuel consumed while idling to estimate the fuel consumption benefits associated with the NYC deployment.[9] This methodology uses Equation 1 for estimating the amount of fuel consumed while idling.

$$FC = I * n * R \qquad (1)$$

Where:

FC = total amount of fuel consumed by idling (gallons)
I = average duration spent idling (hours of idling per vehicle)
n = number of vehicles experiencing idling (vehicles)
R = rate of fuel consumed while idling (gallons per hour of idling)

Argonne also developed fuel consumption rates for different idling gasoline- and diesel-powered vehicles. Table 10 shows these fuel consumption rates for different vehicle types. These rates are for vehicles with no load (i.e., no use of accessories such as air conditioners, fans, etc.) on the engines.

Table 10. Fuel Consumption during Idling for Different Vehicle Types.[9]

Vehicle Type	Fuel Type	Engine Size (Liter)	Gross Vehicle Weight (Lbs)	Idling Fuel Use (gal/hour with No Load)
Compact sedan	Gasoline	2	—	0.16
Large sedan	Gasoline	4.6	—	0.39
Compact sedan	Diesel	2	—	0.17
Medium heavy truck	Gasoline	5–7	19,700–26,000	0.84
Delivery truck	Diesel	—	19,500	0.84
Tow truck	Diesel	—	26,000	0.59
Medium heavy truck	Diesel	6-10	23,000–33,000	0.44
Transit bus	Diesel	—	30,000	0.97

Vehicle Type	Fuel Type	Engine Size (Liter)	Gross Vehicle Weight (Lbs)	Idling Fuel Use (gal/hour with No Load)
Combination truck	Diesel	—	32,000	0.49
Bucket truck	Diesel	—	37,000	0.90
Tractor-semitrailer	Diesel	—	80,000	0.64

A dash denotes not applicable.

Source: Argonne National Laboratories

Table 9 shows the effects of a 30-minute capacity reduction at select locations in the NYC CVPD on total system delay. By assuming that total system delay is a close approximation of total idle time, TTI used the differences in modeled total system delay to estimate the delay savings associated with reducing a single incident for occurring at the location. As the exact vehicle fleet composition used in the simulation was not known, the TTI Evaluation Team also assumed that all vehicles impacted by each incident used a fuel consumption rate equivalent to that as a large sedan. Table 11 shows the potential fuel saving benefits based on estimated delay savings that would occur <u>if a crash did not occur</u> at the identified locations.

Table 11. Estimated Fuel Consumption Savings Generated by a Single Reduction in Crashes

Simulated Crash	Total Vehicle Hours of Delay (without Incident)	Total Vehicle Hours of Delay (with Incident)	Delay Savings (Vehicle Hours)	Fuel Consumption Savings* (gal)
Crash 1	102.9	154.8	51.9	20.2
Crash 2	57.1	60.4	3.3	1.3
Crash 3	633.4	934.2	300.8	117.3
Crash 4	58.1	73.6	15.5	6.0

* Assumes that all vehicles in the traffic stream are large sedans with a fuel consumption rate 0.39 gallons per hour of idle time.

Source: Texas A&M Transportation Institute, 2022

The results shown in Table 11 suggest that reducing the congestion caused by moderate lane-blocking crashes could generate a range of potential fuel consumption savings at these locations. For example, each time a CV application successfully kept a crash from occurring at Site #1, a total of 20.2 gallons of fuel (gasoline) could be saved. The amount of fuel consumption savings varies depending on where these crashes occur. Crashes on 1st and 2nd Avenues tend to have a greater impact on traffic than crashes on 5th and 6th Avenues. Obviously, to gain a better estimate of the fuel consumption, the modeling exercise would need to be repeated throughout the corridor. Also, to compute the total amount of fuel saved annually, one would need to know the potential number of crashes reduced annually at these locations.

This analysis assumes that the total vehicle hours of delay are equivalent to time spent idling. While this is not totally accurate, travel speeds in the network are low (the posted speed limit is 25 mph), and the fuel consumption rate at idle is a reasonable approximation for the fuel consumption rate traveling at low speeds. Furthermore, this analysis assumes that all vehicles in the traffic stream at these modeled locations are large sedans. Although the vehicle mix in Midtown is not 100 percent private automobile, TTI assumed that most vehicles traveling in Midtown have the fuel consumption rates of a full-sized sedan. This estimate could be refined if the NYC CVPD Team had reported delays by vehicle class.

Emission Benefits

TTI was unable to estimate the direct emissions benefit of the deployment because of the following reasons:

- The NYC CVPD Team did not report emission benefits resulting from its modeling activities.
- The data collection and obfuscation processes used by the NYC CVPD Team to protect privacy did not allow individual speed and acceleration trajectories to be developed for individual CV vehicles. If these data were available, TTI could have applied these speed and acceleration trajectories in an emission model, such as MOVES, to estimate the potential air quality benefits associated with the deployment.

The U.S. Environmental Protection Agency (EPA) developed a methodology for estimating greenhouse gas equivalencies for several types of energy consumed.(10) The methodology is based on the information contained in the preamble to the joint EPA/USDOT rulemaking on May 7, 2010, that states the two agencies agreed to use a common conversion factor of 8,887 grams of carbon dioxide (CO_2) emissions per gallon of gasoline consumed.(11) This conversion factor assumes that all the carbon in the gasoline is converted to CO_2.(12) Equation 2 shows how the greenhouse gas equivalents are computed using the conversion factor.

$$\text{Greenhouse Gas Equivalent } (CO_2) = \Delta\text{Fuel Consumption} \times 8.887 \text{ Kg of } CO_2/\text{gallons of gas consumed} \quad (2)$$

Using EPA's Greenhouse Emissions Calculator, TTI estimated the reduction in greenhouse gas equivalents because of the fuel consumption savings by eliminating one collision at each location. If the CVPD technology prevented just one collision at each of the locations, NYCDOT would reduce greenhouse gas emissions by approximately 1,287 Kg of CO_2.

Table 12. Estimated Reduction of Greenhouse Gas Emissions

Simulated Crash	Fuel Consumption Savings* (gal)	Greenhouse Gas Equivalent (Kg of CO_2)
Crash 1	20.2	179.5
Crash 2	1.3	11.6
Crash 3	117.3	1,042.4
Crash 4	6.0	53.3

* Assumes that all vehicles in the traffic stream are large sedans with a fuel consumption rate 0.39 gallons per hour of idle time.

Source: Texas A&M Transportation Institute, 2022

Chapter 5. Summary of Findings

This assessment examined the extent to which the NYC CVPD had produce environmental benefits. This impact assessment was conducted using data and information produced by the NYC CVPD *Connected Vehicle Pilot Deployment Program Performance Measurement and Evaluation—New York City Phase 3 Evaluation.*(3)

Improving safety was the primary objective of the NYC CVPD Team. The NYC CVPD Team did not deploy any applications designed specifically to improve mobility or reduce emissions or fuel consumption. Therefore, the NYC CVPD Team did not collect any direct performance measures from which the TTI Team could perform an assessment of the environmental impacts. As a result, TTI had to conduct the assessment based on indirect measurements of the environmental impacts.

The TTI Team used the mobility simulation to provide a high-level estimate of the potential environmental impacts associated with improved safety through the deployment. TTI theorized that the safety applications would reduce the number of crashes that occurred in the deployment area. Reducing the number of crashes would also reduce the amount of crash-related congestion and delays, which in turn could be used to estimate some of the environmental benefits associated with the deployment.

Using an existing microscopic simulation model of midtown Manhattan, the NYC Team conducted similar experiments to estimate the total system delay caused by four hypothetical crashes in the deployment network. Crashes were simulated by creating a 30-minute block at select locations. The NYC CVPD Team compared the result of these simulations to the results of simulating the same conditions except without a lane-blocking event. In the model, simulated drivers could dynamically alter their path to improve their travel times if one existed. The NYC CVPD Team did not allow the model to adjust signal timings in response to crash conditions. Also, the model did not allow traveler alerts to be issued asking drivers to avoid the area of the crash.

From the modeling results, the TTI Team estimated that by preventing collisions at each of the four hypothetical crash locations, the NYC CVPD Team would save 144.8 gallons of gasoline and reduce greenhouse gas emissions by 1,287 Kg.

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