ITS DEPLOYMENT EVALUATION

Executive Briefing


Source: USDOT

Connected Vehicle Pilot Deployment Program (2024 Update)

Highlights

- In June 2018, the three Connected Vehicle Pilots successfully demonstrated cross-site over-the-air interoperability among six participating vendors.
- Following a 12+ month operational period for each of the CV Pilot sites, impacts related to safety, mobility, environment, and public agency efficiency were demonstrated and assessed.

Introduction

Connected vehicle (CV) technology, which enables vehicles to communicate with surrounding vehicles, infrastructure, and vulnerable road users, is poised to transform our streets, communities, and personal lives. But first, we must tackle deployment challenges head on and provide interested regions with examples of success stories and champions. The U.S. Department of Transportation (USDOT) took on this challenge by investing in the CV Pilot Deployment Program. The Program served not only to accelerate deployment of CV but also to uncover how to address barriers to deployment as USDOT embraces a future connected ecosystem enabled by Vehicle-to-Everything (V2X) technology.

In September of 2015, USDOT selected New York City Department of Transportation (NYCDOT), Wyoming Department of Transportation (WYDOT) and Tampa Hillsborough Expressway Authority (THEA) as the recipients of a combined $45 million in federal funding to implement a suite of CV applications and technologies tailored to meet their region's unique transportation needs. These pilot sites served to help connected vehicles make the final leap into real-world deployment so that they can deliver on their promises of increasing safety and improving mobility. These sites laid the groundwork for even more dramatic transformations as other deployers followed in their footsteps [1].

The sites conducted the pilots in three Phases. Under Phase 1, the sites spent 12 months preparing a comprehensive deployment concept to ensure rapid and efficient connected vehicle roll out. This included identifying specific performance measures and capabilities associated with performance monitoring and performance management.

> *Asked if this technology is the most exciting thing in his 30-year career, "I would definitely say so, definitely. This is game changing [2]."*
> *– Mohamad Talas, NYCDOT*

This brief is based on past evaluation data contained in the ITS Databases at: www.itskrs.its.dot.gov. The databases are maintained by the U.S. DOT's ITS JPO Evaluation Program to support informed decision making regarding ITS investments. The brief presents benefits, costs and best practices from past evaluations of ITS projects.

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In Phase 2, the sites each embarked on a 3-5 year process to design, build, and test a complex and extensive deployment of integrated, wireless technologies deployed in-vehicle, on mobile devices, and via roadside infrastructure. In Phase 3, the tested pilot deployment applications and technologies were placed into operational practice, where the safety, mobility, and environmental impacts of the deployments were monitored and reported on a set of key performance measures.

The **Wyoming Department of Transportation (WYDOT)** CV Pilot focused on the efficient and safe movement of freight through the I-80 east-west corridor, a critical corridor for commercial heavy-duty vehicles moving across the northern portion of our country. The pilot aimed to address the needs of commercial vehicle operators in the State of Wyoming and developed applications that use vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) connectivity to support a flexible range of advisory services including roadside alerts, parking notifications and dynamic travel guidance. This WYDOT CV Pilot sought to reduce the number of blow-over incidents and adverse weather-related incidents (including secondary incidents) in the corridor to improve safety and reduce incident-related delays. WYDOT developed systems that supported the use of CV Technology along the 402 miles of I-80 in Wyoming. WYDOT equipped approximately 325 vehicles, a combination of fleet vehicles and commercial trucks, with on-board units (OBUs). The 325 equipped vehicles included nearly 170 heavy trucks that were regular users of I-80 and over 150 WYDOT fleet vehicles, snowplows and highway patrol vehicles.

Figure 1: A member of the WYDOT installation crew installs the onboard units (Source: WYDOT).

The **New York City Department of Transportation (NYCDOT)** led the New York City Pilot, which aimed to improve the safety of travelers and pedestrians in the city through the deployment of V2V and V2I connected vehicle technologies. NYCDOT's deployment provided an ideal opportunity to evaluate connected vehicle technology and applications in tightly spaced intersections typical in a dense urban transportation system. The NYCDOT CV Pilot Deployment project area encompassed three distinct zones in the boroughs of Manhattan and Brooklyn. Approximately 3,000 City fleet vehicles that frequent these areas were outfitted with the CV technology, along with 12 Metropolitan Transit Authority (MTA) buses. As a city bustling with pedestrians, the pilot also focused on reducing vehicle-pedestrian conflicts through in-vehicle pedestrian warnings. An additional V2I/I2V project component equipped approximately 25 visually

Figure 2: NYC's mobile pedestrian application being tested at the confined Safety City lot in Manhattan (Source: NYCDOT).

challenged pedestrians with personal devices that provide audible alerts to orient them and assist them in safely crossing the street at signalized intersections.

The **Tampa Hillsborough Expressway Authority (THEA)** CV Pilot employed innovative V2V and V2I communication technology to improve safety and traffic conditions in downtown Tampa. The pilot sought to address peak rush-hour congestion in downtown Tampa, reduce the risk of collisions by detecting and warning wrong-way drivers before they get on the expressway, enhance pedestrian safety at signalized intersections, and provide transit signal priority to help keep buses on schedule. Additionally, the pilot aimed to reduce conflicts by deploying wireless communication devices onto streetcars, enabling communication with other connected vehicles and pedestrians. The THEA CV Pilot employed CV technology to enable transmissions among approximately 1,000 cars, 7 buses, and 8 trolleys. To support this initiative, THEA worked with their primary partners, The City of Tampa (COT), Florida Department of Transportation (FDOT) and Hillsborough Area Regional Transit (HART) to create a region-wide Connected Vehicle Task Force.

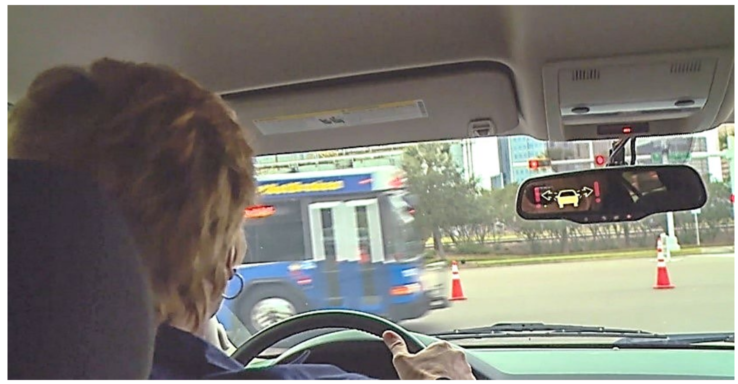

Figure 3: A driver of a Tampa-connected vehicle receives a side collision alert in the vehicle's rearview mirror (Source: THEA).

Benefits

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 pilot sites as well as complementary evaluations by independent evaluators. The USDOT's Volpe National Transportation Systems Center conducted an independent safety impact assessment of the deployments, while Texas Transportation Institute (TTI) engaged with each site to survey and gather subjective feedback from participants, site personnel and other stakeholders related to mobility, environmental, and public agency efficiency impacts. Key findings from the Program are summarized in Table 1.

Table 1: Select Benefits from the Connected Vehicle Pilot Deployment Program

CV Pilot Site	Goal Area	Finding
WYDOT	Safety	The evaluation found that 50 percent of drivers given a work zone or winter weather warnings reduced their speeds. (2023-B01735).
WYDOT	Safety	Drivers reduced speed within 3 seconds of receiving a Forward Collision Warning (FCW) for 85% of FCW events [3].
NYCDOT	Safety	Red Light Violation Warning reduced red-light running by 41% (2022-B01691).

CV Pilot Site	Goal Area	Finding
NYCDOT	Safety	Lane Change Warning reduced unsafe lane change rate by 46% (2022-B01691).
NYCDOT	Safety	Curve Speed Compliance alerts reduced average speeds by 8.75 mph (2022-B01650).
THEA	Safety	Wrong-Way Entry application correctly warned 14 drivers from entering the wrong way (2021-B01550).
THEA	Mobility	End of Ramp Deceleration Warning was estimated to reduce the travel-time index (defined by peak travel time / off-peak travel time) by 30% (2021-B01583).
WYDOT	Environment	CV applications had an estimated savings of 46.5 gallons of diesel from reduced idling for trucks per one-hour road closure (2023-B01761).
NYCDOT	Environment	CV applications had an estimated reduction in emissions of 1,287 kg (based on modeling the prevention of 4 hypothetical collisions) (2022-B01701).
NYCDOT	Customer Satisfaction	Survey findings indicated 83% of pedestrians felt safer using the mobile crossing application (2022-B01650).
THEA	Customer Satisfaction	Survey findings indicated 79% of drivers found the End of Ramp Deceleration Warning helpful (2022-B01702).
WYDOT	Public Agency Efficiency	Data from the CVs increased the quantity of road condition reports nearly 4x, improving the ability of the TMC to generate more accurate alerts and advisories (2023-B01735).

Best Practices

The CV Pilot sites employed a systems engineering process and thus developed a concept of operations, high-level design, and detailed design and implementation plans. This experience enabled the sites to encounter first-hand the challenges associated with the deployment of CV technology, including, but not limited to:

- Updates to the standards and modifications to the device specifications.
- Deployment of the Security Credential Management System (SCMS) and changing requirements for its use after the program changed from the planned prototype USDOT SCMS system to a commercial SCMS provider.
- Development of Over-The-Air (OTA) firmware updates for the OBUs using Dedicated Short-Range Communications (DSRC).
- Development of a central data management system.
- Testing and tuning of V2V and V2I safety applications.

- Device certification by OmniAir Consortium. This was a learning experience for the vendors since it took time to stabilize the testing procedures, test equipment, and test environment.
- Development of OBU installation procedures which varies by vehicle model and year.
- Obtaining Federal Communications Commission's (FCC) licensing for the 500+ RSUs being deployed by the three sites (NYC alone had to apply for more than 1,000 RSU licenses).
- Various procurement and installation contractual management issues due to the desire for multiple vendors, the required device development, and the uncertainty of specific vehicle installation procedures.
- Development of a testing environment—for the technology, the installation, and troubleshooting the radio frequency field conditions—which experienced interference and GPS jamming.

Below the sites offer insights on how they overcame some of their most difficult technical challenges faced (2019-00871).

If using the 5.9 GHz band, consider purchasing interference tracking equipment to detect potential interference from other users in the band that can compromise data exchange.

The FCC originally allocated the 5.9 GHz band strictly for DSRC-based ITS applications. However, in 2013, the FCC began allowing unlicensed devices to share the spectrum with primary users as long as they were not found to be interfering with the primary DSRC users. During acceptance testing, THEA detected and tracked down an interference on their DSRC communication channels coming from a local amateur radio operator.

> *"This is quickly emerging technology. And that's why we're documenting as much information as possible for other states to help them figure out infrastructure [4]." – Vince Garcia, WYDOT*

While the amateur ham radio could not receive DSRC radio messages due to the far lesser range of DSRC, THEA's DSRC radio would receive the ham radio messages, causing the radio to consider the channel "busy" and not "clear to send." The additional signal on THEA's channels impacted the performance of their equipment in terms of data exchange and back haul speed, with testing indicating a degradation in data uploads by up to 50%. Upon review of these findings, Florida Department of Transportation, who operates the state-wide FCC licensing, ordered the amateur radio operator to vacate the channel. Through this experience, the THEA team learned that ham Operators are "licensed" in the spectrum and thus should be approached as secondary, licensed users and not unlicensed intruders. Due to the larger scale of the NYC deployment and thus the increased likelihood for interference, the NYC team invested in the purchase of sophisticated interference checking and radio frequency spectrum analysis equipment.

Following the FCC's December 2020 ruling that phases out DSRC, the WYDOT CV Pilot went on to participate in a Phase 4 that focused on replacing the DSRC devices with Cellular Vehicle to Everything (C-V2X) devices [5].

Assess vehicle OBUs' ability to monitor its position accurately in dense urban environments to determine whether a correction is needed.
New York City is known for its "urban canyons" which provide a challenging environment for GPS technology that is often limited to open sky. The current standard (J2945/1) requires the vehicle to cease transmission if it loses GPS "lock," which is not practical in a dense urban environment. As a result, additional techniques were required in the OBUs positioning algorithms to provide the accuracy needed for many of the V2V and V2I safety applications to function properly. The NYC vendors were required to augment their location determination algorithms to include inertial navigation, map matching, tethering to the vehicle, and RSU triangulation. Preliminary testing indicated that this combination of supporting techniques, with the proper algorithms and tuning, will meet the applications' stringent location needs.

Refine proper antenna placement to reduce communications interferences.
The location of the antenna on the vehicle is critical to ensure continuous wireless communication without loss of signal strength. The New York City and Tampa teams found that for light-vehicles, antennas mounted near the rear-center of the rooftop was most ideal. However, large vehicles, such as the semi-trucks that the WYDOT pilot installed onboard units on, often have "self-blocking" physical elements that obstruct the vehicle's own DSRC antennas from direct line of sight with other vehicles. This resulted in "shadows" for the Wyoming vehicles that prevented remote vehicles from properly communicating with the trucks. To alleviate this effect, the Wyoming team worked with USDOT's communication experts to perform numerous tests in Wyoming and at the Aberdeen Proving Grounds. The testing concluded that the effect of the DSRC shadows could be best alleviated by mounting the antennas on the side mirrors of the semi-trucks.

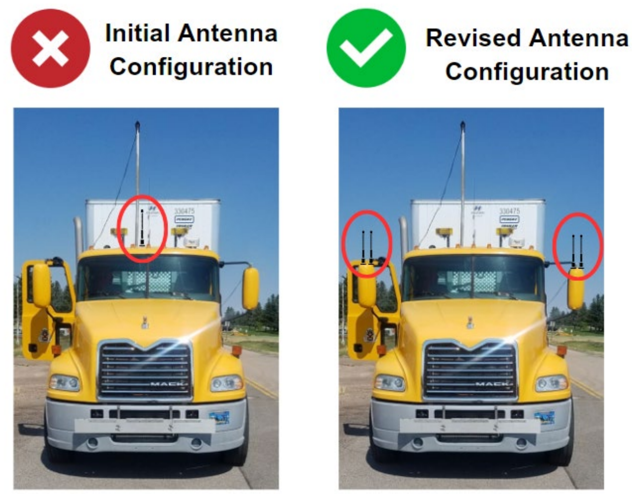

Figure 4: Under the initial configuration on the cab rooftop, the box trailer blocked the signal. Under the revised configuration, antennas were mounted on the side mirrors, improving line of sight for trailing vehicles (Source: WYDOT, modified by USDOT).

Success Story

CV Pilots' Interoperability Test marks watershed moment for connected vehicle technology (2018-00831).

To pave the way for a nationwide deployment, a major long-term goal of the CV Pilot Deployment Program was for the connected vehicle devices and equipment to be interoperable, meaning that they would be able to operate as designed anywhere in the country, regardless of where they were built. The cooperative agreements between the USDOT and the CV Pilot Deployment Sites included a requirement for the CV Pilot sites to perform an activity that showed the devices from the three sites being interoperable. To meet this requirement, the USDOT and CV Pilot sites agreed to perform an Interoperability Test that would test: 1) interactions between different sites' OBUs and (2) interactions between selected OBUs and RSUs.

Figure 5: Group shot of the Interoperability Test participants pictured with the logos of the three CV Pilot sites: New York City (left), Tampa (middle) and Wyoming (right) (Source: USDOT).

Over a period of several months, the CV Pilot sites collaborated to harmonize the data elements that would make such interactions possible. The CV Pilot sites next worked with the USDOT and its support contractor to develop a plan to conduct an Interoperability Test that would take place at Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia from June 26-28, 2018.

Planning for the testing event was jointly led by the CV Pilot sites in coordination with TFHRC and USDOT staff. TFHRC and its Saxton Transportation Operations Laboratory (STOL) contractor provided support to the CV Pilot sites as well as the facility and supporting equipment for the testing. This support included installing the same RSU models used by the sites to allow them to replicate their configurations, installing OBUs from the sites in vehicles and providing trained drivers to operate the vehicles during the interoperability test runs. In addition to the USDOT and sites, representatives of the CV Pilots' Independent Evaluation team were present to observe in support of the broader independent evaluation effort. Six TFHRC-provided vehicles were used for the testing with each vehicle being outfitted with an OBU from one of the CV Pilot site's OBU vendors – Tampa (3), New York City (2) and Wyoming (1). Additionally, the sites each loaded the TFHRC-supplied RSUs with their own software.

The systems' capabilities were demonstrated in staged scenarios on TFHRC's closed road course. In total, 102 interoperability test runs were conducted for four test cases – FCW, Intersection Movement Assist (IMA), Emergency Electronic Brake Lights (EEBL) and reception of Signal Phase and Timing (SPaT)/MAP messages. Data was downloaded off of the OBUs immediately following each test run, with nearly 5 GB worth of data being generated over the test period. This data was uploaded to the USDOT's Secure Data Commons (SDC) for further analysis to help identify lessons learned for future testing. Overall, the three-day testing event was a major success that went above and beyond the event's original testing objectives, with time allotted on the last day for some impromptu tests by the sites. Results of the testing indicated successful transfer of messages between the six vehicles fit with devices from five different OBU vendors. Out of the five vendors, four utilized DSRC and one used both DSRC and SiriusXM Radio. Additionally, equipment from New York City and Tampa's vendors demonstrated the successful transfer of messages between the site-configured RSUs and the sites' OBUs. The event was lauded by many for being well-planned, well-organized, and well-executed, with some attendees reporting that it was the most successful connected vehicle testing event they had ever participated in.

> ***"The data generated from these CV deployment projects will show that A) it works, or B) it doesn't, which is just as important [6]."***
>
> ***– Bob Frey, THEA***

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