Advancing Interoperable Connectivity Deployment: Connected Vehicle Pilot Deployment Results and Findings

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16. Abstract

In September 2015, the U.S. Department of Transportation (USDOT) Intelligent Transportation Systems (ITS) Joint Program Office (JPO) awarded three deployment sites under the Connected Vehicle (CV) Pilot Deployment Program to: the New York City Department of Transportation (NYCDOT); the Tampa Hillsborough Expressway Authority (THEA); and the Wyoming Department of Transportation (WYDOT). Each site planned, built, tested, deployed, and operated a tailored suite of CV applications addressing stakeholder-identified transportation needs in diverse systems, ranging from dense urban grid networks to isolated high-plains interstates. Safety, mobility, environmental, and public agency efficiency impacts of CV applications were assessed by both the sites themselves and independent evaluators. All three sites overcame significant technical and non-technical challenges to integrate still-maturing CV technology within their deployed transportation systems. Due to the limitations of working with emerging technologies, impacts for many applications were reduced. Despite these challenges, the program achieved key goals related to interoperability, cybersecurity, and replicability and demonstrated that CV technologies and foundational standards can be utilized to mount multiple large-scale operational deployments. This report serves as an entry point for readers seeking to understand the objectives, successes, and insights gained from the CV Pilot Deployment Program.

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Table of Contents

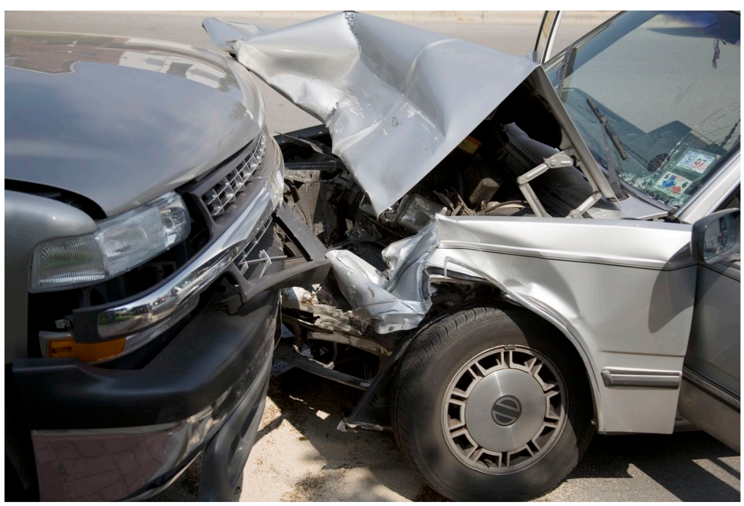
List of Figures

Chapter 1. Connected Vehicle Deployent Program Overview

In September 2015, the U.S. Department of Transportation (USDOT) Intelligent Transportation Systems (ITS) Joint Program Office (JPO) awarded funding to three deployment sites under the Connected Vehicle (CV) Pilot Deployment Program to: the New York City Department of Transportation (NYCDOT) [1]; the Tampa Hillsborough Expressway Authority (THEA) [2]; and the Wyoming Department of Transportation (WYDOT) [3]. Each site planned, built, tested, deployed, operated, and evaluated a tailored suite of CV applications addressing stakeholder-identified transportation needs in diverse systems, ranging from dense urban grid networks to isolated high-plains interstates. The three sites overcame significant technical and non-technical challenges to integrate still-maturing CV technology within their deployed transportation systems. This report serves as an entry point for readers seeking to understand the objectives, successes, and insights gained from the CV Pilot Deployment Program.

Motivation

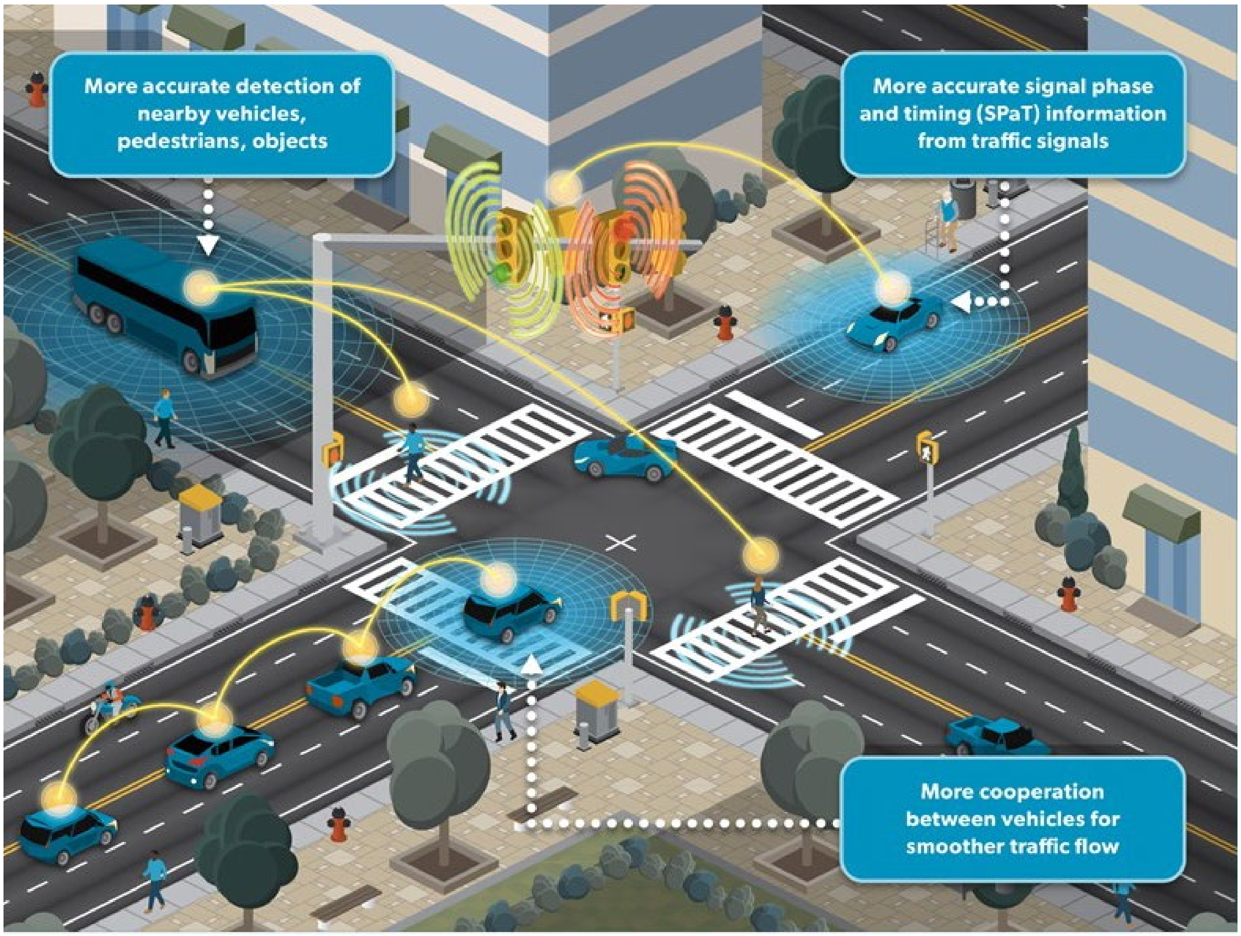
The ITS JPO's mission is to lead collaborative and innovative ITS research and development, and to implement ITS to improve the safety and mobility of people and goods. Prior to the initiation of the CV Pilot Deployment Program, there was an increasing trend in U.S. roadway fatalities, despite the DOT's safety programs. In 2012, before the DOT decided to launch the program, there were an estimated 5.6 million police-reported traffic crashes that resulted in 33,561 fatalities – an average of one fatality every 16 minutes [4].



Source: iStock

Figure 1. Vehicle Crashes Continue to be a Leading Cause of Death in the United States.

After decades of focusing on ways to survive a car crash using airbags, seat belts, and other countermeasures, recent decades have seen a shift in focus on ways to use technology to prevent crashes from happening in the first place. CVs are part of the larger concept where nearly everything will be fit with sensors and connected over networks to help monitor and control the environment. CV technologies enable vehicles, mobile devices, and roadway infrastructure to wirelessly exchange data and "talk" to one another. CVs encompass vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to- pedestrian (V2P) communications, collectively known as "V2X." When integrated into a vehicle, roadway infrastructure, or mobile devices, these technologies can deliver significant transportation safety, mobility, and environmental benefits.



Source: USDOT

Figure 2. Connected Vehicle technology offers a 360-degree awareness. *The CV technology's longer detection distance and ability to "see" around corners or "through" other vehicles helps CVs perceive threats sooner than most advanced crash-avoidance sensors, cameras, or radar can, and warn their drivers accordingly.*

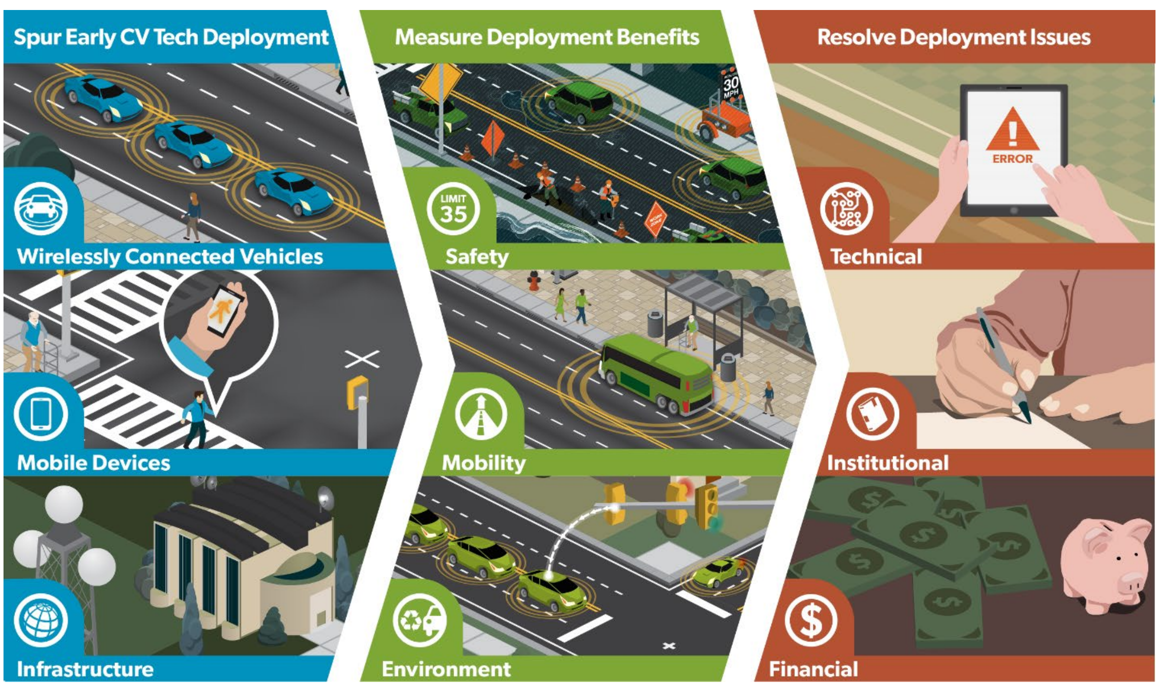
Program Background

The CV Pilot Deployment Program was launched in 2015 to improve safety and mobility by utilizing CV technologies. The CV Pilot Deployment Program built upon decades of related research and development in the public and private sectors. Key ITS JPO precursor efforts included the Safety Pilot Model Deployment (2013-2015) in Ann Arbor, Michigan demonstrating 10 Dedicated Short-Range Communications (DSRC)-based CV safety applications on 3,000 vehicles operating in real-world conditions utilizing integrated, retrofit, or aftermarket CV technologies. In parallel (2010-2015), the Dynamic Mobility Applications (DMA) Program developed and tested 21 CV mobility applications, and released publicly available documentation, open source code (in the ITS CodeHub) and supporting data sets to the broader ITS community. The Data Capture and Management (DCM) Program (2009-2014) developed, tested, and made available web-based resources tailored for ITS project data, including structured CV data (in the ITS DataHub [5]). Building from these efforts and parallel ITS JPO activity in the development of ITS Standards, the CV Pilot Deployment Program was conceived as an integrative effort to bring CV technology to the field to address specific safety and mobility issues of local concern.

Program Vision and Objectives

Below is the program vision (excerpted from the CV Pilot website [6]):

The program seeks to spur innovation among early adopters of connected vehicle application concepts using the best available and emerging ITS and communications technologies. The pilot deployments are expected to integrate connected vehicle research concepts into practical and effective elements, enhancing existing operational capabilities.



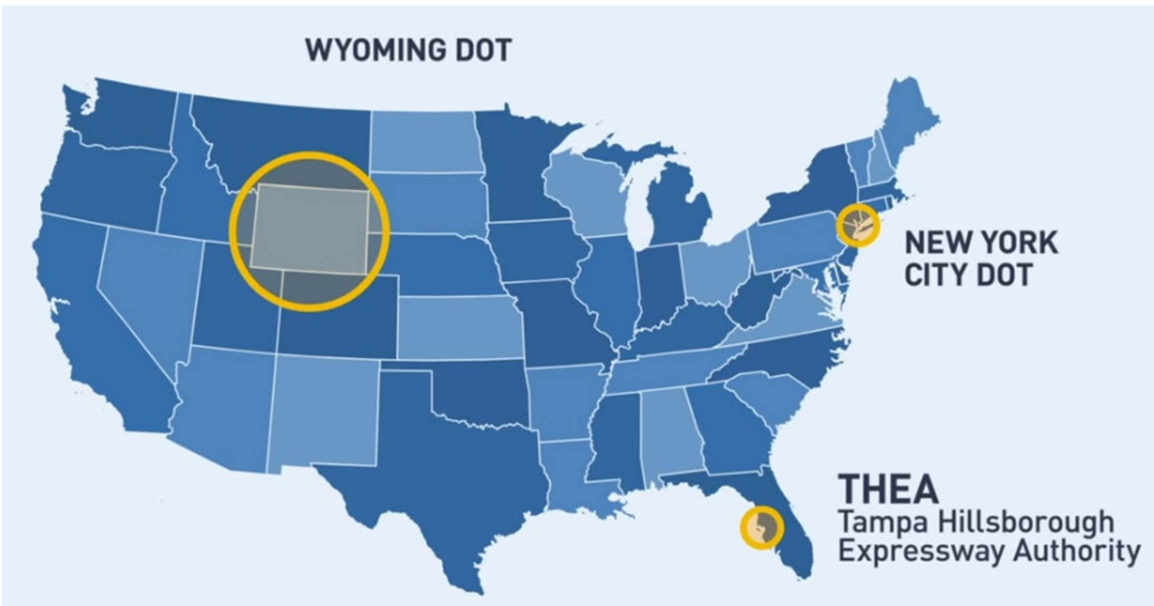
Source: USDOT

Figure 3. Program Objectives.

The program objectives, illustrated above, were to: (1) spur early CV technology deployment combining vehicles, mobile devices, connected infrastructure, and other elements; (2) target improving safety and mobility and environmental impacts and measure impacts; and (3) resolve deployment issues, including technical, institutional, and financial challenges [6].

Solicitation

A full and open Broad Agency Announcement (BAA) was issued in Spring 2015 after a nine-month outreach effort intended to inform potential bidders regarding the intent and nature of the upcoming opportunity. In September 2015, the government selected NYCDOT, THEA, and WYDOT to build, test, deploy, and operate CV technologies and applications addressing their local transportation concerns.

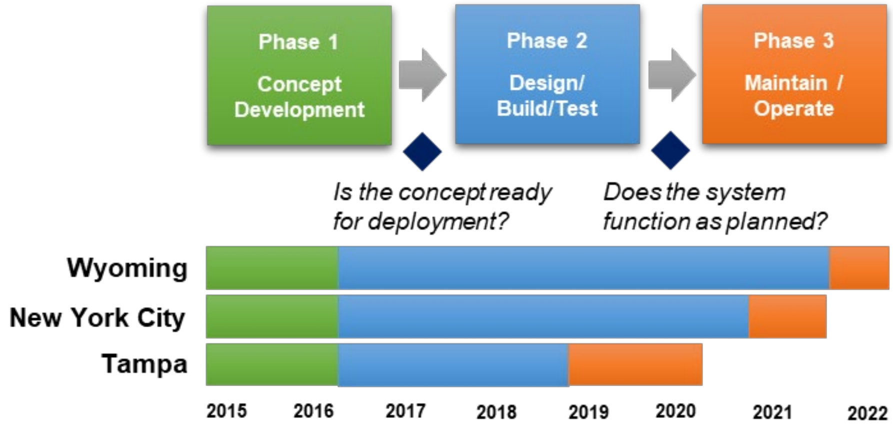


Source: USDOT

Figure 4. Map of the Connected Vehicle Pilot Deployment Program Awardees and Site Locations.

Program Schedule

The three deployment sites were expected to go through three distinct phases, with government go/no-go gates built in at the end of each phase. In Phase 1 (Concept Development), the three sites refined their concepts, identified requirements, and developed comprehensive pilot deployment plans. The program was able to assess the quality of each deployment site team based on Phase 1 deliverables. All three sites passed the Phase 2 gate at the same time and entered a Design/Build/Test phase of activity. When sites were able to demonstrate the deployed systems were safe and operated as planned (the Phase 3 gate) they entered the Maintain/Operate phase. Sites initiated Phase 3 according to their deployment readiness (2018-2021) and concluded all program activity 2020-2022. The intent of the phased program approach was to assist the USDOT in managing non-performance risk in the deployment sites.



Source: USDOT

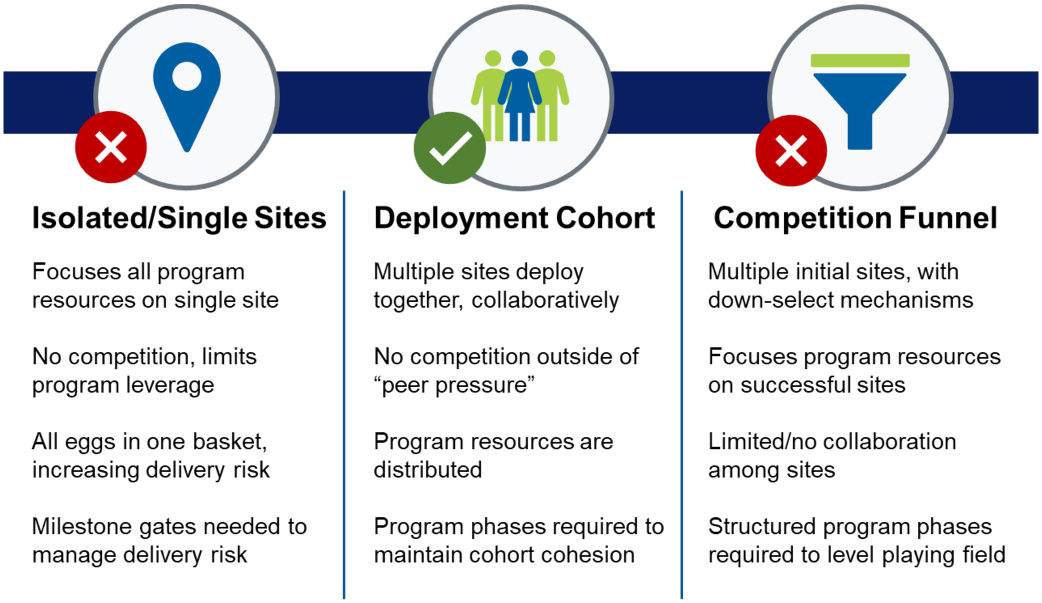
Figure 5. Connected Vehicle Pilot Deployment Program Phased Approach and Timeline.

Program Structure

The CV Pilot Deployment federal team was composed of staff drawn from the ITS JPO, FHWA Office of Operations, FHWA R&D, FTA, FMCSA, FHWA Resource Center, and FHWA Division Offices. CV Pilot Deployment Program Lead Kate Hartman directed the program, with Ms. Hartman, Jonathan Walker and Govind Vadakpat serving in Contracting Officer's Representative (COR) (Phase 1) and Agreement Officer Representative (AOR) (Phase 2-3) positions for each of the three sites. In addition, the team utilized a matrix structure with a federal Subject Matter Expert (SME) identified for key areas (e.g., systems engineering, performance measurement, data management, outreach). The federal team was augmented with contractor staff in roles related to technical and program support and independent evaluation.

The CV Pilot Deployment Program consciously attempted to instill a sense of collaboration among deployment sites. The phase-gating mechanisms were applied independently to each site. There was no downselect among deployment sites by phase. If a site could meet the terms of the phase gate, then it would progress forward, independent of the relative progress or strength of other sites. Observing that encouraging competition among deployers would inherently demotivate collaboration, the CV Pilot Deployment Program pursued a deployment cohort model. The program created recurrent venues for collaboration in the form of technical and other roundtables where sites shared challenges, insights, and solutions.

The Program's structure relied heavily on the systems engineering process to accommodate's each sites' unique size, features, and functionality. Following systems engineering best practices for large disparate systems helped the Program to reduce risks, minimize schedule delays, and avoid cost overruns.



Source: USDOT

Figure 6. Deployment Competition/Collaboration Models. *The CV Pilot Deployment Program adopted a Deployment Cohort model (middle) to systematically encourage cooperation and collaboration among sites, with each site seeking to meet the terms of phase decision gates.*

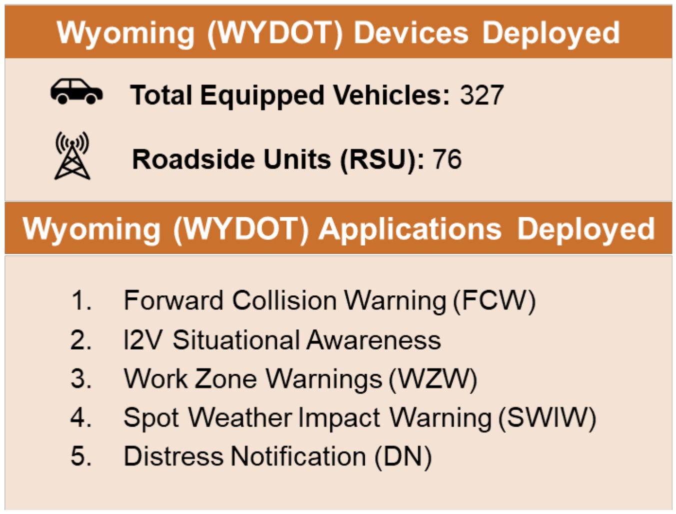
Chapter 2. CV Pilot Deployment Sites Summary

WYDOT Deployment

WYDOT manages Interstate 80 (I-80) in southern Wyoming. This roadway system, which is above 6,000 feet in altitude, is a major corridor for east/west freight movement and moves more than 32 million tons of freight per year. During winter seasons, crash rates on I-80 were found to be three to five times as high as summer crash rates. Persistent truck blow overs under high wind conditions in winter are a recurrent safety issue and can result in lengthy road closures. The WYDOT CV Pilot Deployment focused on the needs of the commercial vehicle operator with CV applications supporting a fleet of 327 CVs composed of commercial tractor/trailer combinations, snowplows, and highway patrol vehicles. A total of 76 RSUs were placed strategically along the 402-mile corridor to support work zone, truck parking, weather, and dynamic travel guidance as well as variable speed lane sections supplemented with CV-enabled forward collision warning applications. Additional details can be found at the WYDOT CV Pilot Deployment website [3].

Source: Wyoming Highway Patrol

Figure 7. Wyoming Deployment Site Challenges. *Severe weather and poor visibility on I-80 can result in multi-vehicle pileups.*



Source: USDOT

Figure 8. Wyoming CV Pilot – Devices and Applications Deployed.

NYCDOT Deployment

NYCDOT led the New York City deployment which aimed to improve the safety of travelers and pedestrians in the city through the deployment of CV applications. The deployment aligned with the city's Vision Zero initiative to reduce the number of fatalities and injuries resulting from traffic crashes. The NYCDOT CV Pilot Deployment project area encompassed four distinct areas in the boroughs of Manhattan and Brooklyn. NYCDOT's deployment provided an ideal opportunity to evaluate CV technology and applications in tightly spaced intersections typical in a dense urban transportation system. In such an environment, the "urban canyon" effect on Global Navigation Satellite System (GNSS) is a significant challenge for CV applications dependent on accurate positioning. The deployment featured a fleet of approximately 3,000 CVs composed of NYC government-owned vehicles (passenger vehicles, buses, trucks, and other vehicles). A total of 470 roadside units (RSUs) were deployed at signalized intersections, along FDR Drive, and other strategic locations to enable system management functions and support infrastructure-based enhanced positioning. The pilot also focused on reducing vehicle-pedestrian conflicts through in-vehicle pedestrian warnings. Additional details can be found at the NYCDOT CV Pilot Deployment website [1].

Source: NYCDOT

Figure 9. New York City Deployment Site Challenges.*In Manhattan, 73% of all crash fatalities involved pedestrians, compared to 14% nationwide* **[7]**.

New York City (NYCDOT) Devices Deployed

Total Equipped Vehicles: 3,000

Roadside Units (RSU): 470

Vulnerable Road User (Pedestrians) Devices: 5 **PED Detection System:** 10

New York City (NYCDOT) Applications Deployed

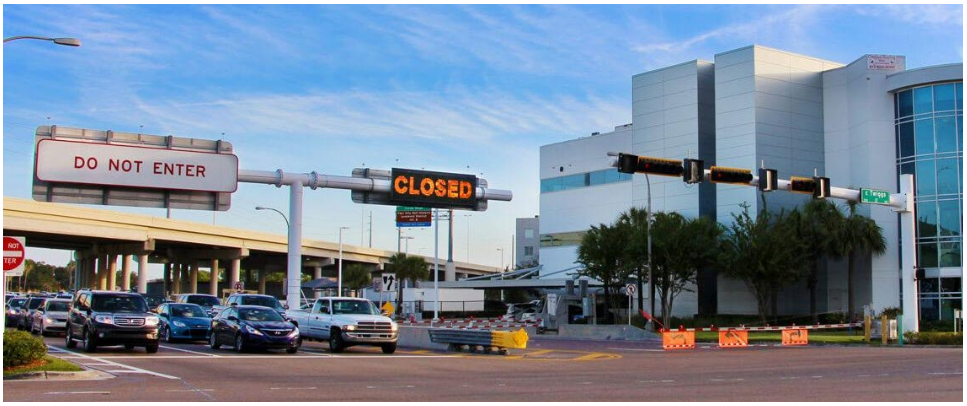
1. Speed Compliance
2. Curve Speed Compliance
3. Speed Compliance/Work Zone
4. Red Light Violation Warning
5. Oversize Vehicle Compliance
6. Emergency Communications and Evacuation Information
7. Forward Crash Warning (FCW)
8. Emergency Electronics Brake Lights (EEBL)
9. Blind Spot Warning (BSW)
10. Lane Change Warning/Assist (LCA)
11. Intersection Movement Assist (IMA)
12. Vehicle Turning Right in Front of Bus Warning
13. Pedestrian in Signalized Crosswalk
14. Mobile Accessible Pedestrian Signal System (PED-SIG)
15. Intelligent Traffic Signal System (I-SIGCVDATA)

Source: USDOT

Figure 10. New York City CV Pilot – Devices and Applications Deployed.

THEA Deployment

THEA owns and operates the Selmon Reversible Express Lanes (REL), a major route into and out of the downtown Tampa commercial business district. Peak period system delays often result in (or are caused by) frequent rear-end crashes where the REL facility intersects with the downtown Tampa surface street system. Further, because the Selmon expressway lanes are reversible, wrong way entries can occur with sometimes fatal consequences. The THEA pilot deployed CV applications to relieve congestion, reduce collisions, and prevent wrong way entry at the REL exit. The THEA deployment featured over 1,000 cars, 10 buses, and eight trolleys. Most of the equipped cars were personal vehicles of drivers who frequently traverse the REL and received a reduction in tolls as one incentive to participate in the deployment. A total of 47 RSUs were deployed along city streets. Additional details can be found at the THEA CV Pilot Deployment website [2].



Source: THEA

Figure 11. Tampa Deployment Site Challenges. *The downtown end of the Lee Roy Selmon Expressway's Reversible Express Lanes is a potential entry point for wrong-way drivers.*

Tampa (THEA) Devices Deployed

Total Equipped Vehicles: 1,035

Roadside Units (RSU): 47

Tampa (THEA) Applications Deployed

1. End of Ramp Deceleration Warning (ERDW)
2. Wrong Way Entry (WWE)
3. Pedestrian Collision Warning (PCW)
4. Emergency Electronic Brake Lights (EEBL)
5. Forward Collision Warning (FCW)
6. Intersection Movement Assist (IMA)
7. Vehicle Turning Right in Front of a Transit Vehicle (VTRFTV)
8. Intelligent Traffic Signal System (I-SIG)
9. Transit Signal Priority (TSP)

Source: USDOT

Figure 12. Tampa CV Pilot – Devices and Applications Deployed

Chapter 3. Meeting Program Goals: Spur Early Deployment

A primary goal of the CV Pilot Deployment Program was to spur early deployment of CV applications using the best available and emerging ITS and communications technologies. The program facilitated the planning, implementation, operation, and evaluation of CV technology in Tampa, New York City, and Wyoming. The program developed technical white papers on complex topics; organized collaborative roundtable discussions under three key areas (system design, build, and test; performance measurement and evaluation; and outreach); created a misbehavior detection capability to improve cybersecurity; and developed templates to ensure consistency, value, and usability of site deliverables.

Concurrently, the program disseminated technical, institutional, and financial lessons learned for the benefit of prospective CV planners and deployers [8]. The program also partnered with the CV Deployment Technical Assistance (CVDTA) Program to develop a series of knowledge and technology transfer materials over the course of the pilot deployments. The ITS JPO Professional Capacity Building (PCB) Program launched the Connected Vehicle Deployer Resources Library, which serves as a central location for resources intended to foster collaboration and enable early deployers to build and maintain interoperable connected vehicle deployments [9]. These resources are also available in the Smart Communities Research Center (SCRC) that was launched in 2023 [10].

Throughout the duration of the project, the USDOT identified several “shadow deployers,” including Virginia DOT, Iowa DOT, Colorado DOT, and City of Denver [11]. The shadow deployers, while not part of the CV Pilot Deployment Program, closely followed pilot deployment sites progress through published documentation and public webinars. The shadow deployers have reported these published reference documents to be good models for their CV development and planning efforts. The USDOT established an Early Deployer Cohort through the ITS Early Deployer Cohort Program (previously known as the CVDTA Program) that holds monthly roundtable discussions. The shadow deployers have been participating in these discussions to advance the state of the practice in deploying CV applications, including the ACTMTD grantees.

Chapter 4. Meeting Program Goals: Measuring Deployment Benefits

A second goal of the CV Pilot Deployment Program was to measure the safety, mobility, environmental, and public agency efficiency impacts associated with the deployments.

To measure the impacts of the deployments, the CV Pilot Deployment Program designed an evaluation framework that made use of self-evaluations by the three deployment sites as well as complementary evaluations by independent evaluators to minimize potential bias. The framework was designed to minimize technical risks due to lack of sufficient, valid data or potential non-performance by any of the players.

As part of the deployment, the three sites measured the performance of their respective deployments. Each site represented a diverse geographic and travel environment, each with its own needs regarding safety improvements and mix of deployed applications. The USDOT's Volpe National Transportation Systems Center conducted an independent safety impact assessment on the deployments, focusing on safety-related benefits and outcomes, while recognizing the limitations in making conclusive findings based on the available data. In addition, the overall independent evaluator, Texas Transportation Institute (TTI), engaged with each site to survey and gather subjective feedback from participants, site personnel and other stakeholders.

Safety Impacts. Performance reporting by the three sites showed certain CV applications resulted in measurable changes in driver safety behavior. For other applications, despite showing an improvement in driver situational awareness and response times, the limited quantity of non-obfuscated and valid data often resulted in an inability to make statistically significant conclusions. It is important to note that the safety applications deployed in the three sites were early deployment prototypes and performance of production-grade applications would be expected to be designed and tuned to provide drivers with a more robust experience, including a need for minimizing false positives or nuisance alerts.

Mobility Impacts. Statistically significant system-level mobility impacts were confounded by relatively small sample of CV-enabled vehicles. Another key factor that constrained the assessment of system level mobility impacts was the outbreak of COVID-19, which altered normal travel conditions at the pilot deployment sites. As a result, marginal system level mobility benefits were realized across all three sites. Contrary to the demonstrated ability of CV technology to improve vehicle travel, personal mobility applications (e.g., pedestrian collision warning) were not adequately evaluated due to technical implementation challenges emanating from GPS positioning issues.

User Satisfaction Impacts. The sites and independent evaluators sought to gauge participant and stakeholder perceptions such as improvements to safety from the pilot deployments. Driver satisfaction and acceptance of CV technology was mostly positive and freeway-based mobility applications were found to improve situational awareness related to road closures and weather conditions. Onboard CV applications demonstrated the ability to detect dynamic traffic conditions and deliver timely information to drivers to optimize their trips.

Public Agency Efficiency Impacts. Traffic Management Center (TMC) and public-sector staff found the CV-enhanced applications helped to improve their overall work efficiency. The CV Pilot Deployment showed the potential of CV technology to improve operational efficiencies through the depth and breadth of data that allowed agencies to effectively respond to changing traffic conditions within their jurisdictions.

Source: USDOT

Figure 13. CV Pilot Deployment Program – Key Impacts.

Chapter 5. Meeting Program Goals: Resolve Deployment Issues

A third goal of the CV Pilot Deployment Program was to identify and resolve key deployment issues, including technical, institutional, and financial challenges. The program identified some issues ahead of the deployment and tracked throughout (e.g., technical maturity of aftermarket CV technology) while others were wholly unanticipated (e.g., the COVID pandemic and related impacts on travel starting in March 2020).

Technical Maturity and Industrial Supply. In 2015, it was unclear that sufficient technology maturity and industrial supply were in place to support three concurrent large-scale deployments. This known and significant challenge was reflected in the program design as well as the provision of technical support to deployers. In addition, each site took steps to manage the technology risk. The NYCDOT pilot prepared detailed equipment requirements and shared with the vendor community prior to soliciting equipment; conducted detailed vendor testing and equipment assessment; and pursued a multi-vendor approach for roadside and in-vehicle technologies. The THEA pilot included vehicle and roadway industrial suppliers within the deployment team; and pursued a multi-vendor approach for in-vehicle technologies. The WYDOT pilot employed an open source/open architecture approach in systems design, particularly for data management.

In parallel, the USDOT pursued activities to assist in the systematic certification of CV devices including support for the development of a certification process for CV technologies. This led to the development of an independent, third-party certification process and the certification of vendor technologies. Certification processes were new and generally took more time and effort than sites had anticipated. Certification activities did, however, ensure compliance with standards, which assisted in program goals around interoperability.

Despite these efforts, the maturity of the delivered technologies varied. Some vendor-supplied equipment did not perform reliably. Extensive testing and parameter tuning were required for most applications, which were an added burden on pilot teams. Integration and testing of CV roadside and in-vehicle units had both cost and schedule impacts in all three sites.

Impact of COVID-19 Pandemic. The CV Pilot Deployment Program life cycle included the disruption to typical travel patterns resulting from the COVID-19 pandemic (starting in March 2020). At that point in time, the three sites were either in the final Operate and Maintain phase (Phase 3) or concluding the Design and Test phase (Phase 2). The pandemic did not significantly impact the deployment, testing, and operation of the site technology. However, the change in travel patterns created a significant and critical confounding factor, impacting the evaluation of safety and mobility impacts of the deployed CV applications. There was significant drop in overall vehicle travel, which was most pronounced in the NYCDOT and THEA deployments [12], [13]. The overall result on the CV Pilot Deployment Program was an increase in difficulty in identifying changes in system safety and mobility related to the deployment of CV technology. The pandemic also resulted in significant supply chain disruptions that impacted the

WYDOT pilot, who had to switch to another vendor to fulfill OBU orders when the primary vendor dropped out of the DSRC device business. This resulted in schedule impacts.

Emergence of Ride-Hailing Business Models. The emergence of ride-hailing services over the period 2015-2021 was an unanticipated challenge for the NYCDOT pilot. The NYCDOT pilot had initially planned for participation of 5,850 taxis in the pilot, as a part of an agreement with the New York City Taxi and Limousine Commission (TLC). As the pilot moved from planning into installation and testing, the impact of ride-hailing services created significant financial issues for the TLC, forcing them to leave the partnership.

Source: USDOT

Figure 14. NYC CV Pilot Deployment Site Fleet Make-up. *The pilot team expanded the number of city-owned vehicles to compensate for Taxi and Limousine Commission leaving the partnership due to significant financial constraints. The original expected total count of 8,000 vehicles was reduced to 3,000 vehicles.*

Changes in Wireless Communications Spectrum Allocation. In 1999, the Federal Communications Commission (FCC) allocated 75 MHz of radio spectrum in the 5.9 GHz band to be used for vehicle and infrastructure communications. As a result, this part of the radio spectrum was reserved specifically for transportation applications with two channels reserved for safety applications utilizing common wireless standards, DSRC. In 2017, a proposed rulemaking that would require all new vehicles to be DSRC-capable was abandoned. In 2020, perceiving an underutilized spectrum, the FCC issued a report and order releasing 45 MHz of the 5.9 GHz band to general (unlicensed) use and the remainder to safety-related vehicle and infrastructure communications (not exclusively DSRC) [14]. Existing FCC-issued DSRC-based licenses were no longer valid. More information on the history and current updates on the 5.9 GHz band can be found at a USDOT-maintained website [15].

During initiation of the CV Pilot Deployment Program, wireless connectivity through DSRC represented a viable but not singular option. For example, the WYDOT CV Pilot Deployment featured DSRC communications in combination with satellite communications. As the CV Pilot Deployment Program evolved from planning to design and test to operations, the underlying assumption about 5.9 GHz band being reserved for DSRC-based vehicle and infrastructure communications changed. All three sites were able to deploy, test, and operate their DSRC-dependent elements prior to the impact of the FCC report and order. However, each site had to make decisions related to continued operations of DSRC-dependent deployment elements.

Chapter 6. Insights

As a part of the program design to meet the high demand for technical insights, proven approaches, and measured impacts, the ITS JPO organized the CV Pilot Deployment Program around core principles of systems engineering and impact assessment. The program implemented an innovative, coordinated procurement strategy featuring templatized deliverables, leading to the creation of a significant body of documents [16], data sets [5], and other materials documenting technical approaches, insights, lessons learned, and measured impacts [8], available on the CV Pilot Deployment website. The program website has been the most-visited ITS JPO microsite over the last five years. In May 2019, datasets from the THEA and WYDOT pilots were among the top three datasets downloaded of all time from Data.Transportation.Gov.

This section presents a summary of key insights, drawn from the collective set of program documentation, to highlight key take-aways regarding the viability, impact, and potential of CV technologies.

Insights: Enabling Interoperability

A major long-term goal of the CV Pilot Deployment Program was for a nationwide deployment of CV technology. For CV technologies to operate as designed anywhere in the country, regardless of where they were built, they would need to be interoperable. Pockets of incompatible or non-interoperable CV technologies in different states and localities can become a critical barrier to a national-level rollout.

To this end, the deployment sites held collaborative roundtable discussions on the utilization and refinement of existing CV standards that at the time were inconsistent and lacking in sufficient maturity to enable sites to simply deploy without refinement and coordination. After significant collaboration, development, testing, and in-field tuning, an enhanced set of CV standards were found to be mature enough to conduct an interoperability test to assess: (1) interactions between different sites' onboard units (OBUs) and (2) interactions between selected OBUs and RSUs.

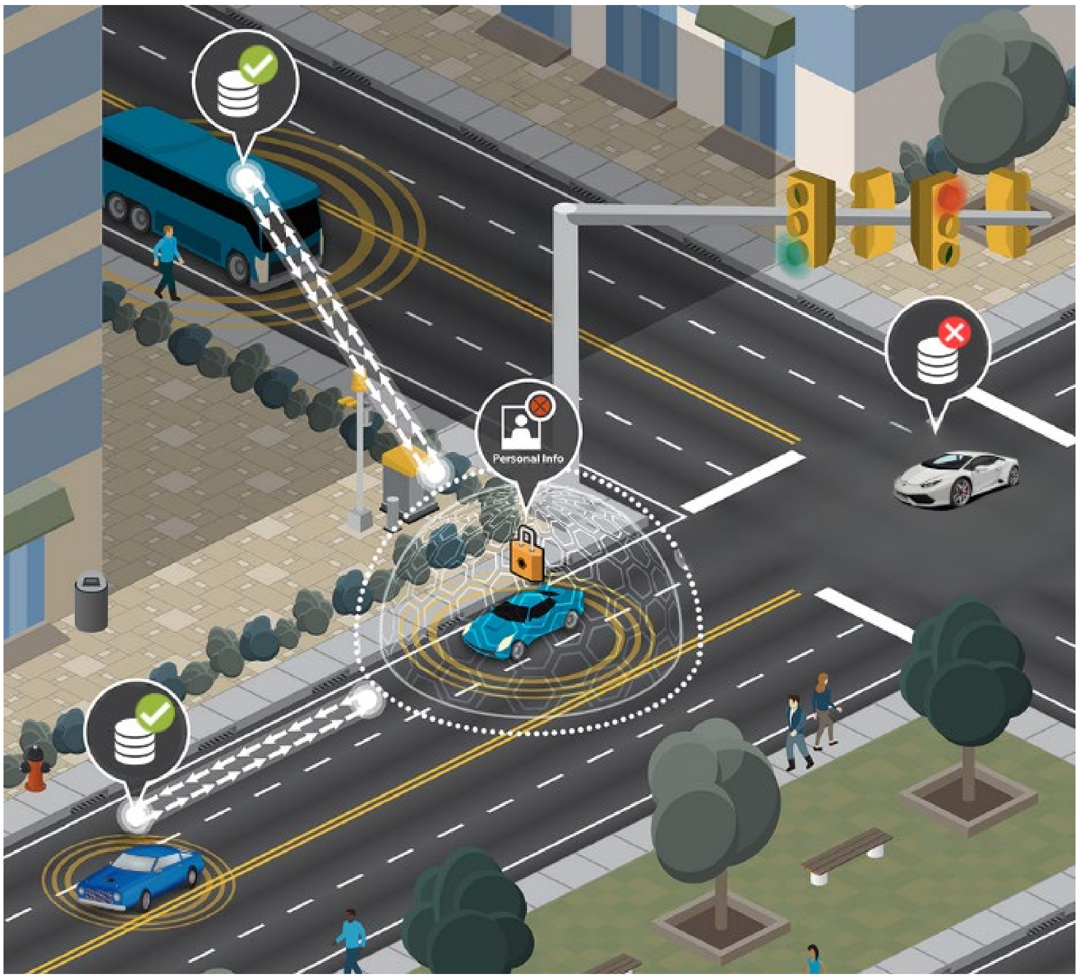
Over the course of the Program, the CV Pilot sites' experiences helped refine the following standards:

- SAE J2735 – V2X Message Set Dictionary
- SAE J2945/4 – Road Safety Message
- SAE J2945/B - Recommended Practices for Signalized Intersection Applications
- NTCIP 1218 – Object Definitions for Roadside Units (RSU)
- CTI 4001 – Roadside Unit (RSU) Standard
- CTI 4501 – Connected Intersections (CI) Implementation Guide
- ISO 19091 - Intelligent transport systems — Cooperative ITS — Using V2I and I2V communications for applications related to signalized intersections

In 2018, the sites worked with the USDOT and its support contractors to plan and conduct a successful Interoperability Test at Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia from June 26-28, 2018 [17]. The testing served to identify potential interoperability issues that would require resolution prior to the sites advancing to an operational phase of the CV Pilot Deployment Program later in 2018 [18]. The three-day testing event was a major victory for the Program, successfully demonstrating cross-site over-the-air interoperability among the six participating vendors.

Insights: Ensuring Cybersecurity

To ensure safety, security, and privacy of CV technologies, the USDOT and partners designed, developed, and tested a state-of-the-art security system, Security Credential Management System (SCMS), to ensure that users can trust in the validity of information received from other system users [19].



Source: USDOT

Figure 15. Security Credential Management System (SCMS). *The SCMS provides the mechanism for devices to exchange information in a trustworthy and privacy-preserving manner using digital certificates.*

The deployment sites utilized a single third-party SCMS supporting the isolation of potentially malfunctioning or compromised CV equipment in the system. The three sites were some of the first deployments to use devices fully connected to the SCMS and demonstrate feasibility of SCMS key concepts to include existence of capable SCMS providers. The Interoperability Test conducted in 2018 included the use of credentials from the supporting SCMS [17]. Prior to the test, all devices to be used were enrolled in the commercial "test" SCMS. As a result, the devices were able to use the credentials to sign messages being communicated with other devices including the Basic Safety Message (BSM). This was a significant achievement in several regards: helped to increase the familiarity with the SCMS for the sites as they worked toward real-world operations and bolstered the laboratory testbed team that provides support to other CV deployers.

The deployment sites captured lessons learned from their enrollment in the commercial test SCMS for the interoperability test [20]. For example, during the deployment, there were persistent issues across the three sites with security certificates expiring and many connected vehicles not being able to request new certificates to be topped off. This was degrading the operation and performance of OBUs and RSUs. To address this issue, the WYDOT pilot installed a firmware release on their RSUs to reduce error logging and slow log file size growth so that RSUs could resume normal processing of CV messages. The NYCDOT pilot implemented a weekly device monitoring and reporting mechanism for certificate top off success or failure and detection of issues with the SCMS interface. The pilot team also implemented a mechanism for tracking the cause of unsuccessful certificate updates. The THEA pilot preemptively decided during the design phase to download three years' worth of certificates to avoid having to periodically download certificates to vehicles.

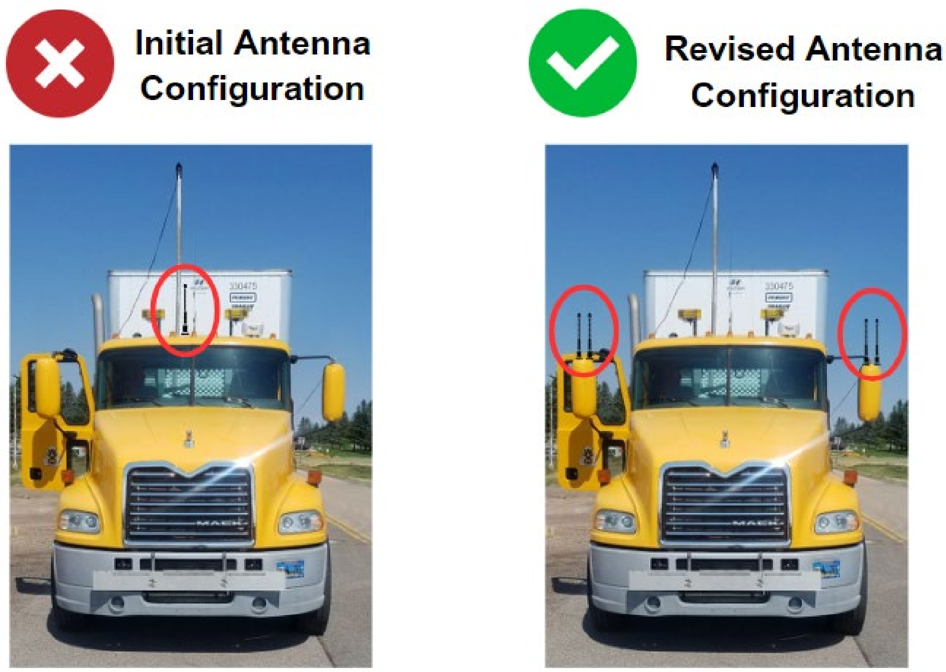
The sites also documented best practices based on their experience with an operational SCMS [21]. These documents are likely applicable to other agencies deploying connected vehicles devices, device vendors, and SCMS providers.

Insights: Deploying Wireless Communications

A key goal of the CV Pilot Deployment Program was to investigate best practices in field deployment of CV technologies, including communication media. While Dedicated Short Range Communication (DSRC) was required to be used for at least one application by all deployment sites, the sites were not limited only to DSRC communication. The deployment sites were encouraged to design systems that used multiple communication media to disseminate information to or collect information from vehicles. The deployment sites operated CV technologies using a variety of wireless communications media, including DSRC, satellite, and cellular. The sites overcame several challenges to successfully operate their systems.

Throughout the CV Pilot Deployment Program, CV technology deployers had all 75 MHz of the 5.9 GHz Transportation Band to utilize to support their communications needs. In total there were seven 10 MHz channels, with three channels reserved for safety applications. To ensure the V2V and V2I applications worked reliably, those identified as support applications for configuration and system management had to use a separate channel from the safety applications.

NYCDOT, who made use of only DSRC within their deployment, overcame challenges by planning the allocation of services across RSUs as they had many locations with multiple overlapping RSU coverage areas. During initial installations and testing, WYDOT discovered that improper antenna placement on a tractor-trailer was blocking signal broadcast and was able to resolve the issue [22].



Source: WYDOT, modified by USDOT

Figure 16. Wyoming Antenna Configuration for Trucks. *Under the initial configuration on the cab rooftop, the box trailer blocked the signal. Under the revised configuration, antennas were mounted on the side mirrors, improving line of sight for trailing vehicles.*

Frequency (GHz)	5.850	5.855	5.865	5.875	5.885	5.895	5.905	5.915 5.925
Channel	Guard Band	172	174	176	178	180	182	184
			175			181		
Usage		Chanel 172	Service Channel	Service Channel	Control Channel	Service Channel	Service Channel	High Power Public Safety Channel
WYDOT		V2V Safety, Distress Notification		SCMS, V2I Upload, Probe Vehicle Data	Service Advertisement, Traveler Information			
NYCDOT		V2V Safety, V2I Safety	SCMS I2V Download	V2I Upload	Service Advertisement, Traveler Information	V2I Upload	SCMS, I2V Download	
THEA		V2V Safety, V2I Safety		Personal Safety Message, SCMS, Signal Priority, Data Logs	Service Advertisement, Traveler Information, Roadside Alert	Data Logs	OTA File Broadcast	

Lower 45 MHz	(blue)
Upper 30 MHz	(green)

Source: USDOT

Figure 17. CV Pilots DSRC Channel Utilization. *The CV Pilot sites utilized all of the 10 MHz channels of the 5.9 GHz Transportation Band, with the exception of the high power public safety channel, in order to reliably support their communications needs.*

In 2013, the FCC allowed certain classes of devices to receive secondary licenses that would allow them to share the spectrum originally allocated for DSRC-based ITS applications on a non-interference basis. During testing of THEA pilot devices, the deployment team observed radio traffic on several DSRC channels planned for use in the pilot. The traffic impacted data exchange and back haul speed performance up to 50% degradation in data uploads. Using a detection equipment, the site determined a secondary licensed amateur radio, also known as HAM radio, operator was utilizing the spectrum and was able to resolve the interference [23].

To supplement areas with no DSRC coverage, WYDOT incorporated satellite communication to disseminate traveler information. As most smartphones do not use DSRC networks, THEA used WiFi to overcome the challenge of communicating with pedestrians via their smartphones. The THEA pilot developed an application that received messages from nearby RSUs through WiFi to enable safer intersection crossings.

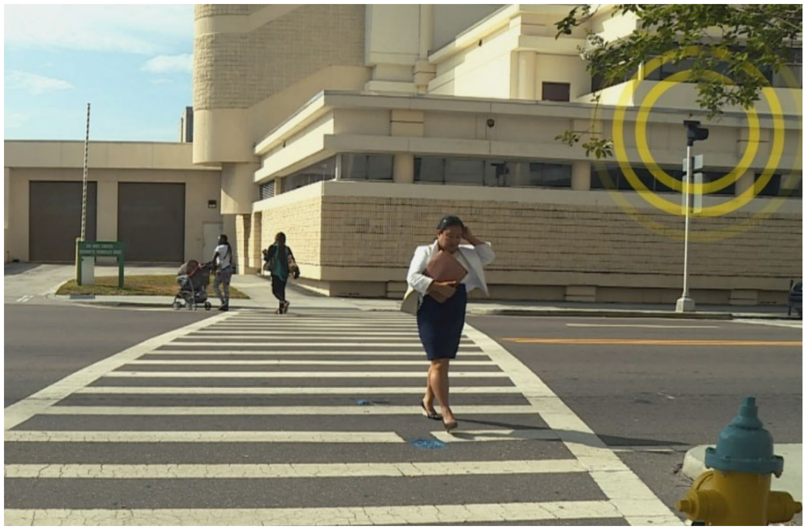
Insights: Improving Positioning Accuracy

Positioning accuracy is a key requirement of many CV applications. In dense urban environments, the “urban canyon” effect on Global Navigation Satellite System (GNSS) is a significant challenge for CV applications dependent on accurate positioning. Unfortunately, some vendor-supplied out-of-the box CV technologies did not meet these requirements.

During the interoperability test, sites noted that the devices’ GPS accuracy was often a factor in whether an alert was reported or not. After updating lane width configuration settings in the devices, alert consistency was greatly improved. All sites, but particularly the NYCDOT deployment, continued to develop innovative methods to improve positioning accuracy as a part of their deployment testing. The NYCDOT deployment area proved to be a challenging environment for GPS technology that is often limited to open sky. To improve the positioning accuracy of GPS technology, NYCDOT introduced a combination of techniques, including dead reckoning, CAN bus integration for speed information, Inertial Measurement Unit (IMU) integration, and RSU time-of-flight feature [23]. The augmented positioning accuracy allowed V2I and V2V applications to function safely and properly while the connected vehicles passed under bridges, through tunnels, and on elevated roadways.

Site experiences revealed that intersection geometry must be updated for accurate MAP message generation [23]. Onboard devices compare GPS location readings on the vehicle against the MAP message’s static intersection geometry data to determine a vehicle’s approach. Future deployments should verify that MAP data is properly coded and validated for vehicles to have an exact reference point within the intersection.

An initial demonstration of NYCDOT’s Mobile Accessible Pedestrian Signal System application in Manhattan using Personal Information Devices (PIDs) was unsuccessful due to the devices’ inaccurate GPS readings and frequent loss of satellite signals. To address these issues with PIDs, NYCDOT installed traditional ITS pedestrian detection equipment that utilized infrared cameras for the Pedestrian in Signalized Crosswalk Warning (PEDINXWALK) application to detect and inform RSUs at the intersection of the presence of pedestrians in the crosswalk. Similarly, during testing of THEA’s Pedestrian Crossing (PED-X) smartphone application, the mobile devices were unable to determine the pedestrian’s location and speed with sufficient accuracy (e.g., being unable to distinguish stepping into the street from standing on the sidewalk), leading to numerous false alarms. To correct this, THEA modified the vehicular side of the PED-X application to collect pedestrian location data from LIDAR sensors installed near the crosswalk that could provide more precise geo locations. GPS accuracies remain a major technical challenge. Supplemental devices or software may be needed for GPS accuracy correction. These location correction services must be thoroughly tested before deployment.



Source: THEA

Figure 18. Tampa LiDAR Detection.

Insights: Building Partnerships

Prior to 2015, the deployment readiness of key CV technologies (e.g., in-vehicle devices, roadside equipment) was unproven. CV technology had been tested as part of various research efforts and field operational tests. However, a proven deployment template for broad CV implementation nationwide did not exist.

The CV Pilot Deployment Program's success was due to the significant efforts made by the Program's federal, public, private, and academic participants. The federal team was composed of staff drawn from the ITS JPO, FHWA Office of Operations, FHWA R&D, FTA, FMCSA, NHTSA, FHWA Resource Center, and FHWA Division Offices. Consistent meetings established clear channels of communication within the federal team and ensured high team cohesion.

The federal team was augmented with contractor staff in roles related to technical and program support and independent evaluation. Acknowledging the significant technical (and non-technical) risks associated with large-scale deployment of unproven, emerging technologies, the CV Pilot Deployment Program prepared significant resources to assist sites. Federal and contractor staff provided insights and lessons learned on the implementation of systems engineering processes, the use and status of relevant ITS standards, performance measurement and evaluation best practices, and other technical and non-technical considerations. Technical support was also focused on key elements requiring collaboration among the sites, most notably interoperability and cybersecurity considerations.

The pilot deployments were complex, involving multiple jurisdictions, partner agencies, contractors, vendors, and other stakeholders. Sustained engagements between each site and their respective contractors, vendors, partners, and the public were critical to the success of the deployments. For example, a key challenge faced by the THEA pilot was in dispelling pre-conceived notions held by their stakeholders regarding safety and security issues [24]. Once they were educated, they were much better advocates for the pilot. The NYCDOT pilot had a similar approach. The NYCDOT pilot conducted several outreach activities at the beginning of the deployment, even with stakeholders not directly involved with the deployment to gain acceptance and buy-in for future CV deployments [25]. The NYCDOT pilot opined that collaboration played a critical role in the success of their deployment. Their stakeholders were committed to completing the deployment. When challenges arose, the stakeholders banded together to identify solutions. The WYDOT pilot noted that combining partnerships between different disciplines (e.g., vehicle crash expertise, weather expertise) enhanced their system development [26]. A key challenge the WYDOT pilot faced was in getting commitment from trucking partners since the equipment that was still not mature, needed to be retrofitted. They resolved the issue by recruiting additional trucking companies. The WYDOT pilot cautioned that continued outreach is needed even if partners might seem willing at the outset.

As CV technology was still maturing, the CV Pilot Deployment Program decided to organize and host a series of regularly scheduled roundtables to encourage the three deployment sites to discuss issues, challenges, and possible solutions. The idea was that the sites may be facing similar issues and better resolution could be found and progress made by working collaboratively rather than in isolation. Placing a structured emphasis on cooperation vs competition among the sites was effective in addressing many of the technical and operational challenges and ensured that mistakes were not repeated and solutions to common problems were identified.

Insights: Planning CV Deployment

During initiation, the CV Pilot Deployment Program identified several critical technical and non-technical challenges, including availability and reliability of CV equipment at required scale, maintaining sizeable fleets of CVs, addressing policy considerations including privacy protection of drivers and other road users, and developing, testing, and integrating multiple CV technologies to ensure safe, secure, interoperable, and effective deployment in real-world use cases.

The CV Pilot Deployment Program devised an innovative three-phase, two-gate program structure to mitigate these risks. The use of multiple phases firewalled federal monetary and technical support into three logical pieces, and the use of the phase gates provided the government with the flexibility to terminate engagement with sites demonstrating unsatisfactory progress.

Insights: Deploying Roadside Infrastructure

Efficient, reliable, and quality installations of roadside infrastructure is a key requirement of CV applications, especially for larger scale deployments. The sites collectively installed a total of 593 RSUs.

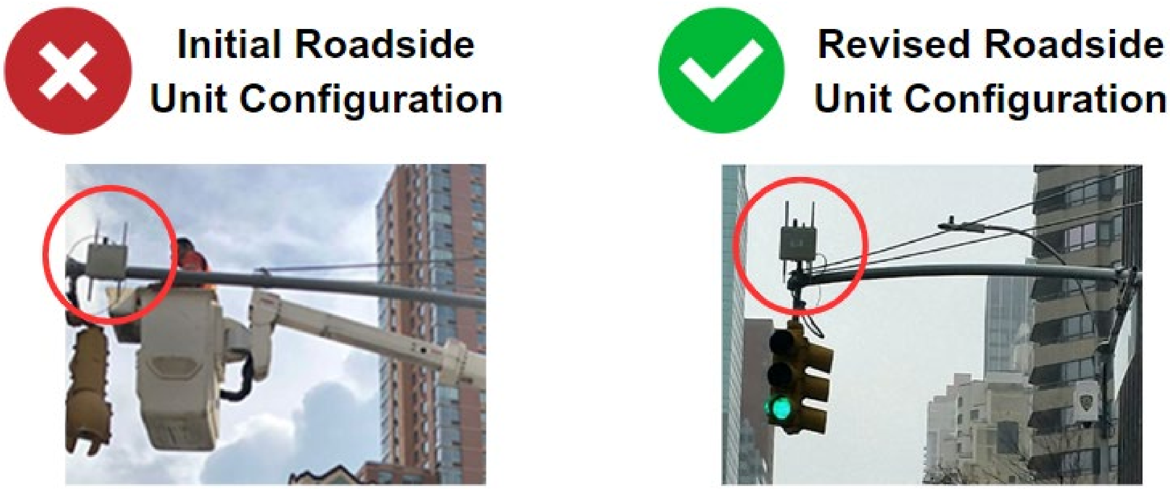
Source: WYDOT

Figure 19. Wyoming RSU Installation along I-80.

To ensure the RSUs were installed and functioning correctly and improve efficiency, the three sites developed detailed installation plans, and training videos for installers. The pilot sites made use of site visits and continuous remote monitoring to ensure uptime of the RSUs. The RSU locations were optimized to achieve clear line of sight, free of radio frequency (RF) signal path interference from trees, bridges, overpasses, and other structures.

The WYDOT pilot installed 76 RSUs along I-80. The pilot team developed detailed installation diagrams, instructions, and pre- and post-installation checklists for installers. The pilot team installed RSUs next to existing roadside infrastructure to take advantage of existing power, and communications equipment. Locations with no infrastructure were contracted out to local construction contractors, who were required to follow the installation checklists. The WYDOT pilot continuously monitored the installed RSUs for uptime. Any RSU that had issues were physically inspected for defects. The WYDOT pilot made use of a single vendor for DSRC-enabled RSUs. The vendor’s software had significant stability issues. When the vendor was unable to continue to support the deployment, the pilot decided to transition to a second vendor. As a result of their experiences, WYDOT staff recommended that future implementors consider multiple vendors.

The NYCDOT pilot developed an installation guide and videos for ensuring proper installation of 470 RSUs. Installers were instructed to not leave the installation site until thorough verification of the installation checklist and procedure. The NYCDOT pilot had to install several RSUs at signalized intersections. The team performed preliminary site inspections to select mast arm locations for the RSUs. These locations were selected to provide line-of-sight for approaches from every direction without altering the intersection’s existing poles, mast arms, and cabinet locations. Shortly after the prototype unit installations were complete, high winds caused a signal head to swing far enough to break an RSU antenna. As a result, an alternative installation method was sought. After several experiments, the NYCDOT pilot selected a vertically mounted extension that had several advantages. The potential for antenna damage was reduced. The additional height improved line-of-sight and reduced the impacts of other devices mounted on the mast arm. The time the installation crews needed to be in the air to attach the equipment was greatly reduced since the RSU and mounting devices were preassembled.



Source: NYCDOT, modified by USDOT

Figure 20. NYC Roadside Unit Configuration.*Under the initial configuration, the RSU was susceptible to damage by swinging signal heads. The revised vertically mounted configuration reduced potential for damage by swinging signal heads and improved line of sight.*

The THEA pilot installed 47 RSUs. The pilot team conducted a site survey of every infrastructure installation location, including an inventory of existing signal controllers, communications, cable conduit, optimum location for RSU antennas and lane marking geometry for MAP file creation. The THEA pilot, during a year of continuous testing, found that four of the forty-four installed RSUs were not communicating with the Master server. The team's investigations revealed that lightning strikes had damaged the RSUs due to improper grounding. The pilot team resolved the issue after replacing the RSUs and grounding them properly.

Insights: Managing CV Fleets

Installations of OBUs and ASDs, in vehicles is a key requirement for CV applications. Sustaining the performance of the devices after installation is critical for an effective deployment. However, this can be challenging especially when deploying the devices in large quantities.

Managing At Scale Installations. The WYDOT pilot had predominantly larger vehicles, including snowplows and freight/commercial vehicles, which presented unique installation issues [27]. The pilot prepared and tested for non-standard installation locations during the initial stages of the design phase. The pilot team conducted rudimentary installations for quick testing prior to permanent installations. These rudimentary installations revealed issues with the hardware, antenna, and HMI placement as well as interference with other devices. The WYDOT pilot made sure their vendor would be able to provide solutions to address any gaps in their existing products. During the permanent installation stage, the pilot team encountered additional installation issues with snowplows. The antenna had no clear line of sight when mounted directly to the roof as it was not the high point of the vehicle. The pilot team dealt with this issue by building a telescoping pole. The base of the antenna was magnetic, but the roof of the cab was not always metal, which was resolved by bolting the antenna to the roof. The antennas were hardened for weather. The pilot benefitted from durability testing done to ensure antennae mounting would support transmission and reception of information. Many freight fleets leased the vehicles. As a result, installations of any equipment that impacted the vehicle's original condition was discussed early on to ensure that the fleet owner/operator understood and approved the modifications.

Source: WYDOT

Figure 21. Wyoming OBU Installation in a semi truck.

To mitigate risk, the NYCDOT Pilot made use of two vendors to provide the required quantities of Aftermarket Safety Devices (ASD) in three delivery stages [28]. The initial delivery stage was of 100 prototype units for evaluation in the NYC environment. A second delivery consisted of 1,000 production units followed by a delivery of the remainder of the production units. Both vendors developed a web-based user-friendly Graphical User Interface (GUI) for installers. Installers were able to use the GUI for downloading BSM logs, upgrading software and firmware, configuring ASDs, and inputting vehicle parameters and antenna offset measurements. As the fleet vehicles were revenue generating vehicles, the installations were fine-tuned and refined during the prototype stage of the design phase for a smooth installation hand-over. For example, the ASDs with magnetic-mount antenna on the Metropolitan Transportation Authority (MTA) buses were not being able to withstand car washes and were breaking off. As a result, the pilot team explored the option of using older MTA bus models which were permitted to have holes drilled for installing the antenna.

Source: NYCDOT

Figure 22. NYC Antenna Installation on a City vehicle.

Source: Bus: MTA, others: NYCDOT

Figure 23. Sample of NYC Fleet Vehicle Types

The THEA pilot installed OBUs in roughly 1,000 private passenger vehicles, 10 buses, and 10 streetcars. THEA contracted Hillsborough Community College (HCC) to provide installation services for passenger vehicles [29]. Students at HCC were given an opportunity to expand their automotive knowledge while installing on participant vehicles as part of their training to become certified mechanics.

Source: THEA

Figure 24. Tampa OBU Installations Performed by Local Students.

Hillsborough Area Regional Transit (HART) supported the bus and streetcar installations. The THEA pilot used multiple antenna configurations depending on the vehicle type. For example, a streetcar requires two separate vehicle systems, as the streetcar can travel in either direction [30]. As the streetcars had wooden rooftops, special metal plates were added to provide proper grounding for the antennas. The antennas were checked to ensure they could operate successfully in close proximity to the high-voltage (640 volt) power line that provides power to the streetcars.

Over-the-Air (OTA) Updates. The deployment sites used OTA updates to ensure timely downloads of security certificates, application software updates, device firmware updates, and configuration parameters, and uploads of messages and log files by OBUs and ASDs. Calculating and testing OTA download speeds early in the design helped to identify issues and allow the deployment sites to work with their vendors on solutions. Once an update was ready, it was initially sent only to test groups for verification to prevent exposing every entity to newer or more significant issues. The sites deployed additional RSUs to enable partial downloads. For example, the NYCDOT pilot deployed approximately 130 RSUs to support OTA updates as well as for improving GPS positioning accuracy. Without the extra RSUs a complete full firmware download would not have been possible for the THEA pilot. The WYDOT pilot tested OTA updates at highway speeds and worked with their vendor to allow for uploads and downloads to occur over multiple RSUs.

Insights: Preserving Privacy

As privacy is an ongoing concern for the public, it was essential that the CV Pilot Deployment Program protected user privacy. This included ensuring that the vehicle information communicated did not identify the driver or vehicle and preventing the possibility of vehicle tracking.

To preserve the privacy of participants in the deployments, the sites used varied, innovative approaches. Although CV messages have privacy built-in by design, data needs for performance measurement and evaluation can violate the protection of user privacy. Keeping this in mind, the NYCDOT deployment team worked with their stakeholders, privacy experts, lawyers, the federal team, and the independent evaluators to develop methods to balance privacy preservation while still collecting sufficient data for performance measurement and evaluation. One such method was to obfuscate both time and location data from event records after removing all unique driver and vehicle identifiers [12]. This was done to prevent matching of a specific event record to other non-CV data that contained personably identifiable information (PII). The NYCDOT pilot factored in these privacy concerns early in the process as part of their system requirements. Additionally, access to different data sets varied between project stakeholders, the evaluators, and the public.

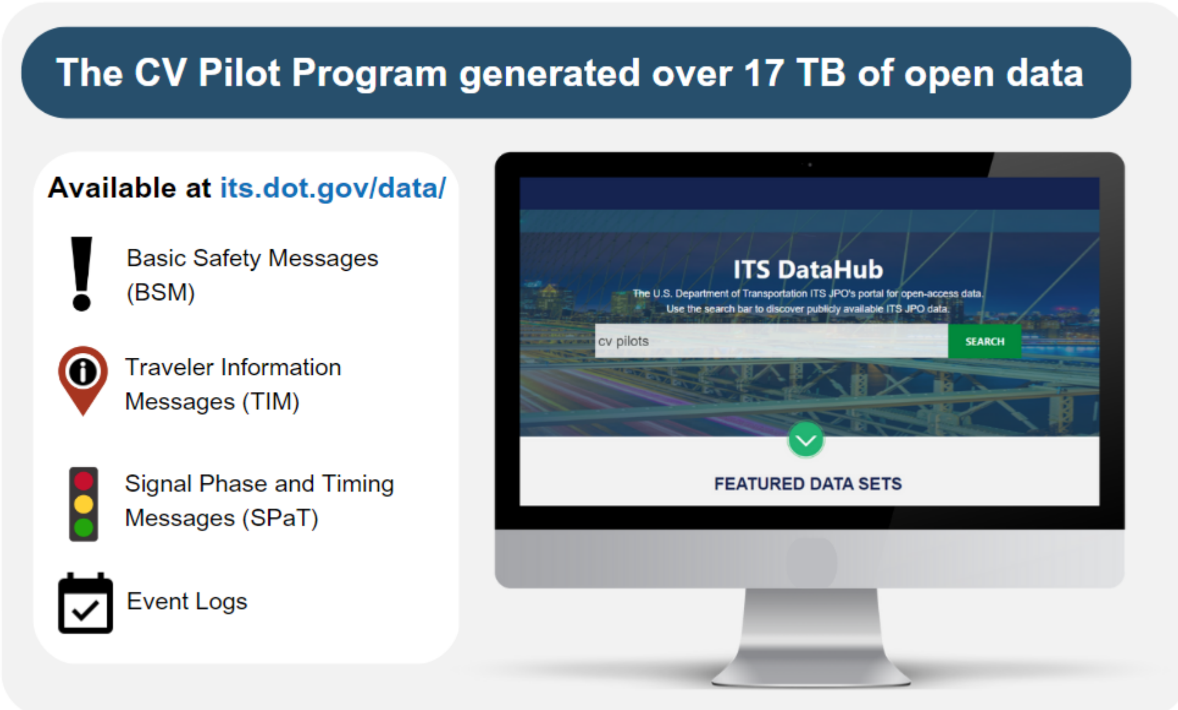
The THEA pilot processed and removed PII data prior to sharing it with the evaluators and the public. They geofenced the study area to eliminate all vehicle records that were outside of the cordon. All remaining records were assigned a new randomly generated identifier that remained constant over the study time frame to allow the independent evaluators assess the performance of their deployment [13]. The unique identifiers were removed prior to sharing the data with the evaluators via the Secure Data Commons and the public via the ITS DataHub.

The WYDOT pilot made use of two groups of vehicles. The “Friendly Fleet,” composed of vehicles from WYDOT, Trihydro Corporation, and Highway Patrol, could be identified using unique identifiers. The Partner CV Fleet, composed of vehicles from partners (e.g., trucking companies), were assigned dynamic identifiers and could not be tracked [26]. The WYDOT pilot shared the data containing the identifiers with the evaluators via the SDC. Data that was scrubbed of all identifiers was shared with the public via the ITS DataHub.

Insights: Managing Data

A key objective of the CV Pilot Deployment Program was to encourage the reuse of connected vehicle pilot data by the community for continued research and development of connected vehicle applications, while protecting personally identifiable information (PII).

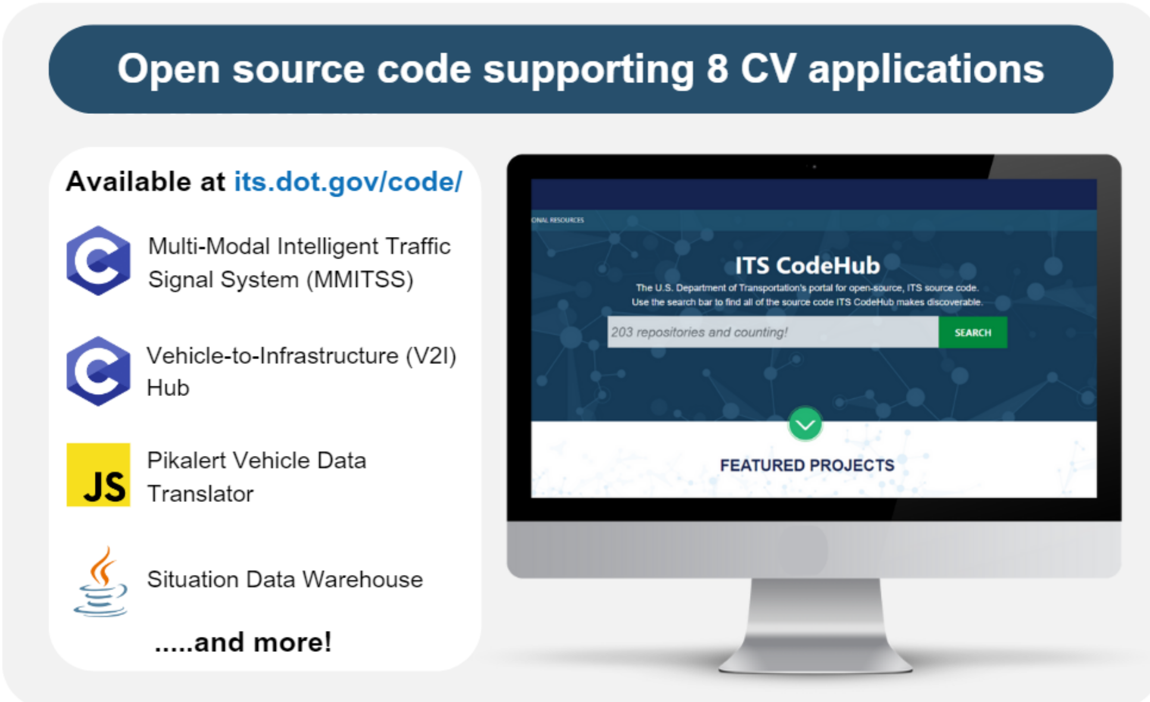
Sharing Data with Community. The CV Pilot Deployment Program partnered with the ITS Data Program to make sanitized and anonymized data from the sites available on a public-facing portal, ITS DataHub [5]. The WYDOT pilot shared BSMs and Traveler Information Messages (TIMs). The BSM and TIM data fields contain elements that follow SAE J2735 standard as well as additional contextual information specific to the WYDOT pilot. The THEA pilot shared BSMs, TIMs, and Signal Phase and Timing (SPaT) data. The BSM data fields follow SAE J2735 and J2945/1 standards, and the TIM and SPaT data fields follow the SAE J2735 standard. The NYCDOT pilot shared event logs, which contain a collection of relevant BSM, TIM, MAP, and SPaT messages, which follow the SAE J2735 standard. These were messages heard by the host vehicle immediately before and after a warning was issued to the driver. Time and location data were obfuscated and aggregated in day-of-week and time-of-day bins to obscure any individual event. A sample of the data from the pilots are also hosted on USDOT's public data portal at Data.Transportation.gov (DTG).



Source: USDOT

Figure 25. Available CV Pilot Deployment Program Data on ITS DataHub. *The CV Pilot Deployment Program shared over 17 TB of open data, free of personally identifiable information, with the community.*

Leveraging CV Pilot Data Beyond Pilots. The WYDOT pilot collaborated with Trihydro to make the pilot data housed in the Situation Data Exchange (SDX) available to drivers, who were not part of the pilot, through an Alexa Skill. Trihydro developed a Traveler Information Skill, which uses the SDX to identify the conditions along a route. During interstate travel, drivers can ask the Alexa Skill about road conditions from their existing location to a destination city. The Traveler Information Skill queries the SDX for TIM messages corresponding to the driver's route, and relevant results are read back to the user.



Source: USDOT

Figure 26. Available CV Pilot Deployment Program Code on ITS CodeHub. *The CV Pilot Deployment Program shared open source code supporting 8 CV applications.*

Insights: Driver Response/Impact

A key hypothesis of the three pilot deployments was the ability to improve driver situational awareness through targeted and timely alerts and messages delivered to equipped vehicles through their OBUs.

The WYDOT pilot generated over 412 million BSMs and 635,000 driver alerts [31]. Most of the driver alerts consisted of TIMs, which were sent from the Traffic Management Center (TMC) to the RSUs and to equipped vehicles through satellite. The TIMs delivered relevant downstream road and weather condition information to drivers along I-80 in Wyoming. Without the CV deployment, these CV drivers would have been limited to a few sources of near-real-time travel information (e.g., dynamic message signs, posted speed limits, Highway Advisory Road, etc.) that may not have been timely or comprehensive enough to aid them in tactical and strategic driving decisions. The CV-enhanced traveler information improved driver situational awareness and enabled drivers and freight operators to make well-informed trip decisions enroute as well as prior to departure. An example of the benefit of improved driver situational awareness involved a CV driver who experienced high winds while traveling westbound on I-80. As wind-related decelerations increased to their extreme maximums, the driver received a high wind warning alert. He was able to slow down more rapidly and pull off the Interstate and stop for safety.

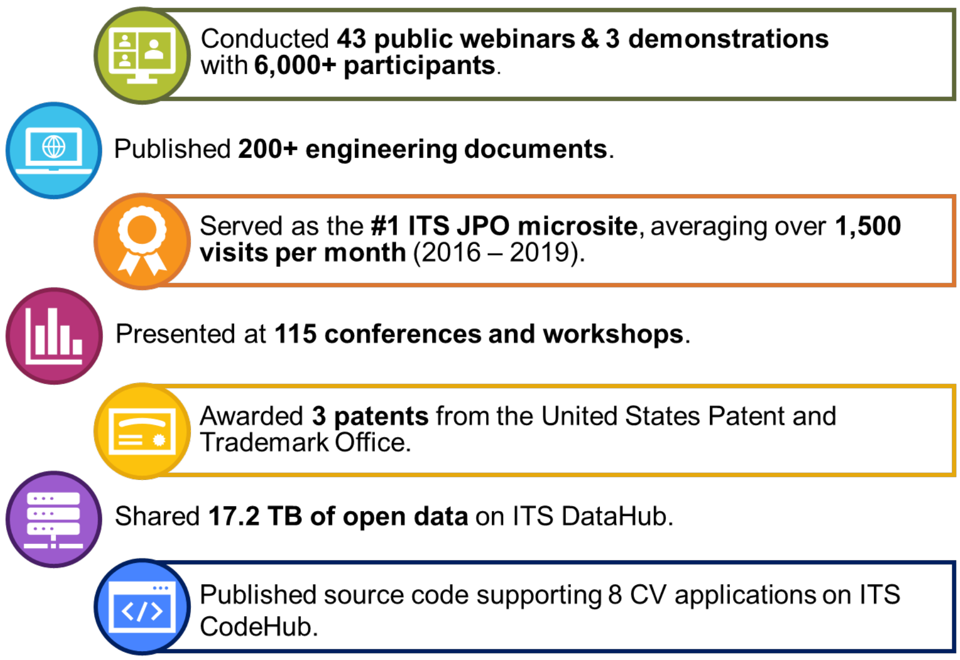
The NYCDOT pilot deployed three types of speed limit compliance applications, including Speed Compliance, Curve Speed Compliance, and Speed Compliance in Work Zone, to improve driver situational awareness and ultimately improve speed limit compliance. All three applications were found to be effective in improving driver situational awareness and speed limit compliance for CV drivers compared to non-CV drivers. For example, with the Speed Compliance application, there was a reduction of more than 47 speed limit violations per 1,000 events among CV drivers receiving speed limit alerts. Vehicles receiving speed compliance warnings decelerated faster (0.148 m/s^2 extra deceleration) and took less time (0.619 seconds less time) to reach compliance than vehicles that did not receive warnings.

Certain CV safety applications improved driver responses in braking situations. In the NYCDOT pilot, drivers given a Red-Light Violation Warning started braking by a statistically significant 0.4 seconds faster and were associated with a 0.137 m/s^2 greater deceleration rate. Intersection Movement Assist warnings resulted in a statistically significant 1.3 s faster driver brake reaction time. Emergency Electric Brake Light (EEBL) warnings resulted in drivers braking earlier by a statistically significant 0.4 seconds. In the WYDOT pilot, a limited safety impact analysis showed that drivers given a Forward Collision Warning (FCW) reduced speeds within 3 seconds by at least 5 mph in 85% of the cases examined.

Chapter 7. Program Contributions

USDOT investment in CV Pilot Deployments significantly advanced the maturity of CV technologies through a series of well-designed actions, including:

- Creating a collaborative environment among deployment sites to resolve technical issues.
- Contributing to CV standards and device certification testing process.
- Developing open-source tools and code.
- Generating near real-time data.
- Identifying safety band interference issue.
- Evaluating deployment benefits and impacts.
- Creating lessons learned for the next generation of deployers



Source: USDOT

Figure 27. CV Pilot Deployment Program - Outputs by the Numbers.

The CV Pilot Deployment Program demonstrated that CV technologies and foundational standards can be utilized to mount multiple large-scale operational deployments. While some standards utilized in the deployments were impacted by recent FCC decisions, the three successful deployments are still relevant. The deployment sites had to overcome multiple technical and non-technical barriers to build, test, and successfully operationalize complex multi-application CV designs. Significant work was required given the nature of early CV technology, a reliance on aftermarket suppliers, and the lack of proven methods and approaches in the protection of privacy, cybersecurity, and interoperability.

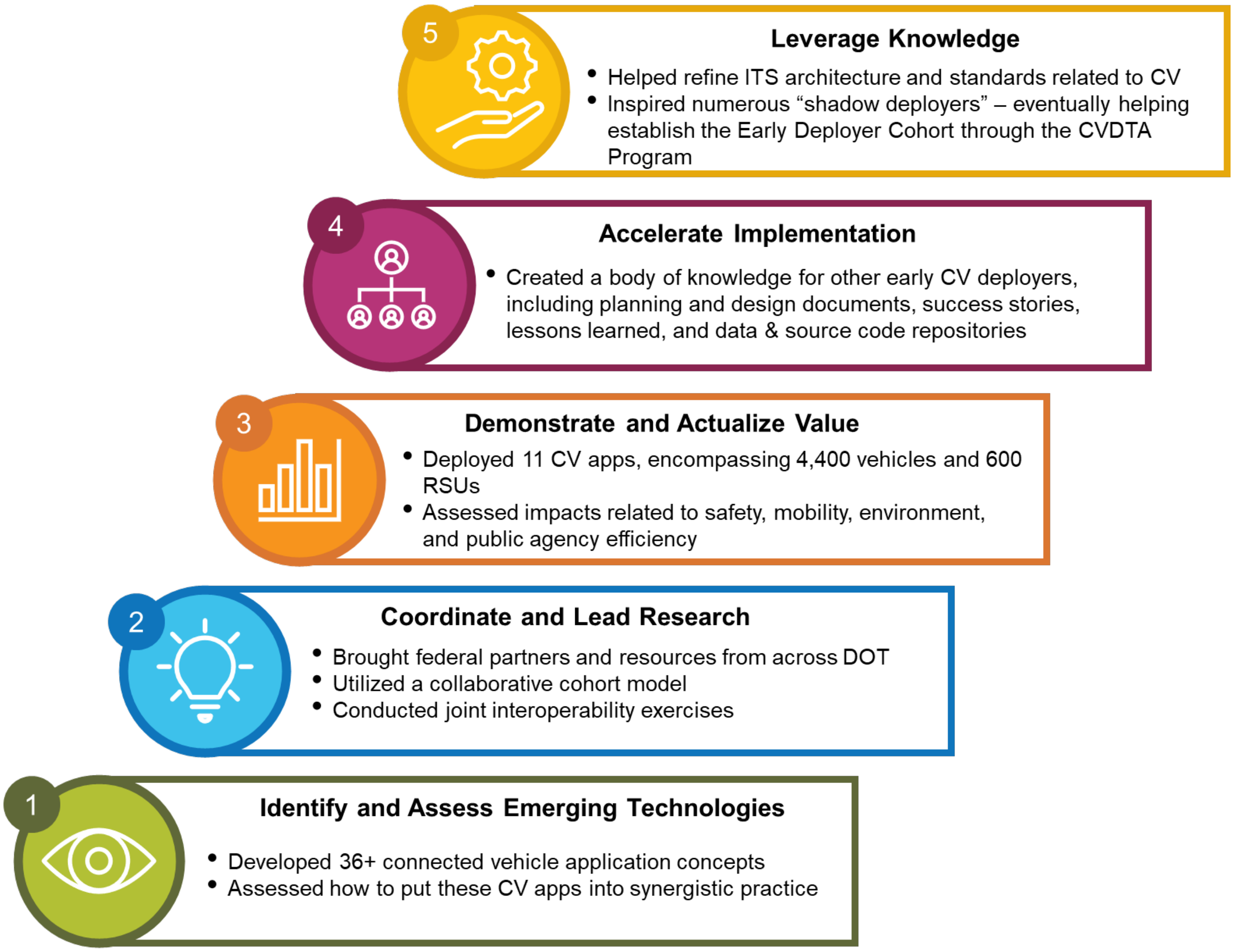
Further, the program achieved key goals related to interoperability, cybersecurity, and replicability. Through the utilization and coordinated refinement of existing standards, the program delivered a first-of-its-kind interoperability demonstration among in-vehicle and roadside technologies deployed in all three sites. The test was a capstone activity for the program as well as USDOT investments in CV standards development. The program delivered a sizeable and detailed body of systems engineering documents and other publications that remain among the most viewed and downloaded ITS JPO resources, helping other early deployers plan and design their projects.

Among the portfolio of deployed CV applications, some CV applications demonstrated safety impacts on driver behavior, while some CV applications demonstrated mobility impacts related to improved agency situational awareness. Other CV applications in the deployment portfolio were less successful because of technical issues, including issues with invalid alerts resulting from positioning errors. The deployments did not field enough CVs to provide statistically supported evidence that CV technologies deployed at sufficient scale, could make significant system-level safety and mobility impacts.

CV technology, particularly when paired with connected infrastructure to address specific problems, has a demonstrated potential to improve both road user safety and system efficiency. Applications building from or inspired by successful elements of the deployments may have a role to play on the nation’s roadway system in reducing crashes and fatalities while improving system productivity. Experiences gained from deployment concepts provide invaluable insights for wider scale deployment possibilities. As a result, CV technologies will continue to be developed and integrated into the nation’s roadway system. The USDOT has a critical role supporting the exploration of safety, security, and interoperability of next generation of CV technologies. This role includes attention to the systems created linking connected vehicles, connected roadway infrastructure elements, and road user mobile devices.

However, uncertainties around wireless communication and standards makes an immediate national-level rollout subject to significant technical, operational, and financial risk. The 2021 FCC Report and Order related to the 5.9 GHz spectrum and applicable standards has had an impact on all CV technology stakeholders, ranging from aftermarket and OEMs/suppliers of roadside and/or in-vehicle CV applications, IOOs, and fleet managers, among others.

Most critically, the USDOT can play a lead role in demonstrating how CV technologies may be maintained, converted, or deployed in an operational environment no longer characterized by access to extensive dedicated spectrum and the body of DSRC standards. Two of the three CV Pilot Deployment sites (THEA and WYDOT) are re-engineering successful elements of their CV deployment to comply with FCC regulation. Such efforts are emblematic in the encouragement of continued development of a more robust, interoperable, and mature CV technology base. There is a risk that the national-level rollout of more mature CV technologies may be significantly delayed without federal engagement. A critical risk is the emergence of multiple pockets of incompatible or non-interoperable CV technologies across the nation.



Source: USDOT

Figure 28. CV Pilot Deployment Program Contributions.

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