Intelligent Transportation Systems Benefits, Costs, and Lessons Learned

2018 Update Report

www.its.dot.gov/index.htm

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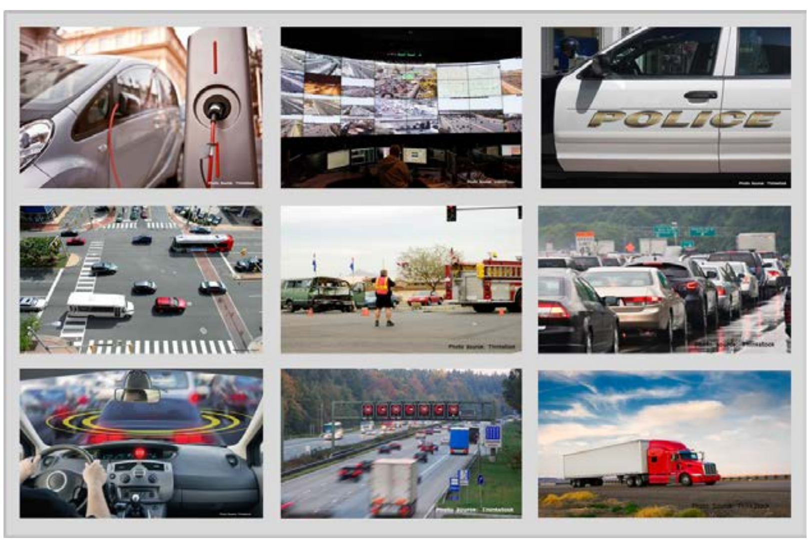

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16. Abstract

Intelligent transportation systems (ITS) provide a proven set of strategies for advancing transportation safety, mobility, and environmental sustainability by integrating communication and information technology applications into the management and operation of the transportation system across all modes. In the future, ITS technologies will transform surface transportation by offering a connected environment among vehicles, the infrastructure and passengers' wireless devices, allowing drivers to send and receive real-time information about potential hazards and road conditions. The U.S. Department of Transportation's (U.S. DOT) ITS research program focuses on the overall advancement of ITS through investments in emerging ITS technologies, as well as supporting the evaluation of deployed ITS. This report presents information on the benefits, costs, and lessons learned regarding ITS planning, deployment, and operations obtained from almost twenty years of evaluation data. The report is based upon three related Web-based databases, known collectively as the ITS Knowledge Resources (KRs). The Knowledge Resources were developed by the U.S. DOT's ITS Joint Program Office (JPO) evaluation program to support informed decision making regarding ITS investments by tracking the effectiveness of deployed ITS. The Knowledge Resources contain over eighteen years of summaries of the benefits, costs, and lessons learned of specific ITS implementations, drawn primarily from written sources such as ITS evaluation studies, research syntheses, handbooks, journal articles, and conference papers. They can be accessed online at www.itskrs.its.dot.gov. The report has been developed as a collection of factsheets presenting information on the performance of deployed ITS, as well as information on the costs, and lessons learned regarding ITS deployment and operations. The report has been designed to be flexible for the user. This 2018 update report includes 10 new or revised factsheets relative to the 2017 Update Report.

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Executive Summary

Intelligent transportation systems (ITS) provide a proven set of strategies for advancing transportation safety, mobility, and environmental sustainability by integrating communication and information technology applications into the management and operation of the transportation system across all modes. In the future, ITS technologies will transform surface transportation by offering a connected environment among vehicles, the infrastructure and passengers' wireless devices, allowing drivers to send and receive real-time information about potential hazards and road conditions.

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The report has been developed as a collection of factsheets presenting information on the performance of deployed ITS, as well as information on the costs and lessons learned regarding ITS deployment and operations. The report has been designed to be flexible for the user. The purpose is to make the information readily available, whether by accessing it through the web, a mobile device or tablet, or by printing sections on one or more application areas.

Findings

As of February 24, 2018, there were a total of 2,141 summaries of ITS benefits, costs, and lessons learned in the ITS Knowledge Resources databases from the United States and around the world, as shown in Table 1. Of the 2,141 summaries, 205 summaries have been added since the publication of last year's report.

Table 1: Summaries in the Knowledge Resources Databases.

Summary Type	Number of Summaries
Benefits	1,112
Costs	368

Summary Type	Number of Summaries
Lessons Learned	661
Total	1,941

Table 2: Summaries by Taxonomy/Application Area.

Taxonomy/Application Area	Number of Benefit Summaries	Number of Cost Summaries	Number of Lesson Summaries
Arterial Management	219	75	82
Freeway Management	163	62	107
Roadway Operations & Maintenance	74	33	47
Crash Prevention & Safety	144	55	27
Road Weather Management	66	52	40
Transportation Management Centers	28	49	69
Alternative Fuels	7	3	4
Traffic Incident Management	88	44	66
Transit Management	152	57	92
Emergency Management	19	17	40
Traveler Information	101	44	84
Driver Assistance	161	38	31
Information Management	15	11	29
Commercial Vehicle Operations	69	24	20
Intermodal Freight	24	5	14
Electronic Payment & Pricing	108	42	81

An important recent addition to the Knowledge Resources is the inclusion of benefit, cost, and lessons learned summaries for the Connected Vehicle Program. These new entries are directly searchable buy a dedicated search button on the home page of the ITS Knowledge Resources.

ITS Evaluation Highlights

In the 21 years that the ITS JPO has been tracking the evaluation of ITS technologies, there has been steady growth in the number of studies documenting the benefits, costs and lessons learned of ITS. Looking back over the last year, the most recent additions to the ITS knowledge resources indicate the following evaluation highlights:

Crash Prevention and Safety

- The new wave of crash prevention and safety strategies includes the integration of vehicle and infrastructure safety systems and implementation of connected vehicle technologies for safety applications.
- Crash statistics show that lane departure warning systems have reduced all relevant crashes by 11 percent, and all relevant injury crashes by 21 percent, controlling for driver demographics.
- In a pilot test, bus drivers using in-vehicle collision avoidance warning systems were involved in 72 percent fewer near-miss events than a control group where the warning feature was turned off.

Accessible Transportation

- In May 2017, the Kansas City Area Transportation Authority (KCATA) rolled out its app-based public transit service, RideKC Freedom On-Demand. The one-year pilot project enabled riders to use a cellphone app to book taxi rides through private taxi companies at any time. After five months, KCATA recorded more than 15,500 trips on RideKC Freedom On-Demand. The new service cost $15.80 a trip compared to a traditional paratransit trip costing $27.13. In the five months since launch, RideKC On-Demand saved the Authority about $166,000.
- The USDOT ATTRI program has awarded six projects for application development in the four application areas: automation and robotics; safe intersection crossing; wayfinding and navigation; and pre-trip concierge and virtualization.

Mobility on Demand

- Since 2010, the Capital Bikeshare service has connected a network of over 450 stations via 4,000 bicycles across several jurisdictions in the Washington, DC area including Arlington County, VA. Arlington County reported on progress on the service’s performance measures, which included a 24 percent growth in ridership between FY2013 and FY2014, saving Arlington members a combined estimated $2 million in transportation spending, and a total of 14,390,372 calories burned.
- Many carsharing programs have agreements with municipalities for free on-street parking as well as to provide dedicated parking spaces. Typically, the carsharing company pays the city a fee to cover these costs. Depending on the agreement the car company may also pay for other costs to

operate that include insurance, pilot evaluation, car removal in cases of parking restriction violations. Annual payments per year per vehicle ranged between $1,303 in Portland, Oregon and $2,644 in Washington, DC.

Information Management

- The ITS JPO and its multimodal partners are dedicated to providing open access to archival and real-time publicly funded research data. Beginning in 2018, the ITS Public Data Hub became the USDOT's primary storage and access system for ITS data.

- The ITS Public Data Hub offers several visualization tools that users are encouraged to play around with. Six prototype visualization elements are available for viewing at https://www.its.dot.gov/data/visualizations/.

- A major accomplishment of the ITS Public Data Hub is the addition of the Connected Vehicle Pilot Deployment data from Wyoming occurring in near-real time.

Connected Vehicle – Safety

- V2P detection systems can be implemented in vehicles, infrastructure, or with pedestrians themselves to provide warnings to drivers, pedestrians, or both through in-vehicle systems and handheld devices. These include PED-SIG (Mobile Accessible Pedestrian Signal System), PED-X (Pedestrian and Signalized Crosswalk), Intelligent Pedestrian Traffic Signal (IPTS), and Intelligent Pedestrian Detectors (IPD).

- In one study, 23 percent of pedestrians reported that a crosswalk transit vehicle turn warning system help them avoid a collision with a bus.

CV Pilot Deployment

- USDOT selected the New York City Department of Transportation (NYCDOT), Wyoming Department of Transportation (WYDOT) and Tampa Hillsborough Expressway Authority (THEA) as recipients of a combined $42 million in federal funding to implement a suite of connected vehicle applications and technologies tailored to meet their region's unique transportation needs.

- CV Pilot Deployment sites have completed Phase 1, preparing a comprehensive deployment concept, and are currently in Phase 2. In Phase 2, the sites embark on a 20-month phase of activity to design, build and test deployment of integrated wireless in-vehicle, mobile device, and roadside technologies.

- Experiences from the New York site suggest that including technical, operations, and legal personnel in stakeholder meetings helps address the requirements of the CV deployment and ensure that participants' privacy is maintained.

- The Wyoming site focuses on the needs of commercial vehicle operators. To reduce the need for channel switching, a potential distraction, designing CV communications including dual radios is suggested.

- Experience at the Tampa site suggests installing additional vehicle detection equipment if it is determined that there is insufficient market penetration for CV traffic signal control applications to work at their full potential.

Automated Vehicles – Truck Platooning

- Truck platooning works by creating a close, constant coupling between platooning vehicles, providing fuel benefits for both the lead and following trucks. Operating as a unit, truck platoons can also smooth traffic flow to increase efficiency and roadway capacity.

- Class-8 trucks with standard-trailers net a fuel savings of between 5.2 and 7.8 percent in a three-truck CACC platoon. With aerodynamic-trailers, these savings grow to 14.2 percent at a minimum separation distance of 17.4 m (57.1 ft).

- A traffic microsimulation study of driver assistive truck platooning (DATP) found a travel time reduction benefit for each of the simulation cases featuring current traffic and two increased levels (115 percent and 130 percent) of traffic volumes on a five-mile section of I-85 in Alabama. Travel time savings during peak hour traffic conditions ranged from a two percent improvement (with 20 percent market penetration) to 69 percent improvement (with 100 percent market penetration).

Automated Vehicles – Driver Assistance

- Field testing and evaluation of GlidePath Cooperative Adaptive Cruise Control (CACC) systems installed on partially automated vehicles show these system can improve fuel economy by 17 to 22 percent and reduce travel time up to 64 percent.

- A survey of 21 volunteer participants in the Seattle area who drove DSRC equipped vehicles designed to collect speed and road weather data from other connected vehicles and infrastructure-based systems suggested that on-board applications such as queue warning, speed harmonization, and weather responsive traffic management (WRTM) messaging systems enabled drivers to take action in advance of congestion, reducing the need to slow down or stop suddenly.

- Observations of OEM driver assistance technology pricing over the last few years show these system can add from $300 to $10,800 to the purchase price of a new vehicle. Most systems are $4500 or less.

Chapter 1. Crash Prevention and Safety

Introduction

A major goal of the ITS program is to improve safety and reduce risk for road users including pedestrians, cyclists, operators, and occupants of all vehicles who travel along our roadways. After many years of declining motor vehicle crashes and fatalities on the Nation's roadways, reaching a low of 29,867 in 2011, fatalities have slowly started to creep upward, although the number of fatalities per hundred million vehicle miles of travel (VMT) has remained relatively constant. Traffic fatalities for 2016 totaled 37,461, an increase of about six percent compared to the year prior.[1]

Crash prevention and safety systems detect unsafe conditions and provide warnings to travelers to take action to avoid crashes. These systems provide alerts for traffic approaching dangerous curves, off ramps, restricted overpasses, highway-rail crossings, high-volume intersections, work zones, adverse weather conditions, and also provide warnings of the presence of pedestrians, bicyclists, and even animals on the roadway. Crash prevention and safety systems typically employ sensors to monitor the speed and characteristics of approaching vehicles and frequently also include environmental sensors to monitor roadway conditions and visibility. These systems may be either permanent or temporary. Some systems provide a general warning of the recommended speed for prevailing roadway conditions. Other systems provide a specific warning by considering specific vehicle characteristics (truck or car) and a calculation of the recommended speed for the particular vehicle based on conditions. In some cases, manual systems are employed, where pedestrians or bicyclists manually set the system to provide warnings of their presence to travelers; however these systems are being replaced with automated systems with the increasing implementation of connected vehicle technologies. With the introduction of connected vehicle safety applications, crash prevention and safety systems are also moving from passive driver warning systems, to active driver assistance systems where the vehicle can automatically react to other vehicles or road sensors during hazardous conditions.

Intersection Collision Warning Systems: Intersection collision warning systems use sensors to monitor traffic approaching dangerous intersections and warn vehicles of approaching cross traffic, using roadside infrastructure, in-vehicle systems, or some combination of the two. The newer approaches to intersection collision warning systems provide information to drivers on proper maneuvers (gap acceptance assistance) and warn drivers of right-of-way violations at intersections. The warnings may include the driver's vehicle violating traffic control signs or signals or of another vehicle violating, or about to violate, the subject vehicle's right-of-way. Specific examples are provided below:

- Left Turn Assist: Warnings given to driver via an in-vehicle system when trying to make a left turn that may be visually blocked by another car or object. Warnings can alert the driver that a left turn should not be attempted.

- Traffic Control Violation Warning: Warnings given to drivers via in-vehicle systems if it is determined the driver may violate a red light or other traffic control device.

- Stop Sign Gap Assist: Information provided to drivers while stopped at a stop sign where only the minor road has stop signs. The driver receives information of any danger to the vehicle proceeding through the intersection from vehicles approaching on the cross street.

Collision Avoidance Systems: To improve the ability of drivers to avoid accidents, vehicle-mounted collision warning systems (CWS) continue to be tested and deployed. These applications use a variety of sensors to monitor the vehicles surroundings and alert the driver of conditions that could lead to a collision. Examples include forward collision warning, obstacle detection systems, rear impact collision warning, “do not pass” warnings, and road departure warning systems.

Collision Notification: In an effort to improve response times and save lives, collision notification systems have been designed to detect and report the location and severity of incidents to agencies and services responsible for coordinating appropriate emergency response actions. These systems can be activated manually (Mayday), or automatically with automatic collision notification, and advanced systems may transmit information on the type of crash, number of passengers, and the likelihood of injuries.

Benefits

Crash Prevention and Safety strategies include collision avoidance systems and systems that warn drivers of potential road hazards. These systems have demonstrated success in detecting potential conflicts and warning motorists of crash potential. Evaluations of these systems find reduction in road crashes, injuries and fatalities as summarized in Table 3.

Table 3: Selected Benefits for Crash Prevention and Safety Strategies.

Categories	Selected Findings
Collision Avoidance for Passenger Vehicles	A Korean study finds that Automatic Crash Information Notification Systems would reduce freeway fatalities by 11.8 to 18.1 percent. (2013-00864) Electronic Stability Control (ESC) systems can reduce the risk of fatal crashes by 33 percent. (2013-00861)
Collision Avoidance for Trucks	Forward collision warning systems have potential to prevent 23.8 percent of crashes involving large trucks. (2012-00811)
Collision Avoidance for Transit Vehicles	In a pilot test, bus drivers using in-vehicle collision avoidance warning systems were involved in 72 percent fewer near-miss events than a control group where the warning feature was turned off. (2017-01198) The camera-based system with a *regular* angle lens reduced 43 percent of blind zones, and wide-angle camera systems were able to entirely eliminate blind zones. (2013-00853)
Lane Depature Warning	Crash statistics show that lane departure warning systems have reduced all relevant crashes by 11 percent, and all relevant injury crashes by 21 percent, controlling for driver demographics. (2017-01175)
Pedestrian Safety	In Tucson, Arizona, installation of High-Intensity Activated Crosswalk (HAWK) pedestrian beacons showed 69 percent reduction in crashes involving pedestrians. (2013-00848)

In-vehicle active and passive safety technologies have also shown to provide significant benefits to road users. The most significant findings are that in-vehicle technologies, including automated braking systems, have the ability to significantly reduce the injury and fatalities due to collisions. Table 4 highlights some of these findings.

Table 4: Selected Benefits for In-vehicle Safety Technologies.

Categories	Selected Findings
Automated Braking System	Light vehicles that automatically activate in-vehicle alerts, seat belt tensioners, and braking systems can reduce fatalities by 3.7 percent. (2013-00833) In-vehicle technologies that use automated braking to prevent rear-end collisions can reduce drivers injured by 19 to 57 percent. (2013-00832)
Combined In-vehicle Safety Systems	A literature review of in-vehicle safety systems in the United States and New South Wales, Australia found that active and passive in-vehicle safety technologies are expected to decrease fatalities up to 16 percent. (2013-00827) Forward collision warning (FCW) alone, low-speed autonomous emergency braking (AEB), and FCW combined with AEB that operates at highway speeds reduced rear-end striking crash involvement rates by 27 percent, 43 percent, and 50 percent, respectively. (2017-01177)

Figure 1 shows ranges of benefits for select entries in the ITS Knowledge Resource database at: http://www.itsknowledgeresources.its.dot.gov/. Benefits of collision notification and avoidance system include reduction in fatalities and injury to drivers.

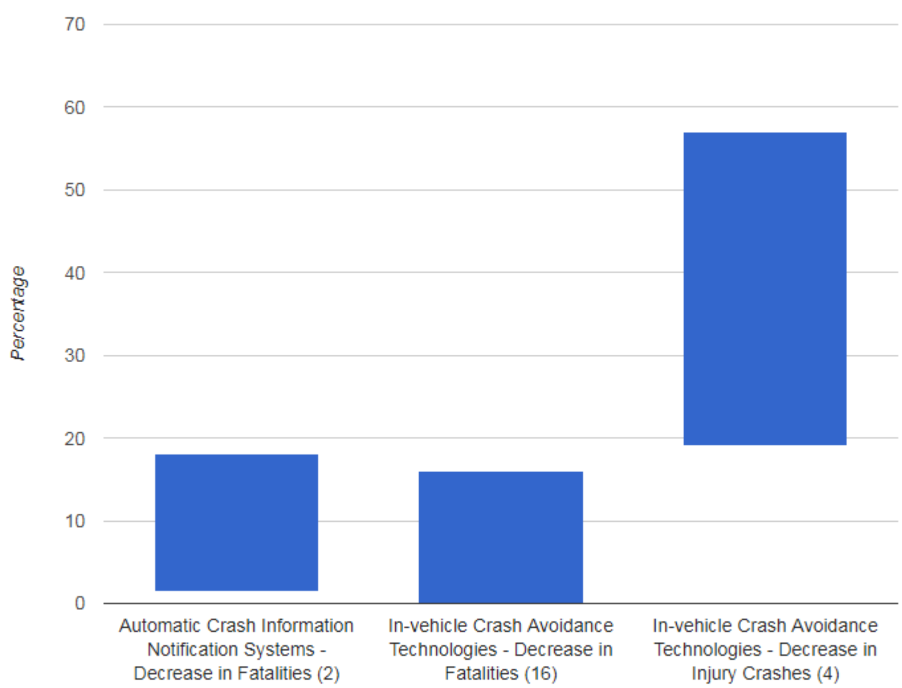


Figure 1: Range of Benefits for Crash Avoidance Technologies (Source: ITS Knowledge Resources).

The online versions of the factsheets feature interactive graphs that contain all the data points included in the ranges. Here, each metric has a number after the text, representing the number of data points used to create the range; no number means only there was only one data point.

Several crash warning systems have also shown significant benefits in reducing overall number of crashes**.** Figure 2 shows the ranges of these benefits.

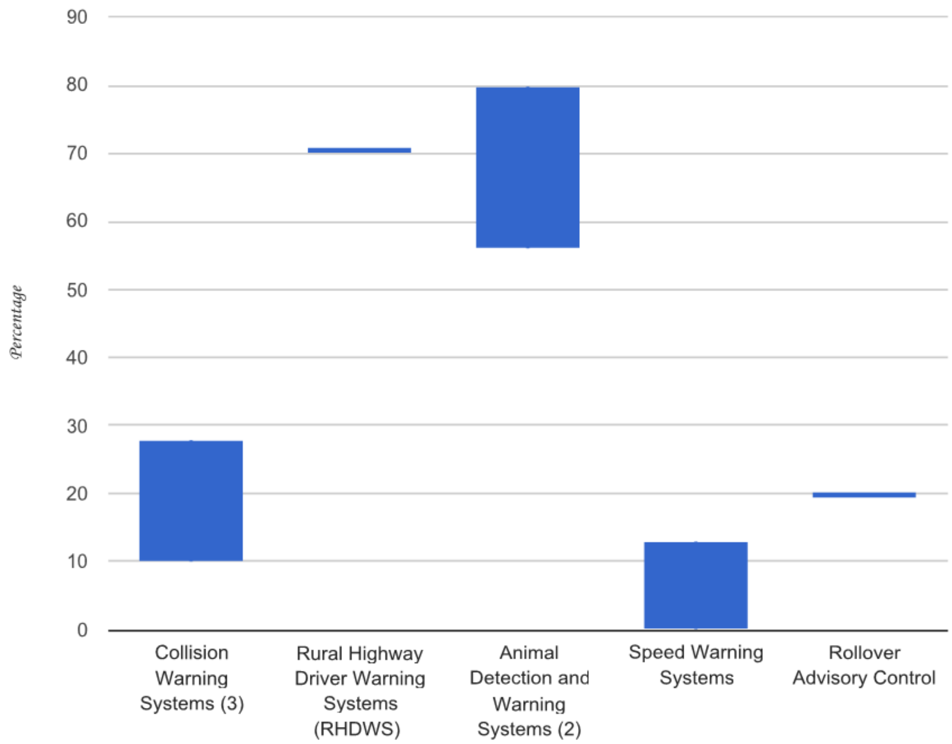
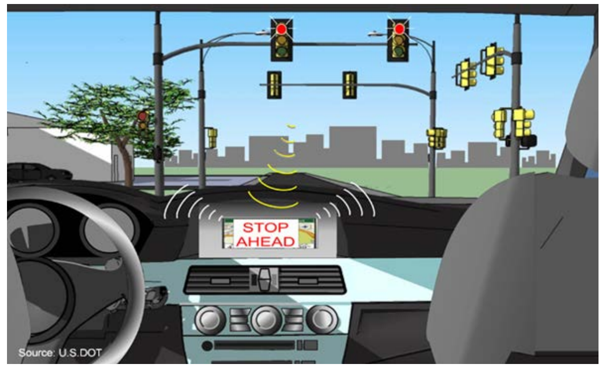


Figure 2: Range of Crash Reduction Benefits from Collision Warning Systems (Source: ITS Knowledge Resources).

As connected vehicle technologies are just now being developed and tested, few evaluations are available. However, driver acceptance clinics were conducted at six different cities in the United States to assess how motorists respond to connected vehicle technologies and benefit from in-vehicle alerts and warnings. The preliminary findings showed that 91 percent of volunteer drivers that tested vehicle-to-vehicle (V2V) communications safety features indicated they would like to have these technologies on their personal vehicle (2012-00785).

Additionally, a European study evaluated the potential benefits and costs of V2V and vehicle-to-infrastructure (V2I) technologies. This study concluded that V2V applications can have positive benefit-cost ratios at fleet penetration rates above 6.1 percent, whereas V2I technologies require a greater market share (2013-00842).

Costs



The ITS Knowledge Resources database provides a variety of system costs for crash prevention and safety strategies that range from individual in-vehicle collision avoidance systems to estimates of nationwide implementations of connected vehicle environments.

The database includes several recent cost estimates for in-vehicle collision avoidance systems shown in Table 5. Delphi study techniques, using independent estimates from multiple industry experts and multiple rounds to achieve consensus, were used to forecast the estimated costs for future years.

Table 5: Cost Estimates for In-vehicle collision avoidance systems

In-vehicle collision avoidance systems	Year	System Costs
Advanced Emergency Brake System in the UK (2012-00275)	2011	$334 - $1,337
Side collision warning system (Blind Spot Warning) (2013-00287)	2010	$760 - $2,000
Radar-based Truck Collision Avoidance system (2017-00382)	2014	$2,500 - $4,000
Cost to Vehicle Manufacturers for Embedded On-board DSRC equipment (2013-00288)	2017	$175
Cost to Vehicle Manufacturers for Embedded On-board DSRC equipment (2013-00288)	2022	$75
Cost Added to Base Vehicle Price for DSRC equipment (2013-00288)	2017	$350
Cost Added to Base Vehicle Price for DSRC equipment (2013-00288)	2022	$300
Aftermarket DSRC equipment (2013-00288)	2017	$200
Aftermarket DSRC equipment (2013-00288)	2022	$75

Lessons Learned

The ITS Knowledge Resources database identifies several lessons learned from crash prevention strategies. A national evaluation of ITS applications presents new approaches to address distracted driving when designing and developing ITS applications (2013-00651).

- **Communicate alerts designed to orient drivers to general traffic conditions ahead, and therefore, make them more attentive to the driving environment to help reduce driver distraction.**
- **Use "geofencing" as an approach to limiting driver distraction.** The geofencing technique attempts to determine which mode the traveler is using in order to allow transit users to continue to receive updates while on the move while preventing them from using the information while driving. It was demonstrated that it is feasible to determine whether a smart phone user is traveling on a transit vehicle versus in a vehicle on a road. Therefore it is possible to provide travel information to smart phone users while minimizing the risk of distraction.
- **Continue to explore avenues for advancements in technology to prevent driver distraction as well as instilling a safety culture mindset to support the goal of a change in driver behavior.** As in-vehicle technology continues to develop, supporting safe driving habits will continue to be a challenge.

Case Study – Intelligent Dilemma Zone Protection System at High-Speed Intersections (2017-01212)

Drivers' actions in an intersection's dilemma zone, the area where the decision to stop at a yellow light or continue through it is not clear-cut, can lead to side-angle and rear-end crashes. In Maryland, researchers developed an intelligent dilemma zone protection system (DZPS) to reducing these crashes by anticipating drivers' decisions and responding.

Methodology

The DZPS system was deployed at two high-speed rural intersections (US-40 at Western Maryland Parkway in Hagerstown, MD and MD-213 at Williams/Locust Point Road in Elkton, MD) and has three components: (1) two wide-range sensors to track speeds and locations of all vehicles within the identified dilemma zones; (2) software to predict the response of drivers during the yellow phase and to activate the all-red extension function if needed; and (3) a web-based module for engineers/technicians to monitor the system's performance from a control center. Field evaluations of the deployed DZPS were conducted about one month after the system activation dates, and real-time system monitoring and performance analysis was carried out with respect to the traffic flow characteristics impacts and the all-red extension activations.

Findings

The maximum length of the dilemma zone was reduced by 960 to 670 feet (vehicles traveling at 75 mi/h), a 30 percent reduction, at the intersection of US 40 and Western Maryland Parkway. The total length of dilemma zones weighted by traffic volume in each speed bin (increments of 5 mi/h from 25 mi/h to 75 mi/h), a 40 percent reduction, from 73 feet to 44 feet. Similar reductions were noted at the intersection of MD 213 and Williams/Locust Point Road.

Chapter 2. Accessible Transportation

Introduction

In 2010, the U.S. Census reported that approximately 56.7 million people in the U.S. (18.7 percent of the U.S. population) had some type of disability. One study found that over 6 million people with disabilities have difficulties obtaining the transportation they need[1]; nearly one-third of people with disabilities reported having inadequate access to transportation.[2] Transportation is critical to enhancing access to education, jobs, healthcare, and independent living within communities. Individuals with disabilities currently suffer a 63 percent unemployment rate, with half of the household income and three times the poverty rate of people without disabilities.

A user needs assessment on transportation challenges faced by people with disabilities, veterans with disabilities, and older adults, conducted by the United States Department of Transportation's Accessible Transportation Technology Research Initiative (ATTRI), concluded that needs and barriers vary by sub-population and type of disability. The assessment identified mobility concerns as barriers to employment, recreational and retail opportunities, and other meaningful lifetime activities.[3] "Independent mobility" refers to the ability of an individual to travel to a destination without being accompanied by a family member or caregiver, regardless of functional ability.

Source: USDOT

The USDOT ATTRI program has awarded six projects for application development in the four application areas defined by the program. The Federal Transit Administration and Intelligent Transportation Systems Joint Program Office (ITS JPO) are jointly funding work in the Smart Wayfinding and Navigation, Pre-trip Concierge and Virtualization, and Smart Intersection Crossing applications areas. The USDOT is collaborating with the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR) to fund the Robotics and Automation application area. Below are the awarded projects:

Wayfinding and Navigation:

- City College of New York – Smart Cane for Assistive Navigation, a wayfinding solution for those with low vision integrated with a smart phone application
- AbleLink – An open wayfinding media standard and related infrastructure to create geographically-specific, cloud-based libraries of routes in metropolitan or rural areas
- Pathways Solutions – A wayfinding tool for wheelchair users and people with visual impairment that guides users along routes tailored to their preferences
- TRX Systems – A smart wayfinding and navigation system to obtain real-time location, en-route assistance, and situational awareness.

Pre-Trip Concierge and Virtualization:

- AbleLink – A suite of assessment, self-directed learning, and trip execution technologies to support pre-trip planning for individuals with cognitive disabilities

Safe Intersection Crossing:

- Carnegie Mellon University – A tool to connect pedestrians with disabilities to the traffic signal systems infrastructure (and nearby connected vehicles and infrastructure) and create situational awareness to improve the safety of intersection crossing and increase independent mobility.

Robotics and Automation

- Carnegie Mellon University – This project researches and develops seamless transportation assistance from cloud-based autonomy and shared robots located in and around transportation hubs.

As the ATTRI projects develop their technologies and provide demonstrations, the USDOT will perform detailed evaluations for each project and make the evaluation results available in the ITS Knowledge Resources database.

While these technologies are currently in the development stage, the ITS Knowledge Resources databases contain several examples of the application of advanced technology to improve mobility of people with disabilities. Many of these transportation projects are focused on providing information in different formats (audio, visual and haptic), as well as using shared used mobility solutions enabled by smartphone technology to increase access to paratransit. Finally, while still in the development phase, the US Army is piloting semi-autonomous vehicles to address mobility needs of veterans with disabilities. This research has promise to fulfil first mile last mile needs of all travelers, especially those with disabilities.

Benefits

The ITS Knowledge resource database contains several examples of successful accessibility-enhancing deployments. Located in Williamsport, PA, River Valley Transit provides real-time customer information at its transit center. River Valley Transit uses a combination of automatic vehicle location (AVL) and mobile data terminals technology to provide real-time in-terminal customer information. The Traveler Information System (TIS) informs customers both visually and audibly as to which of the 10 loading bays buses will arrive at and depart from. It also gives customers a 20-second notification before buses depart on their next trip. The system even notifies drivers when they have pulled into the wrong bus bay.

The successful implementation of the TIS demonstrated a number of benefits for customers. The transit agency increased accessibility for persons with disabilities including to the customer information systems that include visual and audio announcements are especially helpful to people with disabilities. In addition to these technology-specific benefits, the research team identified a number of benefits.

- Increased community confidence – ITS deployments have the potential to increase community confidence in the agency’s ability to operate an efficient, effective transportation system.

- Potential for increased ridership and revenue – ITS increases the attractiveness of the transit service, which could potentially increase ridership and farebox revenues.

Case Study – RideKC Freedom On-Demand (Kansas City, MO) 2018-01244).

In May 2017, the Kansas City Area Transportation Authority (KCATA) rolled out its app-based public transit service called RideKC Freedom On-Demand. The one-year pilot project enabled riders to use a cellphone app to book taxi rides through private taxi companies any day, at any time without reserving a trip 24 hours ahead of time. Customers had the option of using their iphone or Android smartphones to download an app to summon the taxis. They could then use the smartphone to track their rides in real-time. Customer also had the option to book a taxi by telephone.

"We are seeing some customers move away from using traditional paratransit services in favor of the new on-demand option." – *Tyler Means, KCATA*

The cost for riders who qualify under the American with Disabilities Act (ADA) was $3 for the first eight miles and $2 for each additional mile. The cost for the general public was $10 for the first five miles and $2 for each additional mile. A portion of regularly priced fares on non-ADA trips was returned to KCATA to reinvest in transit service.

A comparison of Freedom On-Demand and traditional paratransit is shown below.[4]

Table 6: Comparison of Freedom On-Demand and Traditional Paratransit

Freedom On-Demand	Freedom (Previously Share-A-Fare)
No advance reservation required	Schedule at least 24 hours in advance
Curb-to-curb service	Door-to-door service
To book a trip: use app or call 816.842.9070	To book a trip: call 816.842.9070
Pay with cash, credit or debit card, or through the app	Pay cash
ADA: $3 for the first 8 miles & $2 each mile after Ages 65+: $5 for the first 8 miles & $2 each mile after	ADA $3 per trip
Up to 4 trips per day	Unlimited daily trips
Book a trip for a friend or family member	Book a trip for a friend or family member
Up to three guests	No guests

Source: RideKC

After five months, KCATA recorded more than 15,500 trips on RideKC Freedom On-Demand. The new service cost $15.80 a trip compared to the traditional paratransit trip which cost $27.13. In the five months since launch, RideKC On-Demand saved the Authority about $166,000.

KCATA surveyed 300 Freedom On-demand users, and 75 percent to 80 percent viewed the service favorably.

Case Study – Applied Robotics for Installation and base Operations (ARIBO)

The ARIBO program is run by the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC) with the objective to coordinate development, investment, and operational use to accelerate fielding automated technologies. ARIBO seeks to improve the safety and efficiency of vehicles on roadways and fully understand the most advantageous and cost-effective applications that will accelerate the widespread adoption of (semi)autonomous systems. The ATTRI program has been in partnership with the ARIBO program for several years to affordably leverage federal investments in automated ground systems for common goals.

ARIBO is conducting a series of pilot projects specifically focused on personal mobility for veterans with disabilities. Users are continuously interacting with the technologies, identifying improvements and discovering new uses at the same time they are becoming more comfortable with the technology. Throughout this agile feedback loop, valuable data is being collected documenting operational, maintenance, and reliability factors which, in turn, improve the veracity of the business case and help target future system improvements. Users come to understand the technology, its capabilities, and its potential. Developers come to understand the real uses and required tweaks to the systems, their real costs, and their real benefits.[6]

ARIBO has three primary strategic objectives:

1. Socialize users and non-users with automated systems
2. Identify operational issues and help with development of mitigation strategies to increase use of automated systems

3. Generate empirical data (e.g. performance, reliability, maintenance, etc.)

Currently, ARIBO is piloting its Autonomous Warrior Transport On-base (AWTO) project that is addressing the real-world needs of the Warrior Transition Battalion at Fort Bragg, NC. The soldiers in this battalion, some of whom have mobility difficulties, often require transportation assistance from the barracks to the Womack Army Medical Center. TARDEC is utilizing robotic technology to provide an unmanned transport system and reservation/reminder system for these soldiers and their caretakers. The AWTO transportation system is an on-demand service, where users can request a ride from their mobile phone or on-site kiosks. The shuttle transports participants over a roughly one square mile area with five pickup/drop-off locations.[5] ARIBO expects the automated shuttles to save $20 million over the next seven years based on the reduction in vehicles the Army would need to maintain and operate.[7]

Chapter 3. Mobility on Demand

Introduction

Mobility on Demand (MOD) is a multimodal, integrated, accessible, and connected transportation system in which personalized mobility is a key objective. MOD enables the use of on demand information, real-time data, and predictive analysis to provide individual travelers with transportation choices that best serve their specific needs and circumstances. Modes facilitated through MOD providers can include: carsharing, bikesharing, ridesharing, ridesourcing, microtransit, shuttle services, public transportation, and other emerging transportation solutions.

A number of key trends are laying the foundation for MOD.[1] These include:

- **Increasing population**. Over the next 30 years, the U.S. population is expected to grow by about 70 million, with most of this growth occurring in cities. Growing urbanization will continue to put significant strain on city infrastructure and transportation networks.
- **Aging population.** By 2045, the number of Americans over the age of 65 will increase by 77 percent. Older Americans require mobility choices allowing them to age in place.
- **1 in 5 Americans are disabled.** Persons with disabilities comprise nearly 20 percent of the U.S. population. About one-third of people over age 65 have a disability that limits mobility.
- **Rise of mobile devices.** Ninety (90) percent of American adults own a mobile phone allowing them to access everything from traffic data to transit schedules to inform travel choices. In addition, 20 percent of adults use their phones for up-to-the-minute traffic or transit data and smartphones are regularly used for turn-by-turn navigation.
- **Millennials waning interest in car ownership.** Millennials are becoming less and less reliant on car ownership compared to previous generations. By the end of the 2000's, they drove over 20 percent fewer miles than at the start of the decade. Millennials are the first generation to have access to internet during their formative years and are often early adopters of technology solutions including shared-use mobility services.
- **Growing popularity of shared mobility and modes.** There is growing popularity of shared mobility and shared modes, such as bikesharing and ridesourcing. The sharing economy and new transportation services are providing people with more options, helping to overcome barriers to the use of non-driving forms of transportation, and shifting individuals' travel choices.
- **Big Data era.** The transportation sector is increasingly relying on data to drive decisions. Data is projected to grow by 40 percent annually. Data enables innovative transportation options such as carsharing, ridesharing, and pop-up bus services.
- **Rise of connected vehicles and infrastructure**. Data derived from connected vehicles provide insights to transportation operators helping to understand demand and assist in predicting and responding to movements around a city.

The transportation landscape is changing, and research in new mobility options is necessary to document, evaluate, and adequately plan for growing mobility demands, new technologies, and changing demographics, amidst challenging financial realities. New business models and the demand for situational mobility choices offer new opportunities in shared-use mobility, such as car sharing, bike sharing, and ridesharing, and app-based ridesourcing provided by Transportation Network Companies (TNCs). Likewise, there is a renewed interest in demand-responsive operations largely driven by mobile technologies and the nearly ubiquitous smartphone. Along with traditional transportation options, these new trends provide real opportunities to develop an integrated system of mobility choices focused on meeting the needs of a diverse cross section of users while enhancing the safety of all travelers. MOD is poised to contribute to this new ecosystem with connected travelers, infrastructure, innovative operations and personal mobility needs.[1]

In 2016, the Federal Transit Administration (FTA) and Intelligent Transportation Systems Joint Program Office (ITS JPO) launched the MOD Sandbox Program that aims to provide a platform where integrated MOD concepts and solutions, supported through key local partnerships, are demonstrated in real-world settings. These projects will use smartphone apps, open data platforms, and other advanced technologies to better connect transit riders to their destinations, aided by private companies and research institutions in fields such as software development, ride-sharing, and bike-share. The 11 project selections receiving nearly $8 million in funding are described below.[2]

Table 7: MOD Sandbox Program Grantees and their Proposed Projects

Agency	Project Description
Regional Transportation Authority (Pima County, AZ)	Integrates fixed route, subscription based ride-sharing and social carpooling services into a platform to address first mile/last mile issues.
Valley Metro Rail (Phoenix, AZ)	Smart phone mobility platform that integrates mobile ticketing and multimodal trip planning, including ride-hailing, bike sharing, and car-sharing companies.
City of Palo Alto, CA	Commuter planning project incorporating trip reduction software, a multi-modal trip planning app, and workplace parking rebates.
Los Angeles County Metropolitan Transportation Authority	Mobility on demand partnership with the car-sharing company, Lyft. *This project, led by LA Metro, includes a companion project in Seattle, WA.
San Francisco Bay Area Rapid Transit	Integrated carpool-to-transit program.
Pinellas Suncoast Transit Authority (Pinellas County, FL)	On-demand paratransit using taxis and a car-sharing company to provide door-to-door service.
Chicago Transit Authority	Incorporates local bike-sharing company Divvy into CTA's transit trip planning app.
Tri-County Metropolitan Transportation District of Oregon (Portland, OR)	Platform integrating transit and shared-use mobility options. By integrating data, the project will allow users to plan trips that address first/last mile issues while traveling by transit.
Dallas Area Rapid Transit	Integrates ride-sharing services into DART’s GoPass ticketing app.
Vermont Agency of Transportation	Statewide transit trip planner incorporating flex-route, hail-a-ride, and other non-fixed-route services into mobility apps.

Agency	Project Description
Pierce Transit (Pierce County, WA)	Limited Access Connections project connects service across two transit systems – local and regional – and ride-share companies to increase transit use across the Seattle region.

While the MOD Sandbox projects are still in the process of being deployed and evaluated, other pilot projects are demonstrating MOD concepts with the following benefits, costs and lessons learned.

Benefits

Carsharing

MOD enables smarter, more efficient, and safer mobility within a multimodal ecosystem that benefits individual travelers, transportation operators, and system managers alike. One such form of MOD, carsharing, is becoming increasingly popular due to its appeal as being personally convenient and more eco-friendly.

Car2go is currently the largest carsharing operator in the world, with a presence in nine countries and nearly 30 cities. It operates as a one-way instant access carsharing system within a pre-defined urban zone. The University of California Berkeley's Transportation Sustainability Research Center conducted a one-way carsharing impact study and found that car2go's flexible one-way carsharing model can work in tandem with existing mass transit options. The study gathered and analyzed car2go activity data from approximately 9,500 car2go members residing in Calgary, San Diego, Seattle, Vancouver and Washington, DC to determine the impacts on vehicle ownership, modal shift, vehicle miles traveled (VMT), and greenhouse gas (GHG) emissions.

Overall, the results of this study suggest that car2go one-way carsharing is substantively impacting travel behavior, miles driven, GHG emissions, and the number of vehicles on urban roads within operating regions (2016-01125).

Across the five study cities, it is estimated that:

- Car2go members sold (gave up ownership of) between 1 to 3 vehicles per car2go vehicle (on average)
- Car2go members suppressed the need for (reduced vehicle usage) for between 4 to 9 vehicles per car2go vehicle (on average)
- Overall, when considering both effects together, each car2go vehicle removed between 7 to 11 vehicles from the road of the five cities studied (on average)
- On balance car2go reduced VMT by 6 percent to 16 percent, per car2go household
- GHG emissions were reduced by 4 percent to 18 percent per car2go household

Bikesharing

Since 2010, the Capital Bikeshare service has connected a network of over 450 stations via 4,000 bicycles across several jurisdictions in the Washington, DC area including Arlington County, VA. Arlington County reported on progress on the service's performance measures in its FY2016-FY2021 Transit Development Plan Update & Progress Report (2018-01252).

Results from 2013 to 2014 show increases in ridership, with slightly shorter trips as follows:

- Ridership grew by 24 percent between FY2013 and FY2014 as the system expanded service.
- The average annual number of trips per bicycle decreased slightly between 2013 and 2014 from 393 to 381. This decrease was expected as the system expanded to outside of Arlington's Metrorail corridors where the highest ridership is located.
- The service saved Arlington members a combined estimated $2 million dollars in transportation spending in 2014.
- Overall the total calories burned by users grew to 14,390,372 calories in 2014, reflecting higher ridership.
- Calories burned per trip decreased from 2013 to 2014, from 80 to 75 due to a decrease in average trip distance.
- The service improved its operating cost recovery ratio from 59 percent in FY2013 to 63 percent in FY2014.

Arlington County intends to expand the bikesharing service, while working on increasing the diversity of the user base and reducing its dependency on Arlington County operating funds.

Costs

A limited number of ITS applications have been deployed to support MOD systems, with cost data not publically reported. However, costs to operate shared used services are starting to become available.

Carsharing

The primary concern of cities implementing a carsharing agreement involves issues of parking. Many carsharing programs have agreements with municipalities to allow for free on-street parking. The companies also have agreements with cities that provide a number of dedicated spaces, indicated by city signs, paint, or other markings. Typically the carsharing company pays the city a fee to cover these costs, which can generate significant revenues. Depending on the agreement the car company may also pay for other costs to operate that include insurance, pilot evaluation, car removal in cases of parking restriction violations. Information on payments made by Car2Go when launching its carsharing service is U.S. markets is shown below (2018-00395).

Table 8: Car2Go's Payment per Vehicle to Various U.S. Cities

City	Payment per Vehicle per Year	Year	Notes
Arlington County, VA	$1,645	2015	Includes payment for pilot program administration and evaluation costs. Car2Go also agreed to move cars that have remained parked for 24 hours in areas zoned for residential permit parking and parked for 36 hours elsewhere
Austin, TX	$1,449	2011	
Minneapolis, MN	$1,689 for first 250 vehicles $1,614 for each additional vehicle	2013	Includes administrative cost, meter revenue recovery, event revenue recovery, and residential permits
Portland, OR	$1,303	2015	
Washington, DC	$2,644	2012	Initially paid $578,000 for 200 cars; paid an additional $215,300 to add 100 vehicles

Bikesharing

Recently Arlington County reported its cost to operate the Capital Bikeshare service in its region. Bikesharing is a service in which bicycles are made available for shared use to individuals for a short time period for a fee. The rider reserves and pays for the bicycle rental with a smartphone applications although many services also allow credit card payments at the docking station. Operating costs for 70 stations with 493 bicycles were broken out by system operations and management and marketing. System costs were projected to increase in FY2015 due to expansion of the service by up to 22 stations (2018-00396).

Table 9: Arlington County's Capital Bikeshare Operating Expenditures

	FY2014 (Actual)	FY2015 (Projected)
Expenses		
System Operations	$1,246,000	$1,371,000
Management and Marketing	$185,000	$103,000
Total	$1,431,000	$1,474,000
Revenue		
User Revenue	$792,000	$972,000

	FY2014 (Actual)	FY2015 (Projected)
Private Sponsorships	$102,000	$89,000
Arlington County Commuter Services Commissions	$558,339	$65,000
Local Funding (TCF)	$0	$348,000
Total	$1,452,339	$1,474,000

The overall cost recovery ratio (the portion of operating expenses covered by user revenue and private sponsorships) in FY2014 was 63 percent. Arlington County has a goal to minimize operating costs while providing an effective service at the regional and local levels.

Lessons Learned

Ridesharing

In 2012, Santa Barbara County Association of Governments Traffic Solutions and the Community Environmental Council in Santa Barbara County launched the Dynamic Rideshare project, an FHWA Value Pricing Pilot Program project. The project focused on increasing rideshare participation by implementing a dynamic ridesharing program using a smartphone application (branded as *Carma*) that provided near real time carpool matching for individual trips. The app also provided the ability to incentivize carpooling through micro payments from Traffic Solutions to the riders and drivers. Through GPS enabled mobile devices, actual trip data was tracked for all trips within the app.

Overall, the pilot was unsuccessful at launching Real Time Ridesharing in Santa Barbara County as the *Carma* application failed to garner as much of a user-base as hoped. In total, 274 trips were made which resulted in 3,325 miles of ridesharing. The failure of adoption of the Real Time Rideshare Program can be attributed to several factors, including the lengthy app development process, the steep learning curve using the app, and the lack of motivating forces and a culture for Real Time Ridesharing.

Key lessons for communities interested in launching a Real Time Rideshare community are as follows (2016-00751):

- Conduct internal testing of the technology before introducing it to the general public, and only introduce a technology that is stable and user-friendly.
- Target markets that have natural conditions that lend themselves to a Real Time Rideshare solution, such as toll lanes, HOV lanes, expensive parking, and a concentration of travel between select origins and destinations.
- Remember that offering a Real Time Rideshare app does not create its own demand.
- Do not underestimate the level of effort needed to build a critical mass of app users.
- Consider testing smaller Real Time Rideshare groups composed of 15 to 25 individuals that have similar commutes as an incremental approach to building a larger Real Time Rideshare community. Each group should have a champion that will conduct outreach and marketing to form the group.

Case Study – Mobility as a Service *UbiGo* (Gothenburg, Sweden)

UbiGo was a public 6-month trial of a Mobility-as-a-Service (MaaS) model, undertaken by project Go:smart, in the city of Gothenburg, Sweden. The project was developed as an attempt to create better conditions for sustainable travel by demonstrating how new business models and partnerships can reduce the need for private car ownership. The UbiGo model achieves this through a web-based smartphone application that combines public transport, car sharing, rental car service, taxi and bike-sharing services all into one application, all on one invoice. The application provides 24/7 technical support, an "improved" travel guarantee and even bonuses for sustainable travel choices.

Source: UbiGo

The public trial operated from November 2013 to April 2014, and involved 195 users. For the study, trial users subscribed to prepaid monthly packages (similar to a mobile phone subscription) based on their travel needs, with the ability to charge additional trips and save unused trips for later use.

An evaluation of the MaaS model was performed based on surveys, interviews, travel diaries and focus groups. The participant users were interviewed before, during and after the trial about their experience and their satisfaction with the service. After the initial six months of testing, no household stopped using UbiGo, and nearly 80 percent indicated that they would be interested in becoming an UbiGo customer if the pilot became a regular service. Regarding traveler behavior, half of the users changed their modes of travel, four out of ten changed the way they plan their trips, and one out of four changed their "travel-chains". In a follow-up survey, many participants stated that they had become less reliant on private cars and were more likely to use other forms of transportation such as public transit, walking and cycling after their participation in the pilot. Additionally, users stated UbiGo made it easier to pay for travel and gave them better control of expenditures.[3]

The total cost of the project was £1.5 million and overall perceived benefits of the project included greater efficiency to transportation services and a reduction in greenhouse gas emissions (2017-01197).

Case Study – Transportation Network Companies (New York, NY)

A recent report presents findings from a detailed analysis of the growth of app-based ride services in New York City, their impacts on traffic, travel patterns and vehicle mileage since 2013, and implications for policy makers. Results show the increases in trips, passengers and mileage generated by the growth of Uber, Lyft and other app-based ride services since 2013 as follows (2018-01245):

- TNCs provided 80 million trips in 2016, transporting 133 million passengers.
- After accounting for declines in yellow cab, black car and car service ridership, TNCs have generated net increases of 31 million trips and 52 million passengers over the past three years.

- TNCs also accounted for the addition of 600 million miles of vehicular travel over the past three years, after accounting for declines in yellow cab, black car and car service mileage and shifts from personal vehicles.
- Growth in trips, passengers and mileage was seen throughout the city. The majority of net growth occurred in northern Manhattan and the boroughs outside Manhattan. But there was also significant growth in the Manhattan core, all of it since mid-2015.
- Trip growth in Manhattan, after subtracting shifts between industry sectors, has been concentrated during the morning and evening peak periods, late evenings, and weekends.

While increasing mobility options, the growth in TNC trips and mileage has significant implications for New York City's ability to achieve its goals for sustainable population and economic growth. Potential impacts discussed included: travelers moving from transit to TNCs, potentially undermining the revenue base for transit; increased vehicle mileage from TNC increase traffic congestion delaying buses, taxis and other for-hire vehicles, driving up travel time and costs; and increased vehicle mileage from TNCs may reduce traffic safety and increase greenhouse gas emissions.

Chapter 4. Information Management

Introduction

Intelligent transportation systems collect large amounts of data on the operational status of the transportation system. Archiving and analyzing this data can provide significant benefits to transportation agencies.

Archived data management systems (ADMS) collect data from ITS applications and assist in transportation administration, policy evaluation, safety, planning, program assessment, operations research, and other applications. Small-scale data archiving systems can support a single agency or operations center, while larger systems support multiple agencies and can act as a regional warehouse for ITS data.

The 2012 transportation reauthorization law Moving Ahead for Progress in the 21st Century (MAP-21) has set up new requirements for performance-based transportation decision making, including establishing performance measures and targets in seven national goal areas such as congestion reduction and system reliability. Public agencies are seeking real time and archived data to provide metrics and measurements of system performance.

Example uses of archived ITS data include:

- Incident management programs may review incident locations to schedule staging and patrol routes, and frequencies for service patrol vehicles.
- Historical traffic information can be used to develop predictive travel times.
- Transit agencies may review schedule performance data archived from automatic vehicle location, computer-aided dispatch systems and/or automatic passenger counting systems to design more effective schedules and route designs, or to manage operations more efficiently.

As information management and data archiving systems evolve they are moving from archiving information from a single source or system to more complex implementations. In order to provide support for regional operations across jurisdictional and agency boundaries, data fusion from multiple sources and/or agencies, integration of both real time and archived information, and data visualization are being incorporated.

Information management and data archiving from both infrastructure and mobile sources in data environments are also the foundation of the Real-Time Data Capture and Management track of the ITS Research Program.

The collection and storage of data on transportation system performance often occurs at transportation management centers (TMCs). The transportation management centers chapter discusses TMCs in detail. In addition, the transit management chapter discusses the archiving and use of transit performance data.

Benefits

Data archiving enhances ITS integration and allows for coordinated regional decision making. Traffic surveillance system data, as well as data collected from commercial vehicle operations, transit systems, electronic payment systems, and road weather information systems have been the primary sources of archived data available to researchers and planners. Often the benefits of the archived data systems are not easily quantified. The archived data provides information not previously available, and enables analyses of problems and solutions not possible with traditional data. As more advanced data analysis techniques develop and the efficiency of data reporting systems are improved, additional examples of the effectiveness of information management systems will become available. Methodologies for computing the benefits of information management must be developed.

Table 10: Benefits of Information Management.

ITS Goal	Selected Findings
Customer Satisfaction	In Virginia, a web-based archived data management system (ADMS) was deployed to provide decision makers and other transportation professionals with traffic, incident, and weather data needed for planning and traffic analyses. An assessment of website activity indicated that 80 percent of the website usage was devoted to downloading data files needed to create simple maps and graphics. Overall, users were pleased with the ability of the system to provide a variety of data, but wanted more information on traffic counts, turning movements, and work zones, as well as broader coverage. (2008-00560)
Efficiency	In Portland, Oregon, the Tri-Met transit agency used archived AVL data to construct running time distributions (by route and time period) and provide enhanced information to operators and dispatchers. Evaluation data indicated that the reduced variation in run times and improved schedule efficiency maximized the effective use of resources. (2008-00587)
Productivity	The Iowa Department of Transportation (DOT) found that a project to make data reporting and analysis tools available to local law enforcement organizations resulted in an increase in officer-generated crash reports received electronically from 68 percent from 47 percent, allowing the agency to provide statewide crash data on a quarterly basis. At the beginning of the project, the available data was 1.5 to 3 years old. (2013-00882.)
Productivity	A study using archived data at five study locations with a variety of seasonal traffic patterns found that in some situations, up to 75 percent of all days can be missing data at urban locations when calculating annual average daily traffic statistics with archived ITS data. This finding challenges conventional procedures for the calculation of annual average planning statistics. (2013-00873)

Costs

The costs to develop ADMS vary based on the size of the system and features provided. Based on limited data available from a study of six transportation agencies that have established ADMS, costs for one system was $85,000 and $8 million for another. Four of the six systems were developed jointly with a university. Typically, the state DOT pays for the development with the university hosting the system. Operations and maintenance (O&M) costs were in a closer range, $150,000 to $350,000; these costs were usually on an annual basis.

The University of Maryland hosts the Regional Integrated Transportation Information System (RITIS) which collects, archives, and provides data fusion and visualization for agencies in the Washington, D.C. region and beyond. The system costs about $400,000 a year to maintain and operate (in 2011). Costs for an agency to integrate their data within RITIS have varied depending on the system and effort required for integration from a low of $15,000 to a high of $300,000.

A study of the feasibility and implementation options for establishing a regional data archiving system to help monitor and manage traffic operations in Northeast Illinois estimated the cost for developing software to integrate data from multiple agencies in a region and produce both historical and real-time reports as ranging from $700,000 (low) to $1,000,000 (high) (2011-00221).

Table 11: System Costs of Archived Data Management Systems.

Cost Category	Source	Min	Max	Cost ID
ADMS	Washington State TRAC System and Caltrans PeMS	$85,000 (initial R&D)	$8,000,000	2008-00173
Statewide Electronic Crash Data Collection System	Vermont, Virginia	$1,105,000	$2,272,209	2013-00280
Regional Data Archive	Northeast Illinois Regional Data Archive (estimate)	$700,000	$1,046,000	2011-00221

Table 12: Selected Archived Data Management Costs.

Cost Category	Source	Min	Max	Cost ID
Hardware Costs	Illinois Regional Data Archive (estimate)	$42,400	$46,400	2011-00221
Operations and Maintenance	Virginia ADMS University of Maryland RITIS	$150,000 $400,000	$350,000 $400,000	2008-00174 2011-00220
Software Development	Illinois Regional Data Archive (estimate)	$700,000	$1,000,000	2011-00221
Training	Caltrans PeMS	$350,000	$350,000	2013-00291

Lessons Learned

The SafeTrip-21 Initiative demonstrated the feasibility of alternative approaches to collecting and using traffic data. In some cases, applications demonstrated new sources of traffic condition data. In other cases, applications made use of traditional data in new ways. The SafeTrip-21 Initiative highlighted, for example, how the mass-market availability of GPS-enabled smart phones complements traditional fixed sensors as a new data source, as well as offers the potential to deliver personalized travel information (2013-00649). Among the lessons learned are:

Use new and traditional data sources to enhance traffic models and to help solve problems related to mode shift and travel demand. Traffic model development can benefit from integrating traffic probe data with other data sources for both freeways and arterials. Several SafeTrip-21 tests showed that ITS technology is capable of collecting the data needed by traffic and transit operations agencies to collaborate and better understand mode shift and travel demands across modes.

Consider procuring traffic data and information, rather than building in-house data collection systems, to reduce costs. Agencies have traditionally procured hardware, software, and systems that allowed them to collect, analyze, and produce traffic data, which likely proved to be a laborious effort. An emerging alternative is to procure data and/or information services as a more cost-effective, resource-efficient alternative to developing the data and/or end product internally.

Explore the potential of new consumer devices, applications and services for collecting new traffic data and combining it with traditional traffic data to be used in new and innovative ways. For example, cell phone GPS systems can alter the way traffic data is collected by leveraging the existing cell phone infrastructure to collect traffic data and transmit traffic information directly back to drivers.

Assess traffic data and information services carefully to ensure the quality and quantity of data and information needed. The ability to deploy a traveler information concept is only as successful as the availability, timeliness, and accuracy of its data sources. Also, practical concerns of transportation professionals should govern their acceptance of new traffic data services and devices.

Case Study – Using Regional Archived Multimodal Transportation System Data for Policy Analysis

METRANS Transportation Center is a joint partnership of the University of Southern California (USC) and California State University Long Beach. As one of the most congested areas in the country and a center for international trade and immigration, the Southern-California region has one of the largest transit-dependent populations in the country. METRANS' mission is to foster independent, high quality research to solve the nation's transportation problems; train the next generation of transportation workforce; and disseminate information, best practices, and technology to the professional community.

With funding secured from Los Angeles County Metropolitan Transportation Authority (Metro), METRANS owns and operates an ADMS which archives historical highway, arterial and public transit system performance data from Regional Integration of Intelligent Transportation Systems (RIITS), which includes data from Metro, Caltrans, City of Los Angeles Department of Transportation, California Highway Patrol, Long Beach Transit and Foothill Transit. The vast and diverse database includes data from roadway traffic sensors, CCTV video feeds, on-board AVL units, transit passenger counters and accident reports.[1]

A research team from USC's Price School of Public Policy wanted to apply these data sources to urban planning by utilizing the ADMS archives to analyze the impact of the capital investment in the Phase 1 addition of the LA Metro Expo Line. The Expo Line project was touted by officials as an investment that would improve access and mobility of residents and employees and increase transit mode share, all while alleviating congestion. The team was most interested in the effect the rail project had on local freeway and arterial system performance, stating that while transit investments are often promoted as a way to reduce congestion, there is very limited literature on the examined impacts of new rail lines on traffic.

Source: USC

For the study, data pulled from geo-located sensors along the I-10 Freeway and arterial roads over a three-month "pre-Expo Line" period that lasted from November 2011 to January 2012 was compared against three months of "post-Expo Line" data that was collected from November 2012 to January 2013.[1] The team used close to 1 million records from freeway sensors and almost 16 million from arterial road sensors. The researchers found that the records revealed that the Expo Line had little, if any, impact on local arterial or freeway congestion. It did, however, initiate a significant overall rise in transit ridership across the Culver City-Downtown Los Angeles corridor along the Expo Line.

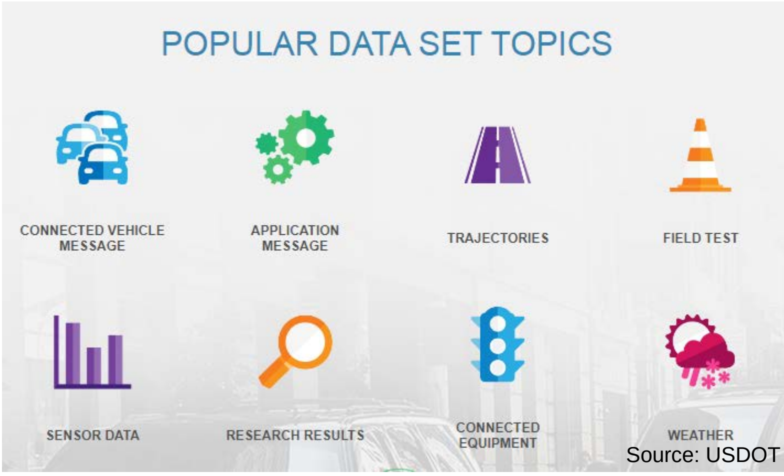
The USC team was awarded the 2017 Chester Rapkin Award by the Association of Collegiate Schools of Planning for the work described in their paper "Using Regional Archived Multimodal Transportation System Data for Policy Analysis: A Case Study of the LA Metro Expo Line".[2] Those involved with the project hope that the findings outlined in their report help transit planners design better projects that increase transit patronage and meet objectives or expectations.

Unlike many transportation agencies where data is collected for real-time operations and disposed of, METRANS ADMS archives this data in a systematic fashion to facilitate effective decision making using predictive data.

Regarding the power of Big Data in transportation, the Southern California region is one of the first areas in the country that are systematically storing real-time data sets in this manner. The ability to do before/after studies opens new possibilities as far as measuring, monitoring and evaluating the performance of systems and new infrastructure projects. One notable application is with predictive route planning. Most existing route-planning algorithms operate on "detect and avoid," however with a data archive such as METRANS', agencies can "predict and avoid," allowing them to plan their schedules better. This manner of utilizing predictive data for effective decision making is all a part of the process to transition Los Angeles to a Smart City.

Case Study – USDOT's *ITS Public Data Hub* Data Sharing Platform

The ITS JPO and its multimodal partners are dedicated to providing open access to archival and real-time publicly funded research data. Beginning in 2018, the ITS Public Data Hub became the USDOT's primary storage and access system for ITS data. By providing access to these data, the USDOT aims to enable third-party research into the effectiveness of emerging ITS technologies, preliminary development of third-party applications, and harmonization of data across similar collections. Features of the ITS Public Data Hub include: timely access to data from ongoing ITS projects; the ability to create visualizations and conduct analysis online; an enhanced user interface for viewing, filtering, and downloading ITS data; and the ability to save and share analysis of ITS data. As of February 2018, there are over 138 datasets (and counting) available on the data hub.



Source: USDOT

Similar to the USDOT's now deprecated Research Data Exchange (RDE), the ITS Public Data Hub offers several visualization tools that users are encouraged to play around with. Six prototype visualization elements are available for viewing at https://www.its.dot.gov/data/visualizations/. The Data Lens feature within the ITS Public Data Hub provides users with a data dashboard-type interface that allows them to create map and chart dashboard cards based on various data through cross filtering. Such cross filtering allows users to see how information in one dashboard card relates to another.

A key milestone for ITS JPO was to have up-to-date data from an ongoing project available on the data hub. This is being accomplished with the Wyoming Connected Vehicle Pilot data that is being added to the ITS Public Data Hub in near-real time. Available data online includes a live running log of approximately one day's worth of sanitized Basic Safety Messages (BSM) as well as a sample of Traveler Information Messages (TIMs) generated by several test vehicles and roadside equipment within the Wyoming Connected Vehicle Pilot. Users also have the opportunity to access the full data set through a standard application programming interface. A great volume of data is expected to be generated by the Wyoming Pilot. In late 2018 when the pilot is operating at full-scale, the system expects to have over 400 connected vehicles generating up to 115 million records a day. The New York City and Tampa Pilots are expected to have an even larger volume of data once their data connections are set up.[3]

A sample analysis performed on the Wyoming Pilot data on the ITS Public Data Hub is portrayed in the screenshot below. In the screenshot, the right hand side shows all the BSMs from the one day sample mapped out along the I-80 corridor in Wyoming, while the left hand side shows three histograms: one breaking down vehicle messages by speed, one on the time the message was generated, and the third on vehicle heading. Within the Data Lens feature, users have the ability to click on specific areas of the map to drill down and do a geographic analysis on where higher concentrations of messages are and what types of messages they are.

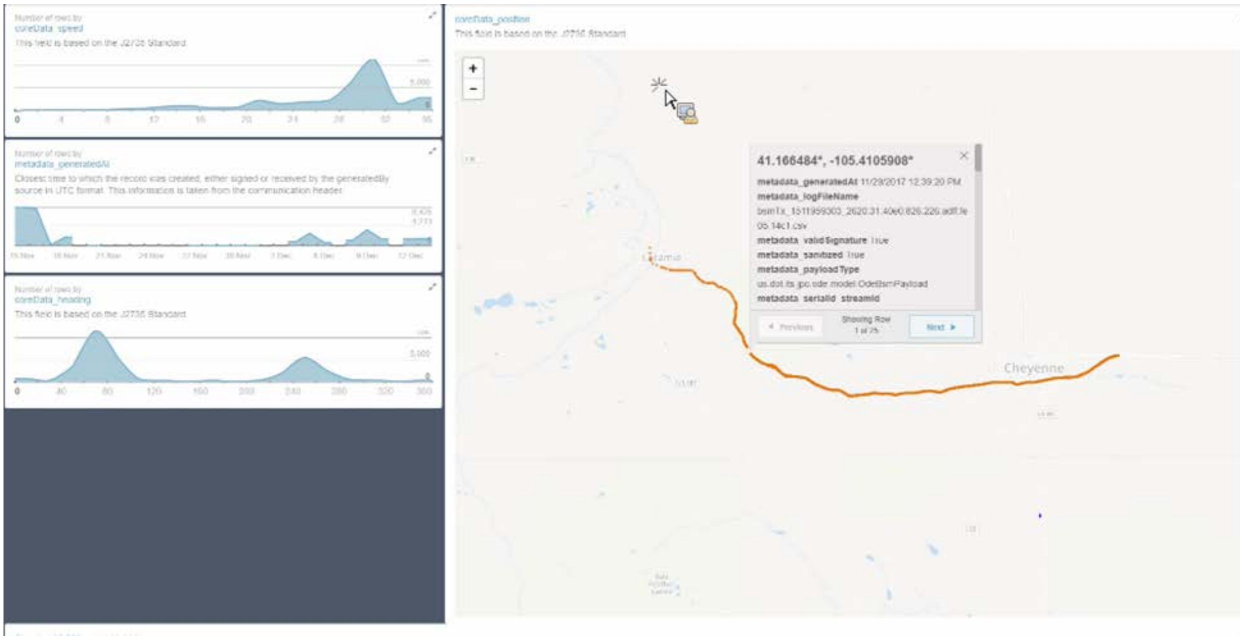


Figure 3: Sample Visualizations of the Wyoming Connected Vehicle Pilot Data within the ITS Public Data Hub[3]

Chapter 5. Connected Vehicle – Safety

Introduction

The U.S. Department of Transportation's (USDOT) Connected Vehicle program is working with state and local transportation agencies, vehicle and device makers, and the public to test and evaluate technology that will enable cars, buses, trucks, trains, roads and other infrastructure, and our smartphones and other devices to “talk” to one another. Cars on the highway, for example, would use short-range radio signals to communicate with each other so every vehicle on the road would be aware of where other nearby vehicles are. Drivers would receive notifications and alerts of dangerous situations, such as someone about to run a red light as they are nearing an intersection or an oncoming car, out of sight beyond a curve, swerving into their lane to avoid an object on the road. Connected Vehicle technologies aim to tackle some of the biggest challenges in the surface transportation industry--in the areas of safety, mobility, and environment. Applications are being developed in each of these areas. Safety applications center on the basic safety message (BSM), a packet of data that contains information about vehicle position, heading, speed, and other information relating to a vehicle’s state and predicted path.

Connected Vehicle (CV) safety applications will enable drivers to have 360-degree awareness of hazards and situations they cannot even see. Through in-car warnings, drivers will be alerted to imminent crash situations, such as merging trucks, cars in the driver's blind side, or when a vehicle ahead brakes suddenly. By communicating with roadside infrastructure, drivers will be alerted when they are entering a school zone, if workers are on the roadside, and if an upcoming traffic light is about to change.


Source: USDOT

CV deployment sites predominantly feature safety applications as the driving force. CV safety applications include Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V), and Vehicle-to-Pedestrian (V2P) applications.

A description of the V2I safety applications follows:

- Red Light Violation Warning (RLVW) – An application that broadcasts signal phase and timing (SPaT) and other data to the in-vehicle device, allowing the vehicle to compute warnings for impending red light violations.
- Stop Sign Violation Warning (SSVW) – An application that broadcasts the presence and position of a stop sign to the in-vehicle device, allowing the vehicle to determine, and provide alerts and warnings, if the driver is at risk of violating the stop sign.
- Stop Sign Gap Assist (SSGA) – An application that utilizes traffic information broadcasting from roadside equipment to warn drivers of potential collisions at two-way stop controlled intersections.

- Pedestrian in Signalized Crosswalk Warning – An application that warns drivers when pedestrians, within the crosswalk of a signalized intersection, are in the intended path of the vehicle.

- Curve Speed Warning (CSW) – An application that broadcasts precise geometric information and road surface friction to the in-vehicle device, allowing the vehicle to provide alerts and warnings to the driver who is approaching the curve at an unsafe speed.

- Spot Weather Impact Warning (SWIW) – An application that warns drivers of local hazardous weather conditions by relaying weather data to roadside equipment, which then re-broadcasts to nearby vehicles.

- Reduced Speed/Work Zone Warning (RSZW) – An application that utilizes roadside equipment to broadcast alerts to drivers warning them to reduce speed, change lanes, or watch for stopped traffic ahead within work zones.

NHTSA estimates that safety applications enabled by V2V and V2I could eliminate or mitigate the severity of up to 80 percent of non-impaired crashes, including crashes at intersections or while changing lanes.

Other V2I safety applications include Oversize Vehicle Warning (OVW) and Railroad Crossing Violation Warning (RCVW). These applications have developed concepts of operations and system requirements, but have not yet been prototyped and tested in an operational environment.

V2V devices would use the dedicated short range communications (DSRC) to transmit data, such as location, direction and speed, to nearby vehicles. That data would be updated and broadcast up to 10 times per second to nearby vehicles, and using that information, V2V-equipped vehicles can identify risks and provide warnings to drivers to avoid imminent crashes. Vehicles that contain automated driving functions—such as automatic emergency braking and adaptive cruise control—could also benefit from the use of V2V data to better avoid or reduce the consequences of crashes.

V2V communications can provide the vehicle and driver with enhanced abilities to address additional crash situations, including those, for example, in which a driver needs to decide if it is safe to pass on a two-lane road (potential head-on collision), make a left turn across the path of oncoming traffic, or determine if a vehicle approaching an intersection appears to be on a collision course. In those situations, V2V communications can detect developing threat situations hundreds of yards away, and often in situations in which the driver and on-board sensors alone cannot detect the threat.

A description of the V2V safety applications follows:

- Forward Collision Warning (FCW) – warns drivers of stopped, slowing, or slower vehicles ahead. FCW addresses rear-end crashes that are separated into three key scenarios based on the movement of lead vehicles: lead-vehicle stopped, lead-vehicle moving at slower constant speed, and lead-vehicle decelerating.

- Emergency Electronic Brake Light (EEBL) – warns drivers of heavy braking ahead in the traffic queue. EEBL would enable vehicles to broadcast its emergency brake and allow the surrounding vehicles' applications to determine the relevance of the emergency brake event and alert the drivers. EEBL is expected to be particularly useful when the driver's visibility is limited or obstructed.

- Intersection Movement Assist (IMA) – warns drivers of vehicles approaching from a lateral direction at an intersection. IMA is designed to avoid intersection crossing crashes, the most severe crashes based on the fatality counts. Intersection crashes include intersection, intersection-related, driveway/alley, and driveway access related crashes. IMA crashes are categorized into two major scenarios: turn-into path into same direction or opposite direction and straight crossing paths.

- Left Turn Assist (LTA) – warns drivers to the presence of oncoming, opposite-direction traffic when attempting a left turn. LTA addresses crashes where one involved vehicle was making a left turn at the intersection and the other vehicle was traveling straight from the opposite direction.

Source: USDOT

- Do Not Pass Warning (DNPW) – warns a driver of an oncoming, opposite-direction vehicle when attempting to pass a slower vehicle on an undivided two-lane roadway. DNPW would assist drivers to avoid opposite-direction crashes that result from passing maneuvers. These crashes include head-on, forward impact, and angle sideswipe crashes.
- Blind Spot/Lane Change Warning (BS/LCW) – alerts drivers to the presence of vehicles approaching or in their blind spot in the adjacent lane. BS/LCW addresses crashes where a vehicle made a lane changing/merging maneuver prior to the crashes.

V2P detection systems can be implemented in vehicles, infrastructure, or with pedestrians themselves to provide warnings to drivers, pedestrians, or both through in-vehicle systems and handheld devices.

A description of V2P safety applications follows:

- Mobile Accessible Pedestrian Signal System (PED-SIG): allows for an automated call from the smartphone from a visually impaired pedestrian to the traffic signal. The application provides audio cues to the pedestrian to safely navigate the crosswalk and alerts drivers attempting to make a turn to the presence of a visually impaired pedestrian.
- Pedestrian and Signalized Crosswalk (PED-X): warns drivers when pedestrians are within the crosswalk of a signalized intersection, or are in the intended path of the vehicle.
- Intelligent Pedestrian Traffic Signal (IPTS): utilizes VRU2I (vulnerable road user-to-infrastructure) communications where pedestrians may activate green light demand for crossing an intersection via their smart phone. While pedestrians are crossing, the IPTS may detect pedestrians to determine if the pedestrian phase should be extended to ensure safe crossing.
- Intelligent Pedestrian Detectors (IPD): automatically detects pedestrians and places requests for pedestrian signals on their behalf, generally shortening the amount of time pedestrians must wait before they can cross.

See the ITS website (www.its.dot.gov) for the most up-to-date information about CV safety applications.

Benefits

NHTSA estimates that safety applications enabled by V2V and V2I could eliminate or mitigate the severity of up to 80 percent of non-impaired crashes, including crashes at intersections or while changing lanes.

V2I Safety Applications. Research on V2I safety applications has revealed the potential population of crashes that can potentially be addressed by various applications. If one assumes full market penetration and 100% effectiveness of the application, those would be crashes they can be avoided. Although we know this is not the case, it provides an upper bound on what could be achieved.

Figure 4 contains a summary of this information. Intersection-focused safety applications may potentially address up to 575,000 crashes per year. Curve Speed Warning safety applications may potentially address up to 169,000 crashes per year.[1]

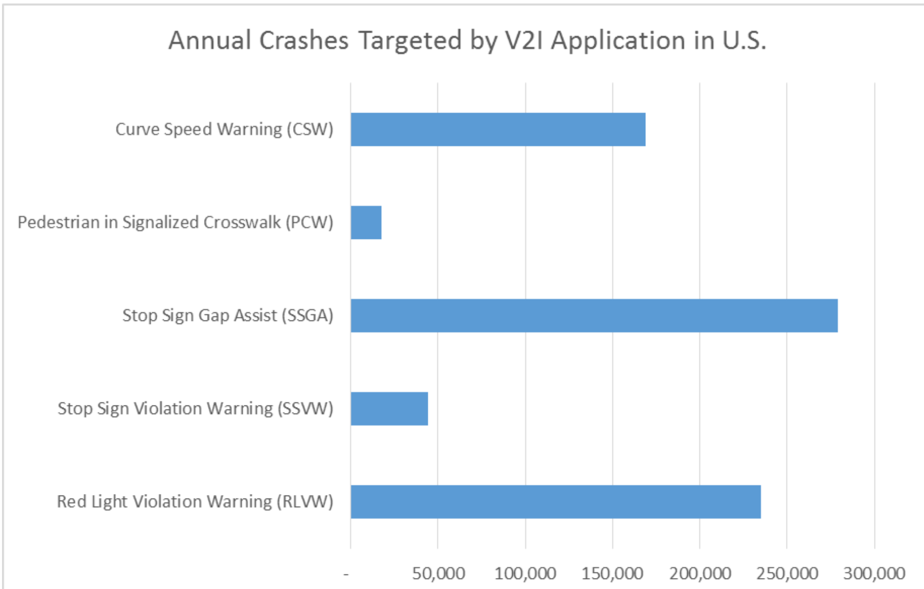


Figure 4: Estimated Range of Benefits for V2I Safety Applications (Targeted Annual Crashes in U.S.).

V2V Safety Applications. NHTSA has released a notice of proposed rulemaking that would require auto manufacturers to install V2V communications in their new vehicles, over a short implementation schedule, capable of producing the basic safety message (BSM**)** and communicating that message with other vehicles.[2] The maximum annual benefits represent the crashes, fatalities, injuries, and property damage only vehicles (PDOVs) that can be reduced annually after the full adoption of DSRC and safety related applications. Once fully deployed, DOT estimates the proposed rule would:

- Prevent 439,000 to 615,000 crashes annually (equivalent to 13 to 18 percent of multiple light-vehicle crashes)
- Save 987 to 1,366 lives
- Reduce 305,000 to 418,000 MAIS 1-5 injuries, and
- Eliminate 537,000 to 746,000 property damage only vehicles (PDOVs)

(MAIS: Maximum Abbreviated Injury Scale)

The costs and benefits of the proposed rule were estimated by considering a scenario where manufacturers would, in addition to the DSRC technology, voluntarily install two safety apps that currently are deemed to be enabled only by V2V. These two safety apps are Intersection Movement Assist (IMA) and Left Turn Assist (LTA). This scenario is reasonable because the incremental cost of IMA and LTA is less than one percent of the DSRC costs and the industry has indicated that these two apps are already in their research and deployment plan. Moreover, it is believed that this scenario is likely to understate benefits because manufacturers may choose to offer other safety apps that use V2V technology beyond these two, as well as various other technologies that use DSRC, such as vehicle-to-infrastructure (V2I) or vehicle-to-pedestrian (V2P) technologies. Note that the range of benefits is due to the use of range of effectiveness rates and the two benefit estimating approaches. The two benefit approaches deployed a different treatment on the distribution of benefits from crashes involving different model year vehicles.

Other illustrative CV safety benefits are highlighted in the table below:

Table 13: CV Safety benefits

Application	Location Deployed or Tested	Results
Pedestrian warning system (V2P)	Portland, OR	• 23% of pedestrians reported that a crosswalk transit vehicle turn warning system help them avoid a collision with a bus. (2015-01001)
Forward collision warning systems (V2V)	France, Germany, Sweden, Italy	• 70% of drivers in a large-scale field operational test (euroFOT) felt that forward collision warning systems increased safety. (2014-00950)
Curve speed warning systems (V2I)	France, Germany, Sweden, Italy	• 75% of drivers in a large-scale field operational test felt that curve speed warning systems increased safety. (2014-00953)
Connected Vehicle Warning Systems with Autonomous Emergency Braking	Australia (simulation study)	• Connected vehicle warning systems and autonomous emergency braking can reduce fatalities by 57 percent (simulation study) (2014-00965)

Costs

For V2V safety equipment with IMA and LTA applications, the proposed rule's vehicle technology cost was initially estimated to range from $249 to $351 per affected vehicle including the component costs for DSRC radios, DSRC antenna, GPS, hardware security module, two apps, and malfunction indicators as well as the installation labor costs. The vehicle component unit costs were based on the supplier's confidential response to the agency's request for cost information. These costs come down to less than $200 per vehicle by 2025 (for one radio).[2]

Case Study / Lessons Learned – Safety Pilot Model Deployment (Ann Arbor)/USDOT

The Connected Vehicle Safety Pilot was a research program that demonstrated the readiness of DSRC-based connected vehicle safety applications for nationwide deployment. The vision of the Connected Vehicle Safety Pilot Program was to test connected vehicle safety applications, based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications systems using dedicated short-range communications (DSRC) technology, in real-world driving scenarios in order to determine their effectiveness at reducing crashes and to ensure that the devices were safe and did not unnecessarily distract motorists or cause unintended consequences.[3]

Research from the National Highway Traffic Safety Administration (NHTSA) showed that connected vehicle technology has the potential to address a very significant number of light vehicle crashes and heavy truck crashes by unimpaired drivers. Since safety is the USDOT's top priority, the potential safety benefits of this technology could not be ignored. At the time, more research was necessary to determine the actual effectiveness of the applications and to understand the best ways to communicate safety messages to motorists without causing unnecessary distraction.

The Connected Vehicle Safety Pilot was part of a major scientific research program run jointly by the U.S. Department of Transportation (USDOT) and its research and development partners in private industry. This research initiative was a multi-modal effort led by the Intelligent Transportation Systems Joint Program Office (ITS JPO) and the National Highway Traffic Safety Administration (NHTSA), with research support from several agencies, including Federal Highway Administration (FHWA), Federal Motor Carrier Safety Administration (FMCSA), and Federal Transit Administration (FTA).

This one-year, real-world deployment was launched in August 2012 in Ann Arbor, Michigan. The deployment utilized connected vehicle technology in over 2,800 vehicles and at 29 infrastructure sites at a total cost of over $50 million dollars in order to test the effectiveness of the connected vehicle technology. Key lessons from the Safety Pilot Model Deployment include:

When deploying complex ITS projects such as those with Connected Vehicle technologies, use a modular project structure and focus on high priority objectives and project components.

- When embarking on a connected vehicle project, develop a focused outreach plan that identifies all stakeholders, the message appropriate for each stakeholder and the method in which you will reach the stakeholders.
- Perform a thorough and thoughtful analysis when scoping, sizing, and identifying the geographic location of connected vehicle projects, and ensure that the strategies used to recruit test subjects or drivers are consistent with these assumptions and those of the experimental plan.
- Clearly communicate requirements and testing procedures to connected vehicle device developers, and allow for industry input and iteration for less mature devices.
- Specify interoperability testing requirements and steps as part of the connected vehicle device requirements prior to starting multiple rounds of testing, feedback, reset, and retesting.
- Conduct a data collection pilot test to validate end-to-end data acquisition, transfer, processing, and quality assessment processes.

More details regarding these lessons can be found online at Safety Pilot Model Deployment: Lessons Learned.

Chapter 6. Connected Vehicle Pilot Deployment Program: New York City

Introduction

Connected vehicles are 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) is taking on this challenge by investing in a regional pilot deployment program that is not only accelerating deployment but also uncovering what barriers remain and how to address them. This program will help ensure that this revolutionary technology can meet its fullest potential in the near future.

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 $42 million in federal funding to implement a suite of connected vehicle applications and technologies tailored to meet their region's unique transportation needs. These pilot sites will 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. Moreover, these sites will lay the groundwork for even more dramatic transformations as other areas follow in their footsteps.

The sites are conducting the pilots in three Phases. Under Phase 1, the sites spent 12 months preparing a comprehensive deployment concept that was suitable for further design, building, testing, and operation. This comprehensive concept included identifying specific performance measures, targets and capabilities associated with performance monitoring and performance management. In Phase 2, the sites embarked on a 20-month phase of activity to design, build and test the nation's most complex and extensive deployment of integrated wireless in-vehicle, mobile device, and roadside technologies. In Phase 3, the tested pilot deployment applications and technologies will be placed into operational practice, where the impact of the deployment on a set of key performance measures will be monitored and reported

The New York City Connected Vehicle Pilot is anticipated to be the largest connected vehicle technology deployment to date.

New York City Pilot Overview[1]

The NYCDOT leads the New York City Pilot, which aims to improve the safety of travelers and pedestrians in the city through the deployment of V2V and V2I connected vehicle technologies. This objective directly aligns with the city's Vision Zero initiative, which seeks to reduce crashes and pedestrian fatalities and increase the safety of travelers in all modes of transportation. NYCDOT's planned deployment provides an ideal opportunity to evaluate connected vehicle technology and applications in tightly-spaced intersections typical in a dense urban transportation system and is anticipated to be the largest connected vehicle technology deployment to date. The NYCDOT CV Pilot Deployment project area encompasses three distinct areas in the boroughs of Manhattan and Brooklyn. The first area includes a 4-mile segment of Franklin D. Roosevelt (FDR) Drive in the Upper East Side and East Harlem neighborhoods of Manhattan. The second area includes four one-way corridors in Midtown and the Upper East Side of Manhattan. The third area covers a 1.6-mile segment of Flatbush Avenue in Brooklyn. Approximately 5,800 taxi cabs, 1,250 MTA buses, 400 commercial fleet delivery trucks, and 500 City vehicles that frequent these areas will be fit with the CV technology. Using Dedicated Short Range Communication (DSRC), the deployment will include approximately 310 signalized intersections for vehicle-to-infrastructure (V2I) technology. In addition, NYCDOT will deploy approximately 8 RSUs along the higher-speed FDR Drive to address challenges such as short-radius curves, a weight limit and a minimum bridge clearance and 36 RSUs at other strategic locations throughout the City to support system management functions. As a city bustling with pedestrians, the pilot will also focus on reducing vehicle-pedestrian conflicts through in-vehicle pedestrian warnings and an additional V2I/I2V project component that will equip approximately 100 pedestrians with personal devices that assist them in safely crossing the street.

Costs

The CV Pilots were each required to submit a Comprehensive Deployment Plan under Phase 2. This plan describes the approach to complete the Phase 2 Design/Build/Test, and Phase 3 Operate and Maintain activities of the program. In the plan are details about the design approach, procurement, development, integration, testing, and final readiness demonstration. Additional details address the preparation of project plans to secure, operate, and maintain the system and protect privacy. A Cost Summary was also included in the plan to provide insight into the types of costs anticipated for this project (Cost ID: 2017-00385).

These costs are broken into broad categories in the table below. The top four categories based on anticipated cost volume are:

1. Labor costs associated with the design, planning, management, procurement, and general oversight for the project. This includes the labor expense for the three key resources, labor expense related to Project Management and labor associated with the project deliverables (excluding time specifically spent on performance measurements, outreach, and training deliverables).
2. Cost for procuring the in-vehicle and roadside devices.
3. Labor and direct costs related to the installation, integration and maintenance of the in vehicle devices, roadside devices and supporting infrastructure.
4. Equipment and labor focused on meeting the Performance Measurement reporting requirements and deliverables.

Table 14: High Level Phase 2 and Phase 3 Costs for the New York City Connected Vehicle Pilot Deployment by Expense Category

Expense Category	Cost
Design/Planning/Project Management/Procurement/Oversight	$5,826,216
Install/integrate/Maintain	$5,649,982
In Vehicle and Roadside Devices	$6,276,000
Performance Measurement Labor and Hardware	$2,690,003
Software Development and Support	$1,510,065
Travel and ODC	$389,900
Outreach	$327,458
Training	$139,002
Infrastructure Adaptions	$692,262
TOTAL	**$23,500,887**

Lessons Learned

Include technical, operations, and legal personnel in stakeholder meetings to address the requirements of the CV deployment and ensure that participants' privacy is being maintained (Lesson ID: 2017-00794)

NYCDOT first approached the Taxi and Limousine Commission, Metropolitan Transportation Authority (MTA), United Parcel Service (UPS), and others to propose a large-scale deployment of connected vehicles. The meetings included technical, operations, and legal personnel to address a wide range of issues, including device installation, maintenance requirements, operating hours, operator selection, geographic coverage areas, stakeholder responsibilities, system operation, driver interface, and data collection activities. A major concern that stakeholders voiced was that any data collected from the onboard units for the performance measurement of the system could be subpoenaed for criminal and/or civil suits or the subject of a freedom of information act (FOIA) request. Once obtained, the data could then be merged with other records (e.g. police

The data being collected from the Pilot alone would not be considered Personally Identifiable Information (PII); however, stakeholders feared that, when merged with additional data (e.g. police accident records), PII could be created.

accident reports) and used in legal proceedings, disciplinary proceedings, or insurance negotiations.

To ensure stakeholders that driver privacy would be maintained, the team eventually came up with a solution that involved scrubbing the detailed latitude and longitude data recorded by the on board unit and converting it to an undefined Cartesian coordinate system for storage and later evaluation. Using this method, each event data set would still be recorded with full precision for all trajectory points relative to each other in the same event data set, but they would not be tied to an exact real-world coordinate. This removed the detailed location data that could be tied to accident records but still preserved all relative details about vehicle movements and driver actions taken in response to the Connected Vehicle application warnings to ensure proper evaluation of the system.

Chapter 7. Connected Vehicle Pilot Deployment Program – Wyoming (WYDOT)

Introduction

Connected vehicles are 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) is taking on this challenge by investing in a regional pilot deployment program that is not only accelerating deployment but also uncovering what barriers remain and how to address them. This program will help ensure that this revolutionary technology can meet its fullest potential in the near future.

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 $42 million in federal funding to implement a suite of connected vehicle applications and technologies tailored to meet their region's unique transportation needs. These pilot sites will 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. Moreover, these sites will lay the groundwork for even more dramatic transformations as other areas follow in their footsteps.

The sites are conducting the pilots in three Phases. Under Phase 1, the sites spent 12 months preparing a comprehensive deployment concept that was suitable for further design, building, testing, and operation. This comprehensive concept included identifying specific performance measures, targets and capabilities associated with performance monitoring and performance management. In Phase 2, the sites embarked on a 20-month phase of activity to design, build and test the nation's most complex and extensive deployment of integrated wireless in-vehicle, mobile device, and roadside technologies. In Phase 3, the tested pilot deployment applications and technologies will be placed into operational practice, where the impact of the deployment on a set of key performance measures will be monitored and reported

Wyoming Pilot Overview[1]

Wyoming is an important freight corridor that plays a critical role in the movement of goods across the country and between the United States, Canada, and Mexico. Interstate 80 (I-80) in southern Wyoming, which is above 6000 feet, is a major corridor for east/west freight movement and moves more than 32 million tons of freight per year. During winter seasons when wind speeds and wind gusts exceed 30 mph and 65 mph respectively, crash rates on I-80 have been found to be 3 to 5 times as high as summer crash rates. This resulted in 200 truck blowovers within 4 years and often led to road closures. Wyoming Department of Transportation (WYDOT) CV Pilot site focuses on the needs of the commercial vehicle operator in the State of Wyoming and will develop applications that use vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) connectivity to support a flexible range of services from advisories including roadside alerts, parking notifications and dynamic travel guidance. This WYDOT CV Pilot is expected to reduce the number of blowover incidents and adverse weather related incidents (including secondary incidents) in the corridor in order to improve safety and reduce incident-related delays.

From October 2015 to September 2016, there were more than 1,600 crashes on I-80, resulting in 18 fatalities and 271 injuries. During this same time, roads were closed to all vehicles for over 1,500 hours. The societal impact of these crashes topped $865 million.[2]

WYDOT will develop systems that support the use of CV Technology along the 402 miles of I-80 in Wyoming. Approximately 75 roadside units (RSUs) that can receive and broadcast message using Dedicated Short Range Communication (DSRC) will be deployed along various sections of I-80. WYDOT will equip around 400 vehicles, a combination of fleet vehicles and commercial trucks with on-board units (OBUs). Of the 400 vehicles, at least 150 will be heavy trucks that are expected to be regular users of I-80. In addition, of the 400 equipped-vehicles, 100 WYDOT fleet vehicles, snowplows and highway patrol vehicles, will be equipped with OBUs and mobile weather sensors.

Costs

The CV Pilots were each required to submit a Comprehensive Deployment Plan under Phase 2. In the plan are details about the design approach, procurement, development, integration, testing, and final readiness demonstration. Additional details address the preparation of project plans to secure, operate, and maintain the system and protect privacy. A Cost Summary was also included in the plan to provide insight into the types of costs anticipated for this project. The table below summarizes the projected cost estimates at a high-level, and is intended to provide information and guidance for other deployers regarding the costs allocated for the project (Cost ID: 2017-00386).

Table 15: High Level Costs for the Wyoming Connected Vehicle Pilot Deployment by Task

Phase / Task	Cost
2-A. Program Management	$ 181,634
2-B. System Architecture and Design	$ 469,066
2-C. Data Management Planning	$ 108,585
2-D. Acquisition and Installation Planning	$ 1,487,077
2-E. Application Development	$ 901,075
2-F. Participant and Staff Training	$ 186,678
2-G. Operational Readiness Test and Demonstration Planning	$ 177,177

Phase / Task	Cost
2-H. Installation and Operational Readiness Testing	$ 171,080
2-I. Maintenance and Operations Planning	$ 154,664
2-J. Stakeholder Outreach	$ 169,699
2-K. Performance Measurement and Independent Eval Support	$ 253,056
2-L. Participation in Standards Development	$ 51,436
Phase 2 Total	$4,311,227
3-A. Program Management	$ 150,009
3-B. System Operations and Maintenance	$ 447,823
3-C. Stakeholder Outreach	$ 157,371
3-D. Performance Measurement and Independent Eval Support	$ 447,754
3-E. Post-Pilot Deployment Transition Planning	$ 115,815
3-F. Participation in Standards Development	$ 125,973
Phase 3 Total	$1,444,745
Phase 2 and Phase 3 Total	**$5,755,972**

Lessons Learned

Prevent the need for channel switching (a safety hazard) by designing CV communications to include dual radios in each vehicle (Lesson ID: 2017-00795)

In the area of communications, the CV Pilot sites are using established standards wherever possible, but in many cases, they are trying out standards in the field for the first time, or are implementing messages for which no national or international standards have yet been established. A key component of connected vehicle communication is Dedicated Short Range Communication (DSRC) in the 5.9 GHz band. Within this band are several channels. Channel 172 is the primary channel, carrying safety-related information and WAVE Service Announcements (WSAs) that advertise the availability of other information and services on other channels. The IEEE 1609.4 standard addresses multi-channel operation for Wireless Access in Vehicular Environments (WAVE), and as such is the "official" set of rules for wireless messages by the CV Pilot sites.

The New York and Tampa teams plan to use dual radios in each vehicle: one to listen to channel 172 and the other to listen to other channels for supplementary information such as Traveler Information Messages. The Wyoming team, on the other hand, originally planned to use a single radio, listening to channel 172 most of the time, but switching to other channels to listen for other messages. Such a channel-switching plan is consistent with IEEE 1609.4 specifications. However, the 1609.4 committee and several manufacturers who are looking ahead to implementation of DSRC required by a ruling from the

National Highway Traffic Safety Administration (NHTSA) maintain strongly that it is not safe to switch away from Channel 172, because a safety-critical message on that channel might be missed.

The Wyoming team has agreed to re-design its communications design to include dual radios. However, the discovery that a single channel-switching radio is technically compliant to the 1609.4 standard is a major loophole in the standard that must be addressed and corrected by the 1609.4 committee.

Chapter 8. Connected Vehicle Pilot Deployment Program – Tampa (THEA)

Introduction

Connected vehicles are 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) is taking on this challenge by investing in a regional pilot deployment program that is not only accelerating deployment but also uncovering what barriers remain and how to address them. This program will help ensure that this revolutionary technology can meet its fullest potential in the near future.

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The sites are conducting the pilots in three Phases. Under Phase 1, the sites spent 12 months preparing a comprehensive deployment concept that was suitable for further design, building, testing, and operation. This comprehensive concept included identifying specific performance measures, targets and capabilities associated with performance monitoring and performance management. In Phase 2, the sites embarked on a 20-month phase of activity to design, build and test the nation's most complex and extensive deployment of integrated wireless in-vehicle, mobile device, and roadside technologies. In Phase 3, the tested pilot deployment applications and technologies will be placed into operational practice, where the impact of the deployment on a set of key performance measures will be monitored and reported

Tampa Pilot Overview[1]

Tampa-Hillsborough Expressway Authority (THEA) owns and operates the Selmon Reversible Express Lanes (REL), which is a first-of-its-kind facility to address urban congestion. The REL morning commute endpoint intersection is on major routes into and out of the downtown Tampa commercial business district. Drivers experience significant delay during the morning peak hour resulting in, and often caused by, a correspondingly large number of rear-end crashes and red light running collisions. Because the lanes are reversible, wrong way entry is possible and fatalities have occurred. The THEA pilot will deploy a variety of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications to relieve congestion, reduce collisions, and prevent wrong way entry at the REL exit. THEA also plans to use CV technology to enhance pedestrian safety, speed bus operations and reduce conflicts between street cars, pedestrians and passenger cars at locations with high volumes of mixed traffic.

The THEA CV Pilot will employ Dedicated Short Range Communication (DSRC) to enable transmissions among approximately 1,600 privately-owned automobiles, 10 buses, 10 trolleys, 500 pedestrians with smartphone applications, and approximately 40 roadside units along city streets. Tampa's pilot is unique from the other two pilots in that volunteer drivers are being recruited for participation in the project, with a 30 percent discount on select tolls on the REL (up to a maximum of $550 in savings per driver) being offered as an incentive.

The THEA Connected Vehicle Pilot is the only pilot to utilize volunteer drivers of privately owned vehicles.

To support the pilot, THEA will be working with their primary partners, The City of Tampa, Florida Department of Transportation (FDOT) and Hillsborough Area Regional Transit to create a region-wide Connected Vehicle Task Force. The primary mission of this Task Force is to support the deployment of Connected Vehicle infrastructure in the region in a uniform manner to ensure interoperability and interagency coordination as these deployments transition from concept to planning to operations.

Costs

The CV Pilots were each required to submit a Comprehensive Deployment Plan under Phase 2. In the plan are details about the design approach, procurement, development, integration, testing, and final readiness demonstration. Additional details address the preparation of project plans to secure, operate, and maintain the system and protect privacy. A Cost Summary was also included in the plan to provide insight into the types of costs anticipated for this project (Cost ID: 2017-00379).

The table below summarizes the projected cost estimates at a high-level, and is intended to provide information and guidance for other deployers regarding the costs allocated for the project.

Table 16: High Level Costs for the Tampa Connected Vehicle Pilot Deployment by Task

Phase / Task	Cost
2-A. Program Management	$1,240,000
2-B. System Architecture and Design	$2,950,000
2-C. Data Management Planning	$1,000,000
2-D. Acquisition and Installation Planning	$4,265,000
2-E. Application Development	$1,400,000
2-F. Participant and Staff Training	$250,000
2-G. Operational Readiness Test and Demonstration Planning	$150,548

Phase / Task	Cost
2-H. Installation and Operational Readiness Testing	$500,000
2-I. Maintenance and Operations Planning	$1,000,000
2-J. Stakeholder Outreach	$400,000
2-K. Performance Measurement and Independent Eval Support	$300,000
2-L. Participation in Standards Development	$450,000
Phase 2 Total	$13,905,548
3-A. Program Management	PM: $350,000; Toll incentive plan: $1,395,000
3-B. System Operations and Maintenance	$1,528,990
3-C. Stakeholder Outreach	$347,000
3-D. Performance Measurement and Independent Eval Support	$1,400,223
3-E. Post-Pilot Deployment Transition Planning	$50,000
3-F. Participation in Standards Development	$100,000
Phase 3 Total	$5,171,213
Phase 2 and Phase 3 Total	**$19,076,761**

Lessons Learned

Consider installing additional vehicle detection equipment if it is determined that there is not sufficient market penetration for CV traffic signal control applications to work at their full potential (Lesson ID: 2017-00793)

For the pilot, THEA is installing "intelligent" traffic signal controllers to help improve the flow of traffic. As THEA moved into the design phase, the project engineers delved into the details of signal optimization with the designers of the signal control process at the University of Arizona. They learned that signal control optimization can reach its full potential only when over 90% of the vehicles approaching the intersection have known location and speeds. The number of vehicles instrumented for V2I communication as part of the CV Pilot program would provide a far smaller percentage of vehicle coverage.

Florida Department of Transportation (FDOT) District 7 and HNTB (THEA's General Engineering Consultant) came to the rescue with a method for obtaining information on all vehicles approaching the instrumented intersections. After considering several technologies, including loop detectors and microwave detectors, FDOT agreed to pay for the procurement and installation of over 40 video traffic detectors at 12 intersections along Florida Ave. and Nebraska Ave. as part of a Joint Partnering Agreement with THEA. HNTB will provide the design to integrate them with the rest of the CV pilot operation under its existing contract, at no cost to the CV Pilot program. THEA will provide ten "Bluetooth" detectors to determine travel time between points on these streets and along Meridian Avenue. These detection technologies will pick up the needed number of unequipped vehicle without identifying or retaining any information about individual drivers or vehicles.

Chapter 9. Automated Vehicles – Truck Platooning

Introduction

The United States Department of Transportation (USDOT) highlights truck platooning as an early application of automated vehicle deployment in the freight industry. As a cooperative system, fully and partially automated trucks, ships, and intermodal freight-transfer facilities can interoperate with automated logistics-driven supply chain management systems to fundamentally transform the global movement of goods. Although autonomous vehicles are not expected to suddenly appear on our nation's roadways, cooperative systems that can connect trucks with infrastructure systems, and exchange information critical to vehicle control and operations are at the forefront of research in the commercial arena.

On trucks, on-board computers monitor sensor systems and integrate data from adaptive speed control, automatic braking, lane-departure warning systems, and vehicle-to-vehicle (V2V) dedicated short-range communication (DSRC) systems. By allowing sensors on one truck to communicate with sensors on another truck, partially automated trucks can travel more closely together to improve fuel efficiency, in a practice known as truck platooning or truck trains.

> **"Platooning and CACC could provide significant increases in highway efficiency. Our research shows that it can reduce the workload for drivers as well as vehicles, reduce emissions, and reduce the enormous fuel expenses involved in freight transportation."**
>
> **- Osman Altan (USDOT)[1]**

Truck platooning works by creating a close, constant coupling between platooning vehicles, providing fuel benefits for both the lead and following truck(s). Operating as a unit, truck platoons can also smooth traffic flow to increase efficiency and roadway capacity. Several technologies work together to support this type of interaction: Adaptive Cruise Control (ACC), Cooperative Adaptive Cruise Control (CACC), and truck automation. ACC supports truck platooning but is not considered a truck platooning system in its own right. ACC systems permit the driver to choose a set speed and activate automated brake and throttle systems to maintain safe following distances. However, the driver is still responsible for steering the vehicle and maintaining an awareness of road conditions in order to minimize headways and maximize performance.

CACC was developed to address coordination shortfalls between ACC-equipped vehicles and safely minimize following gaps. CACC extends an ACC system by including V2V communication to provide important speed and location information from the vehicle in front of the platoon and supplement in-vehicle sensors (including radar, LiDAR, cameras, ultrasonic sensors). This additional information allows following vehicle(s) to adjust speed quickly enabling shorter following gaps, and consequently, smoother acceleration and deceleration profiles to reduce aerodynamic drag and improve fuel economy and emissions for vehicles in the platoon.

Although ACC and CACC are examples of Level 1 automation as defined by both SAE and NHTSA, a higher level of automation would be needed for anything more than the lowest level of vehicle-following performance where only speed is controlled. As with ACC systems, drivers using CACC systems are required to actively steer the vehicle and monitor roadway and traffic conditions. In the future, global coordination strategies that support fleet operations will be required for higher levels of automation. For maximum benefit, operators can use global, local, or ad hoc coordination strategies to form platoons. Researchers at the California Partners for Advanced Transportation Technology (PATH) describe four primary stages of truck platooning.[2]

1. Forming – During the first stage of truck platooning, trucks must identify potential platoon partners based a range of characteristics, including their current location, destination, the number of stops, type of truck, and other variables. This information may be difficult to ascertain if other drivers work for competing firms. To mitigate this issue, current research is evaluating three different methods for forming the platoon:

    a. Scheduled Platooning - A transport company planner can schedule multiple trucks to form a platoon at a given departure time and location. Trucks assigned as part of the platoon know when to break off.

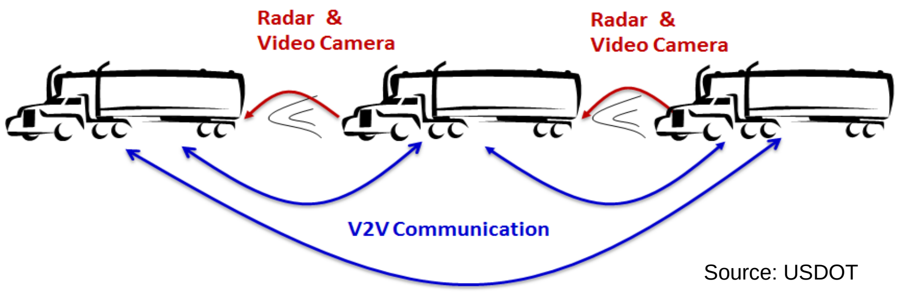
    b. Platooning Service Provider (PSP) - Similar to scheduled platooning, in this method an external specialized company works with multiple trucking companies and individual truck drivers to match them up based on their starting location, departure time, and final destination. The trucks would need to be outfitted with platooning technology and devices allowing the PSP to know where they are headed and their travel times. Using this information, the PSP matches trucks for given sections of their trips and then forms new platoons later with different trucks going in other directions.

    c. On-the-fly platooning - As platooning becomes more mainstream, trucks will not need a single entity like the PSP to coordinate travel. Trucks will be able to form platoons spontaneously with required information being transmitted between partnering trucks. This method provides the most flexibility over the other methods but also requires the largest market penetration of platooning-equipped trucks for proper execution.

2. Steady-State Cruising - The cruising stage occupies the largest period of time while the platooning system is activated. Once a platoon is formed, the drivers will operate the vehicle based on the level of automation in the vehicle. Steady-state cruising would be modified as trucks join or drop out of the platoon or when an unequipped vehicle cuts in. A majority of truck platooning benefits accrue during the cruising stage.

3. Departing or Splitting - Trucks may depart from the platoon when needed in order to complete their trips or make a trip deviation. Once the departing truck has left, the trucks that were following it rejoin the original platoon and close the gap left by the departing vehicle.

4. Abnormal Conditions - This last stage accounts for other situations that are not addressed in the previous three stages. This stage can include potential errors in the system or abnormal operating conditions. Any truck platooning system will need to be able to identify and resolve these unexpected abnormalities.



Source: USDOT

Truck platooning technology typically includes the following:

- Sensors - A combination of both short and long range sensors are used to evaluate the complete environment around the vehicle so it can track not only other vehicles in the platoon but all other objects in the road, including pedestrians and cyclists. Sensors such as LIDAR (light detection and ranging), radar, and cameras all work in conjunction to provide a complete image of the surroundings. The use of different types of sensors provides redundancy in the system.

- Localization services - Global positioning systems (GPS) and inertial navigation systems (INS) are used to determine the location of the vehicle. These systems provide the necessary information to the vehicle to accurately establish the spacing between the platoon vehicles. As with sensors, the system needs to be redundant so if the GPS temporarily fails (as in low coverage areas or tunnels) the INS can use motion sensors and rotation sensors to determine the vehicle orientation until the GPS reestablishes its connection.

- V2V communication - DSRC is utilized for low latency exchange of vehicle performance parameters between vehicles. An extension of Wi-Fi technology, DSRC communicates passing speed and locational information, which allows CACC system to quickly adjust to changing speeds and positions, facilitating an effective platoon.

- Software - Each CACC system requires software-based algorithms that are used to process all of the information from the sensors, the vehicle, and V2V communications. These algorithms are the core of the CACC systems as they are required to predict the movement and speed of the vehicle in front to set the new speed of the following vehicle.

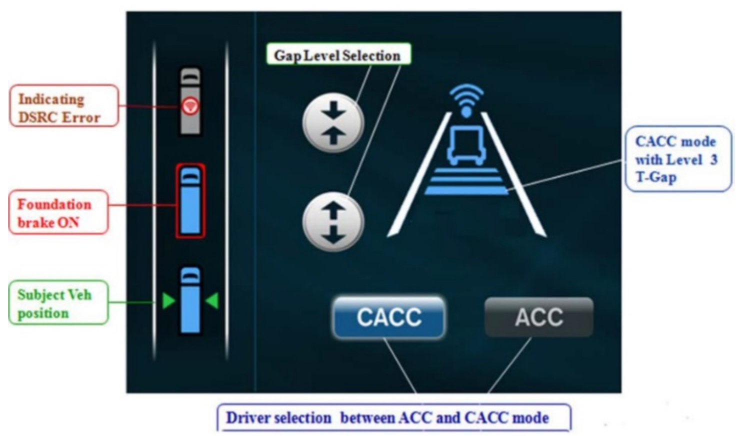


Photo Source: USDOT

- Hardware - There is a broad range of hardware components distributed throughout the vehicle that houses the software for the CACC, connects critical systems, and controls the vehicle speed and braking.

- Human interface - The Human Machine Interface informs the user about changes in the CACC stages. As CACC matures, methods that provide CACC information without causing driver distraction will need to be developed and tested.

The list below describes how platooning can be incorporated into the SAE scale of automation.[3]

- **Level 0: No Automation** – Truck platooning is not possible at this level.
- **Level 1: Driver Assistance** – ACC is currently at this automation level, as the truck platooning technology is only assisting the driver. The driver is mostly in control of the vehicle and each automated function is separate.
- **Level 2: Partial Automation** – At this level vehicle communication and acceleration functions combine with lane centering technologies to control the majority of vehicle functions. However, the driver is still present and retains control of dynamic driving functions.
- **Level 3: Conditional Automation** – At this level drivers cede full control of vehicle functions in certain traffic, roadway, or weather conditions. The automated driving system is now tasked with monitoring the external traveling environment. Drivers are still responsible for promptly responding to requests to intervene and resume control of the vehicle.
- **Level 4: High Automation** – At this level there is a designated driver, but the truck can drive itself under certain roadway, traffic, and weather conditions and the driver does not need to be aware of the roadway or the actions of the lead truck while in a specific driving mode.
- **Level 5: Full Automation** – At this level there is no designated driver. Level 5 allows for fully autonomous driving in all driving modes, including freeway cruising, merging, lower speeds, traffic jams, and other conditions. This level of automation is still in its early stages of research and will not be seen on roadways in the near future.

Benefits

Evaluation studies of truck platooning focus on improved fuel economy (and lower operating costs) due to the aerodynamic effects of closer vehicle spacing, and more efficient use of highway facilities through increased mobility and throughput.

- Connectivity between trucks equipped with automated vehicle technology allow them to operate more smoothly as a unit and automatically reduce and control following gaps between vehicles. Class-8 trucks with standard-trailers net a fuel savings of between 5.2 and 7.8 percent in a three-truck CACC platoon. With aerodynamic-trailers, these savings grow to 14.2 percent at a minimum separation distance of 17.4 m (57.1 ft). (2018-01246)
- The tractor trailer platooning demonstration funded by the Department of Energy NREL using DSRC V2V communications demonstrated fuel savings for the lead truck (up to 5.3 percent) and the trailing truck (up to 9.7 percent); with the platooned pair saving up to 6.4 percent. Variable conditions—ambient temperature, distance between lead and trailing truck, and payload weight—influence the savings. (2015-01054)
- The UC PATH program in California modeled the influence of wind resistance and shorter following made possible with CACC and estimated potential peak fuel efficiency benefits of 20 to 25 percent. Researchers noted, however, that such short following gaps (10 to 20 feet) would

likely require dedicated truck lanes as the ability of other traffic to change lanes across platoons would be limited and platoons would have difficulty responding safely to emergency conditions. (2016-01066)

- The FHWA-sponsored research conducted by Auburn University has produced preliminary findings on travel time savings from truck platooning. A traffic microsimulation study of driver assistive truck platooning (DATP) found a travel time reduction benefit for each of the simulation cases featuring current traffic and two increased levels (115 percent and 130 percent) of traffic volumes on a five-mile section of I-85 in Alabama. Travel time savings during peak hour traffic conditions ranged from a two percent improvement (with 20 percent market penetration) to 69 percent improvement (with 100 percent market penetration). (2017-01200)

- A truck platooning business case study conducted in the Netherlands for three logistics service providers found that compared to conventional cruise control, fuel savings alone from platooning already offsets annual costs, and labor cost savings are pure profits. (2017-01135)

Costs

Although promising, the business case or return on investment (ROI) for truck platooning is still not clear. When surveyed by the American Trucking Research Institute (ATRI) regarding the business case for truck platooning as part of the FHWA-sponsored study of DATP, owner-operators expected a mean payback on investment period of 10 months, while fleet respondents expressed a mean payback expectation of 18 months. Freight companies are currently analyzing the benefits and costs of adopting platooning technology. Additional costs may include equipment acquisition, driver training, logistics and coordination, testing, and insurance costs.[4]

Lessons Learned

In Europe, a large scale demonstration project provided insight into the challenges faced when attempting to coordinate participation from multiple carriers, manufactures, and roadway authorities to achieve interoperability across jurisdictional boundaries.[5] The platooning project called the European Truck Platooning Challenge involved six bands of automated trucks (DAF, Daimler, Iveco, MAN, Scania, and Volvo) that traveled on public roads from several European cities to a common destination in the Netherlands. The following key challenges and knowledge gaps were identified by 69 participant stakeholders who envisioned wide-ranging support for truck platooning by 2025.

Safety and Security

- Demonstrate functional safety of platooning; Cyber security, hacking, and wireless communication security; Safe and reliable braking behavior in emergency situations; Reliability of sensors, components, parts, wireless communication; Safety administration (logging of platooning-related accidents, traffic situations and driver status); Privacy of truck drivers and logging data security; and Immunity to wireless signal jammers.

Technology

- Multi-brand platooning and standardized communication protocols; Active platoons using signaling lights for visibility by other road users; Platoon sequencing (accommodating trucks with various torque ratings, brake capacity and loading weights); Wireless V2X communication reliability; Full platoon control under all mixed traffic situations; Technology development roadmap disparities among truck manufacturers; Effective and real-time estimation of safe inter-vehicle gap distance.

Legal

- Responsibility and liability in the event of an incident when control has been transferred to the system; Driving and resting time regulations amended for driverless vehicles; Vehicle approval procedures; Vehicle following gap distance legislation, Platoon length restrictions (number of vehicles per platoon); Labor rules to assess what is permitted for drivers while platooning.

Logistics Business

- Identifying and guiding trucks that could meet-up together to dynamically form an ad-hoc platoon; System cost and business case for SAE Level 1 or 2 platooning; Platooning service provider to execute platoon formation from differing fleet-owners and brands; Certification of trucking companies and drivers to promote confidence; Logistics process integration to adapt to platooning (routing, inventory management, warehouse operations); Promote business benefits (explain the value of platooning); Decide on the best method of platoon formation (scheduled or ad-hoc platooning or a combination of both); Minimal haul length required to efficiently allow diversion/detours to form platoons; Use real-time data logistics control towers for ad-hoc platoon formation; Urge shippers and carriers to make platooning more attractive by consolidating more loads in the same direction.

User Acceptance and Human Behavior

- Interaction with other road users, e.g. when entering and exiting motorways; Driver acceptance by demonstrating safety and learning to trust the system; Train other road users to accommodate platoons; Driver task trade-off attention versus boredom; Driver job satisfaction insecurity issues; Public opinion backlash against ‘wall of trucks’; Promote societal benefits through positive communication; Anxiety and exhaustion due to small gap distance; Driver training and certification for platooning.

Case Study – FHWA’s Exploratory Advanced Research (EAR) Program

In the United States, the FHWA’s Exploratory Advanced Research (EAR) Program is currently evaluating automated truck technologies to assess feasibility for platooning operations. In a recent field test conducted in live traffic on I-66 in Centreville, Virginia the concept of truck platooning was demonstrated using state-of-the-art Level-1 cooperative adaptive cruise control (CACC) technology. The system installed on three Volvo trucks used advance onboard DSRC (5.9 GHz) wireless radios as to transmit and receive SAE J2735 basic safety messages (BSM) such as position, speed, heading, and brake status at a rate of 10 times per second while automated cruise control (ACC) radar systems measured following distances and communicated with the on-board computers to actuate brake and throttle controls automatically as needed to maintain a headway distance of 45 to 50 feet at 55 mi/h.[7] Drivers were responsible for steering, but relied on CACC systems to detect cut-in passenger vehicles and increase or decrease following gaps as needed for safe operations.

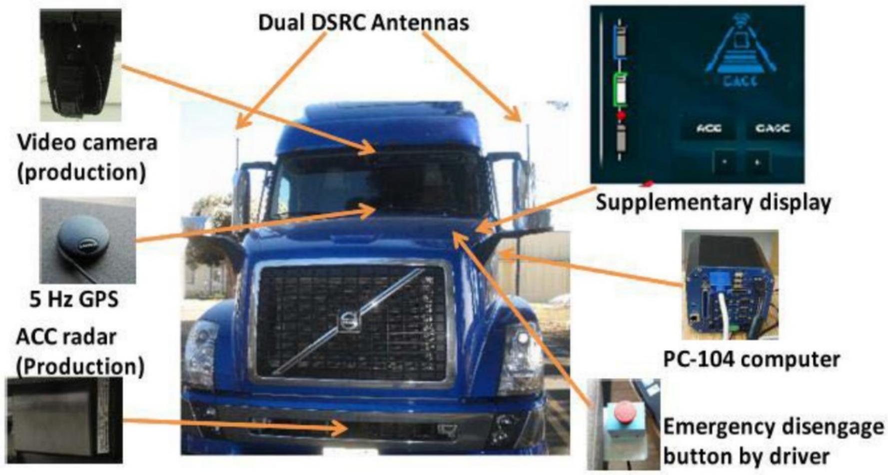


Photo Source: USDOT

Benefits of CACC[8]

V2V wireless communication enabled closer vehicle following between equipped trucks to support:

- Aerodynamic drafting to save energy
- Higher capacity of truck lanes, with higher traffic density but reduced congestion
- Enhanced stability of traffic flow
- Improved safety through faster responses to potential problems ahead
- Reduced driver stress by reducing frequency of cut-ins by other drivers.

Chapter 10. Automated Vehicles – Driver Assistance

Introduction

Controlling the speed of traffic flow either on freeways or arterials can have large impacts on the performance of the roadway in terms of mobility and environment. The basic implementation of this is an intelligent speed control system that limits the maximum speed of a vehicle by sending a message from the roadside infrastructure. Going a step further would involve interactions with other vehicles on the roadway to allow them to all follow a similar speed and smooth traffic flow. Adaptive cruise control systems set specific speeds to automatically follow; if there is a lead vehicle, a gap can be set for the vehicle to automatically keep. In the future, new communication technologies and connected vehicles will make vehicle platooning a realistic option. Platooning consists of vehicle platoons where two or more vehicles travel with small gaps/headways, reducing aerodynamic drag. Platooning relies on vehicle-to-vehicle (V2V) communication that allows vehicles to accelerate or brake with minimal lag to maintain the platoon with the lead vehicle. The reduction of drag results in reduced fuel consumption, greater fuel efficiency, less pollution for vehicles, and increased traffic flow.

Partially automated vehicles that use dedicated short-range communication (DSRC) message sets to interact with advanced signal control systems can reduce travel times up to 64 percent.[1]

Connected vehicle technologies and V2V communications allow things like Cooperative Adaptive Cruise Control (CACC) and vehicle platooning to be possible. Vehicles with these technologies can greatly increase mobility, decrease environmental impacts, and with the continuing development of better autonomous vehicle controls, increase safety.

Today many high end luxury cars are already equipped with some form of an ACC system. As the technology improves and becomes more economical, it will be seen more often in less expensive vehicle models.

All of these in-vehicle technologies are advanced aspects of eco-driving. Eco-driving is simply changing driver patterns and styles to reduce fuel consumption and emissions. When used in combination with in-vehicle communications, customized real-time driving advice can be given to drivers so that they can adjust their driving behavior to save fuel and reduce emissions. This advice includes recommended driving speeds, optimal acceleration, and optimal deceleration profiles based on prevailing traffic conditions and interactions with nearby vehicles. Feedback may be provided to drivers on their driving behavior to encourage driving in a more environmentally efficient manner. Vehicle-assisted strategies where the vehicle automatically implements the eco-driving strategy such as ACC and platooning are a great way to make eco-driving easier for the driver.

Benefits

Figure 5 shows safety, mobility, and environmental benefits of these technologies. The ACC and platooning with automated control of the vehicles provides the safety benefits of crash reductions. All of the technologies lead to environmental benefits including emissions reduction (usually of Carbon dioxide) and fuel consumption reduction.

Eco-Speed Harmonization and Eco-Connected Adaptive Cruise Control applications evaluated as part of the AERIS Program show results of up to a 22 percent reduction in energy and a 33 percent reduction in travel time. (2015-01036)

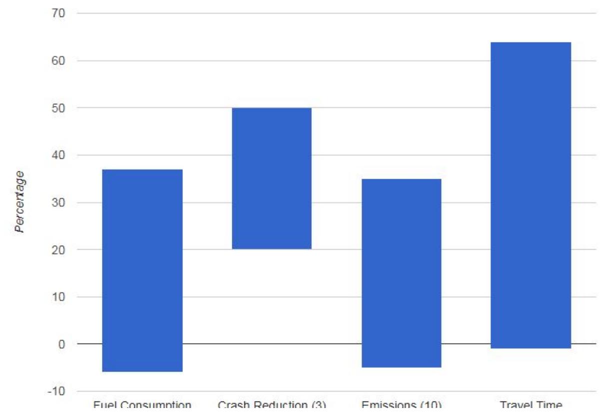


Figure 5: Range of Benefits for Connected Eco-Driving, Intelligent Speed Control, Adaptive Cruise Control, and Platooning (Source: ITS Knowledge Resources).

The online versions of the factsheets feature interactive graphs that contain all the data points included in the ranges. Here, each metric has a number after the text, representing the number of data points used to create the range; no number means only there was only one data point.

Field testing and evaluation of GlidePath Cooperative Adaptive Cruise Control (CACC) systems installed on partially automated vehicles show these system can improve fuel economy by 17 to 22 percent and reduce travel time up to 64 percent. (2017-01173 and 2017-01203). Other research shows that with increasing market penetration Eco-CACC algorithms with merging protocols can improve freeway capacity by at least two-thirds. (2015-01036)

A part of a connected vehicle field test in Seattle, Washington volunteer drivers equipped with CV technologies saw immediate value in intelligent speed control applications. A survey of 21 volunteer participants who drove DSRC equipped vehicles designed to collect speed and road weather data from other connected vehicles and infrastructure based systems suggested that on-board applications such as queue warning, speed harmonization, and weather responsive traffic management (WRTM) messaging systems enabled drivers to take action in advance of congestion, reducing the need to slow down or stop suddenly. (2016-01102).

As connected vehicle technology matures, impacts on congestion are expected to be realized first, followed by increasing safety benefits as the technology matures and market penetration levels increase. Simulation models show that a network of connected vehicles that support platoon-based intersection management applications can reduce average travel times by 4 to 30 percent when traffic volume is high. However, on busy arterials platoon based systems may result in slightly higher fuel consumption and emissions compared to non-platooned based vehicles in a multi-agent environment of adaptive signal control due to the added difficulty of forming and handling platoons in heavy traffic. (2016-01082 and 2016-0183).

Costs

Costs for these in-vehicle systems change rapidly as the technology is changing and improving. Although most options are only available in luxury models, the technology is becoming more accessible as cameras, radar, and laser components get cheaper to manufacture and integrate into new vehicles. Additional features such as automated steering control functions can be a major cost driver. Observations of OEM driver assistance technology pricing over the last few years show these system can add from $300 to $10,800 to the purchase price of a new vehicle. Most systems are $4500 or less. (2017-00373)

Case Study – Eco-Lanes Operational Scenario Modeling Report

(2015-01036)

This study performed modeling of the Eco-Lanes Operational Scenario defined by the Applications for the Environment: Real-Time Information Synthesis (AERIS) Program. The Eco-Lanes Operational Scenario constitutes six applications that use data available in a connected environment to help reduce fuel consumption and emissions by providing driving feedback and speed advice, and by promoting platooning and dedicated "eco-lanes." Two of the seven applications bundled under the Eco-Lanes Operational Scenario were simulated in this modeling effort: Eco-Speed Harmonization (ESH) and Eco-Cooperative Adaptive Cruise Control (Eco-CACC).

Methodology

Simulation and modeling of the ESH and Eco-CACC applications was conducted on State Route 91 Eastbound (SR-91 E) in Southern California between the Orange County Line and Tyler Street in Riverside. Traffic demands, vehicle mix, origin-destination (OD) patterns and driver behavior for the SR-91 E model network were calibrated to field data collected on a representative summer weekday. With the Paramics microsimulation tool and the EPA's Motor Vehicle Emissions Simulator (MOVES) emissions estimation tool, individual vehicle movements were modeled per the scenario implemented, allowing for fuel consumption, emissions of vehicles, and average travel times to be accurately estimated. A variety of sensitivity scenarios were modeled, that included varying parameters such as vehicle demand of the network, connected vehicle (CV) on-board equipment (OBE) penetration rate, triggering distance for the Eco-CACC application, and intra-platoon clearance for the Eco-CACC application. Following the individual modeling of the two applications, they were combined to function simultaneously within the same modeling environment to assess their compatibility. A baseline model that assumed no application deployment (i.e., CV penetration rate set to zero) was also developed from the SR-91 E model and used for comparison purposes.

Key Findings

The modeling study indicated that freeway facilities designed to support dedicated Eco-Lanes in addition to general purpose lanes can give drivers a choice to maximize travel time savings or minimize fuel consumption depending on traffic conditions and individual travel needs.

- At lower traffic volumes, the general purpose lanes experienced a greater energy savings than the dedicated Eco-lane because of the small energy needed for platoon formation. In contrast, at the highest traffic volume, the dedicated Eco-lane experienced a greater energy savings than the general purpose lanes because of the increased capacity provided by Eco-CACC applications.

- Overall, network benefits ranged from 4 to 22 percent savings for energy and -1 to 33 percent savings for travel time.

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Appendix A: List of Acronyms

Acronym	Meaning
ACC	Adaptive Cruise Control
ADA	American with Disabilities Act
ADMS	Archived Data Management Systems
AEB	Autonomous Emergency Braking
AERIS	Applications for the Environment: Real-Time Information Synthesis
ARIBO	Applied Robotics for Installation and Base Operations
ATRI	American Transportation Research Institute
ATTRI	Accessible Transportation Technology Research Initiative
AVL	Automatic Vehicle Location
AWTO	Autonomous Warrior Transport On-base
BS/LCW	Blind Spot/Lane Change Warning
BSM	Basic Safety Message
CACC	Cooperative Adaptive Cruise Control
CCTV	Closed Circuit Television
CSW	Curve Speed Warning
CWS	Collision Warning Systems
DATP	Driver Assistive Truck Platooning
DNPW	Do Not Pass Warning
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
DZPS	Dilemma Zone Protection System
EAR	Exploratory Advanced Research
EEBL	Emergency Electronic Brake Light
ESC	Electronic Stability Control
ESH	Eco-Speed Harmonization
FCW	Forward Collision Warning
FDOT	Florida Department of Transportation
FDR	Franklin D. Roosevelt
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOIA	Freedom Of Information Act
FTA	Federal Transit Administration
GHG	Greenhouse Gas
GPS	Global Positioning System
HAWK	High-Intensity Activated Crosswalk
HOV	High-Occupancy Vehicle
IEEE	Institute of Electrical and Electronics Engineers

Acronym	Meaning
IMA	Intersection Movement Assist
INS	Inertial Navigation Systems
IPD	Intelligent Pedestrian Detectors
IPTS	Intelligent Pedestrian Traffic Signal
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
KCATA	Kansas City Area Transportation Authority
LIDAR	Light Detection And Ranging
LTA	Left Turn Assist
MAIS	Maximum Abbreviated Injury Scale
MAP-21	Moving Ahead for Progress in the 21st Century
MOD	Mobility on Demand
MOVES	Motor Vehicle Emissions Simulator
MTA	Maryland Transit Administration
NHTSA	National Highway Traffic Safety Administration
NIDILRR	National Institute on Disability, Independent Living, and Rehabilitation Research
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
OVW	Oversize Vehicle Warning
PATH	California Partners for Advanced Transportation Technology
PED-SIG	Mobile Accessible Pedestrian Signal System
PED-X	Pedestrian and Signalized Crosswalk
PSP	Platooning Service Provider
RCVW	Railroad Crossing Violation Warning
RDE	Research Data Exchange
REL	Reversible Express Lanes
RIITS	Regional Integration of Intelligent Transportation Systems
RITIS	Regional Integrated Transportation Information System
RLVW	Red Light Violation Warning
ROI	Return on Investment
RSZW	Reduced Speed/Work Zone Warning
SAE	Society of Automotive Engineers
SSGA	Stop Sign Gap Assist
SSVW	Stop Sign Violation Warning
SWIW	Spot Weather Impact Warning
TARDEC	U.S. Army Tank Automotive Research Development and Engineering Center
THEA	Tampa Hillsborough Expressway Authority
TIS	Traveler Information System
TNC	Transportation Network Companies
U.S.DOT	United States Department of Transportation
UPS	United Parcel Service
USC	University of Southern California
USDOT	U.S. Department of Transportation
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian

Acronym	Meaning
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Device
VMT	Vehicle Miles Traveled
VRU2I	Vulnerable Road User-To-Infrastructure
WAVE	Wireless Access in Vehicular Environments
WRTM	Weather Responsive Traffic Management
WYDOT	Wyoming Department of Transportation

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