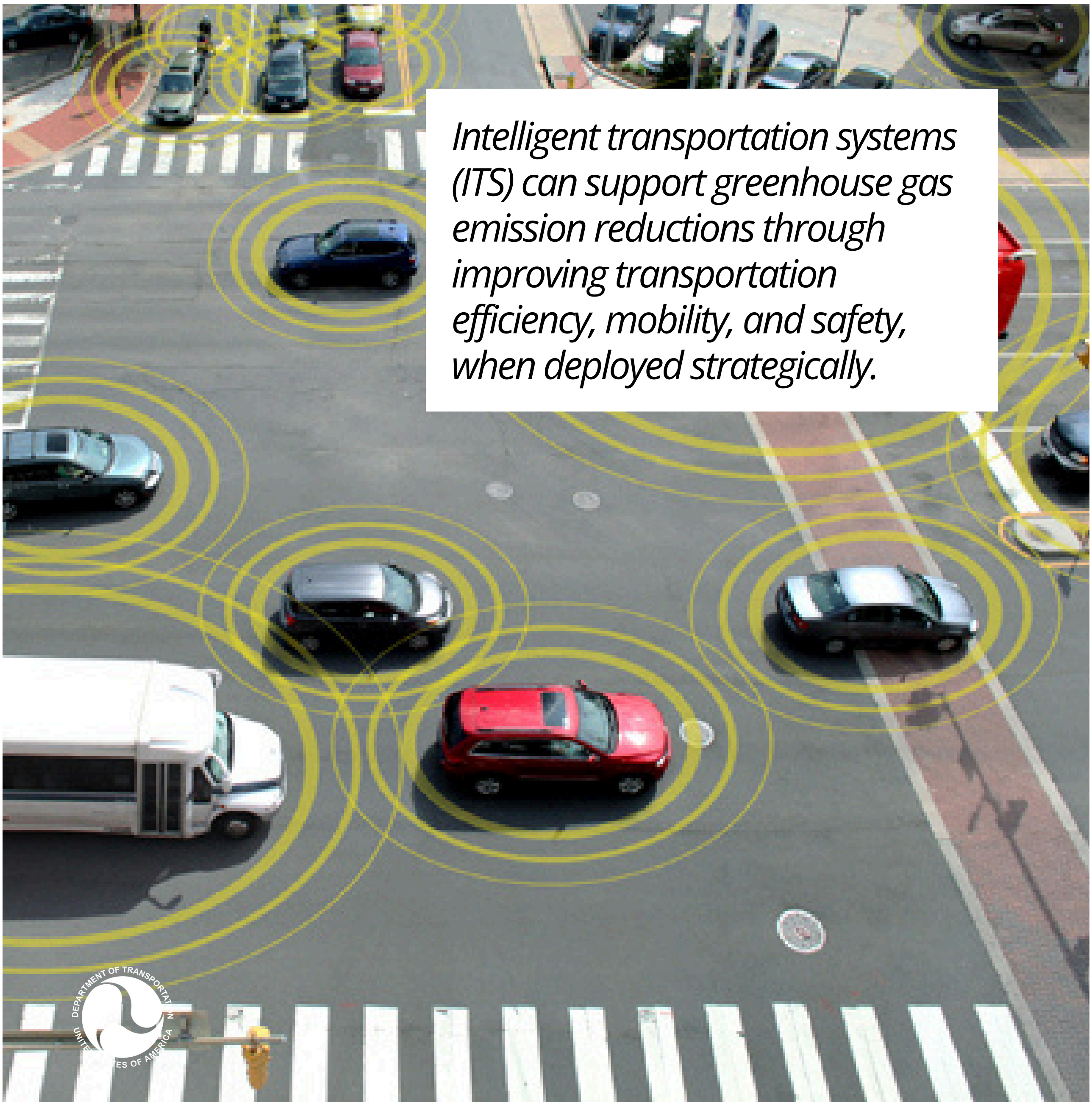
U.S. Department of Transportation, Climate Change Center
Climate Strategies that Work

INTELLIGENT TRANSPORTATION SYSTEMS



Intelligent transportation systems (ITS) can support greenhouse gas emission reductions through improving transportation efficiency, mobility, and safety, when deployed strategically.

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OVERVIEW

Best Suited for:
Long Term
Urban, Suburban, Rural & Tribal

ITS technologies, including connected vehicles (CV) and vehicle-to-everything (V2X) technologies, **can improve transportation system efficiency, mobility, and safety by integrating advanced information and communications-based technologies into transportation infrastructure and vehicles.** Examples of ITS technologies include adaptive signal control, forward collision warning, signal preemption and priority for transit and emergency vehicles, queue warning, work zone safety warnings, vulnerable road user signal crossing applications, and more. Additionally, **ITS data can be used in real time to inform operators and travelers on roadway conditions, safety issues, and overall performance of the transportation network.**

Applied strategically, ITS technologies can facilitate both direct and indirect reductions in greenhouse gas emissions. ITS technologies, particularly when applied synergistically across a region or along a corridor, can reduce congestion, reduce the number of crashes, and reduce stop-and-go behavior and idling, which can in turn reduce overall emissions and improve local air quality.

Did you know?

Smart charging, in which networked charging stations monitor and restrict charging based on real-time demand and grid conditions, can reduce cumulative emissions from electric vehicles by over 30% compared to conventional charging (Jenn and Brown, 2021).

ITS applications make the use of lower carbon modes more efficient (for example, by using transit signal priority) and improve safety for pedestrians, bicyclists, and other vulnerable road users. By improving the safety and convenience of lower carbon modes, ITS technologies may, over time, contribute to increased use of these modes, resulting in reductions in overall transportation greenhouse gas (GHG) emissions in the longer term.

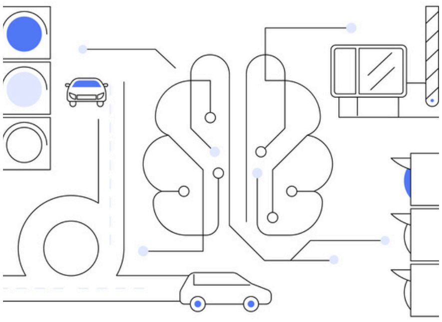
ITS technologies have cross-cutting benefits (Source: ITS JPO).

See summaries of select ITS technologies:

Vehicle-to-everything (V2X) technology enables vehicles to communicate with each other, with road users such as pedestrians and cyclists, and with roadside infrastructure. V2X communication types include: vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P). In the National V2X Deployment Plan (August 2024), USDOT established to deploy V2X on 20% of the National Highway System by 2026, 50% by 2029, and full deployment by 2034. The National V2X Deployment Plan also establishes goals for V2X deployment at signalized intersections, with 85% of intersections in the top 75 metro areas being V2X enabled by 2034.

Overall, V2X safety applications can reduce up to 16% of CO_2 emissions and eco-routing driving applications in individual vehicles can reduce emissions by close to 10% (TNO, 2020).

Adaptive signal control technologies (ASCT) and signal priority systems can reduce travel delays, increase average speeds, and reduce emissions along busy corridors. ASCT and signal priority systems collect real-time demand data, which can be used for optimization of signal timing in response to traffic conditions. Implementing ITS technology at signalized intersections can increase efficiency and reduce delays to motorists and pedestrians. ASCT and signal priority systems can improve the efficiency of the transportation system as the variability and unpredictability of traffic demand on arterial systems often outpace the ability of local and State agencies to update signal timings. ASCT and signal priority systems have demonstrated emission reductions in several deployments across the country through improved traffic flow. (FHWA, 2018; Ban et al., 2014; Dutta et al., 2008; Hutton et al., 2010; Cambridge Systematics, 2016).



Eco-approach and departure at signalized intersections allow drivers to adapt their speed to pass the intersection or stop in the most eco-friendly manner. The GlidePath prototype application, which is a cooperative adaptive cruise control system that uses V2I communications, allows a traffic signal to communicate wirelessly with an equipped vehicle. In comparison to speed recommendations using a driver-vehicle interface incorporated into the speedometer, the V2I GlidePath application provides a 15% reduction in fuel use by minimizing the lag in speed changes and maintaining an optimal speed and approach (ITS JPO, 2016).

Complete streets and shared street uses can adopt ITS technologies to improve safety for vulnerable road users, including pedestrians and cyclists. For example, sensors and signage mounted at intersections can allow for safer vehicle-cyclist interactions, and crosswalks retrofitted with sensors can warn transit buses and trucks when a pedestrian is crossing their intended path. Trucks can be retrofitted with bicyclist/pedestrian detection systems and collision early-warning systems. Adaptable, smart infrastructure, such as intelligent lighting and on-demand conversion of right-of-way for pedestrians and after-school play zones, can promote more equitable land use and incentivize use of lower carbon modes (ITS JPO, 2020).

Variable message signs (VMS) and variable speed limits (VSL) can be used to reduce congestion and manage speeds during inclement weather, traffic accidents, and other roadway conditions. VSL can dynamically manage speeds during planned (peak-hour congestion) and unplanned (incidents) circumstances, while VMS are electronic roadside signs that inform drivers of incidents, special events, and other useful travel information. Both VMS and VSL can help smooth the drive-cycle and reduce idling emissions (FHWA, 2020; MDOT, 2022).

Work zone management leverages ITS technologies to better manage roadway work zones, which often contribute to reductions in roadway capacity and changes in roadway/lane configurations, causing congestion and safety hazards. ITS technologies can be used to communicate with drivers in and around roadway work zones by providing real-time traveler information, recommendations for speed limit adjustments, and audio- and image-based in-vehicle messages to provide drivers with early warnings about road conditions and status. Work zone management can improve safety by preventing crashes and decrease emissions from vehicles passing through work zones by limiting congestion (Li et al., 2018; FHWA, 2014).

Curb management and smart parking technologies can reduce idling time for goods delivery, food delivery, and ridesharing vehicles, and can decrease distance traveled to locate parking. Scheduling applications can also enable curbside and parking reservations and management by replacing a “first-come-first-served” system with the ability to proactively reserve curb and parking space and thereby reduce circling, idling, and double parking (ITS America, 2023). See the *Digital Freight Solutions and Emerging Technologies* page for more information about the potential climate and safety benefits of curb management strategies.

SMART Grants Reduce Emissions through V2X Technology

The Strengthening Mobility and Revolutionizing Transportation (SMART) grant program, established by the Bipartisan Infrastructure Law, funds demonstration projects focused on advanced smart community technologies and systems that improve transportation efficiency and safety. Several SMART projects are applying V2X technology to reduce vehicle emissions and improve safety for road users:

- The City of Colorado Springs is installing radar, lidar, video, and weather/counting stations to enhance detection of all road users (vehicles, pedestrians, cyclists). This deployment will improve safety and efficiency, making traffic flow more responsive to current road conditions and reducing the likelihood of accidents.
- The Orange County Transportation Authority (OCTA) is developing a signalized intersection prototype along Harbor Boulevard, a multimodal corridor that accounts for 8% of all OCTA bus ridership. The prototype will deploy nine signalized intersections with transit signal priority and detection technology. The prototype will improve transportation access by reducing travel times, reduce GHG emissions by minimizing bus idling and stopping, and increase the safety of vulnerable road users through detection technology.

For additional examples, see ITS JPO: Energy & Environment benefits.

GREENHOUSE GAS REDUCTION POTENTIAL

This section provides an overview of greenhouse gas (GHG) emission reductions associated with the strategy. It highlights key findings and relevant metrics from GHG modeling resources, peer-reviewed studies, and real-world applications.

ITS PROJECTS PROVIDE FUEL SAVINGS AND EMISSIONS BENEFITS

Smart Cities and V2X: The Dallas Smart Cities Living Lab pilot implemented several V2X elements, including pedestrian sensors, smart parking, and smart lighting. In addition to increasing foot traffic by 13% year-on-year, the living lab blocks saw a 35% decrease in energy use due to Intelligent LED lighting and an estimated 7-10% decrease in CO_2 emissions associated with cruising for parking (Trey et al., 2018).

Cellular V2X: An initial deployment of cellular-V2X for signal priority in Fulton County, Georgia school buses proved that fuel savings of more than 10% can be expected. The same study also showed decreases in travel time of 13% and a 40% decrease in the number of unplanned stops along bus routes (North Fulton Transportation, 2022).

In-Vehicle Advisories: A study evaluating audio- and image-based in-vehicle warning messages in work zones showed a 16.4% reduction in CO_2 emissions from vehicles passing through the work zone (Li et al., 2018).

Eco-Driving: A traffic microsimulation was used to determine the impacts of cooperative eco-driving (CED) systems on signalized corridors in Riverside, CA. The CED system is expected to reduce energy consumption by 7% and pollutant emissions by up to 59% compared to conventional vehicles (Wang et al., 2019).

Intelligent Intersections: FHWA summarized evaluation data for intelligent intersection signal controls including eco-approach and departure and found that coordinating signals and eco-driving systems (e.g., cooperative adaptive cruise control) provide fuel savings of up to 12-13% (FHWA, 2014).

Smart Charging: Smart charging involves a network of charging stations that optimize energy usage by monitoring and restricting charging based on power grid demand and condition. A 2021 study by UC Davis's Institute of Transportation Studies found that smart charging can reduce cumulative emissions from EVs by over 30% compared to conventional charging (Jenn and Brown, 2021).

Parking Price Management: The San Francisco Municipal Transportation Agency led the SFpark Pricing Pilot demand-based pricing parking management system. Parking prices varied based on the occupancy rate of the parking area, which led parking users to park in areas where there was more availability, spending less time in high-demand areas. The total time to find an available parking spot decreased by 43%, traffic volume decreased by 8%, and GHG emissions decreased by 30% in the pilot areas (SFMTA, 2021).

CO-BENEFITS

This section outlines the multiple co-benefits associated with the strategy, including safety benefits, local air quality improvements, and improved accessibility. Each co-benefit presents examples that demonstrate how the strategy enhances regional or community well-being while addressing emissions.

SAFETY

The Safe System Approach supports zero deaths on roadways through Safe Roads, Safe Vehicles, Safe Road Users, Safe Speeds, and Post-Crash Care. ITS can play a role in each element, saving lives. For example, thermal cameras track pedestrians in real time and improve safety for vulnerable road users (FHWA, 2024).

The National Highway Traffic Safety Administration (NHTSA) noted that the implementation of just two V2X safety applications, Intersection Movement Assist (IMA) and Left Turn Assist (LTA), would prevent 439,000 to 615,000 crashes, 13% to 18% of the total, and save 987 to 1,366 lives. The resulting savings from these reduced crashes would be $55 to $74 billion (ITS America, 2023).

When vehicles are turning into the path of a pedestrian or bicyclist, communications between vehicles and vulnerable road users, such as beacon systems and Bicycle/Pedestrian-to-Vehicle alerts, could potentially avoid 97% of crashes (Qian et al., 2022).

Utah DOT is installing LiDAR sensors to detect pedestrian movements at intersections. The sensors could allow UDOT to adjust signal timing in real time and potentially integrate with cellular vehicle to everything (C-V2X) technology to broadcast pedestrian locations to vehicles approaching an intersection or initiating a turn (Li et al., 2023).

Advanced driver assistance systems (ADAS), including forward collision warning, automatic emergency braking, and lane centering assistance, have the potential to save thousands of lives annually. A large-scale analysis of police crash and vehicle equipment data from 13 states showed the ADAS reduced serious front-to-rear crashes by 42% (Ronne et al., 2022).

A variable speed limit system along a 15-mile section of I-95 in Virginia reduced fatal and serious crashes by 13% (Cho et al., 2023).

COST SAVINGS

There are significant cost savings associated with V2X deployments, including costs related to reductions in fuel use, air pollution, delay time, incidents, injuries, and fatalities.

At the Port of Virginia, truck reservation systems using RFID tags and real-time information from a cloud-based system is expected to reduce truck trip time by 51 minutes (66%) due to reduced queuing and idling, saving trucking companies over $2.7 million in fuel costs (Port of Virginia, 2017).

Intersection conflict warning systems installed at 93 unsignalized rural intersections in Minnesota, Missouri, and North Carolina had estimated benefit-cost rations of 16 to 39 as a result of significant decreases in crashes, fatalities, and injuries (Himes et al., 2016).

ECONOMIC GROWTH

V2X technologies have the potential to bring safety and economic benefits to the transportation network. For example, NHTSA estimates that safety applications enabled by V2X technologies could eliminate or mitigate the severity of up to 80% of non-impaired crashes, or nearly 37,000 fatalities, 3 million injuries, and $800 million in damages (USDOT, 2016).

ACCESSIBILITY AND EQUITY

The Accessible Transportation Technologies Research Initiative (ATTRI) focuses on research to improve the independent mobility of travelers with disabilities through the use of ITS and other advanced technologies. ITS technologies can help track transportation system user's movements, infer map information, and use sensor data to create routes and provide information in audible, tactile, and haptic communication formats (Giampapa et al., 2017).

USDOT's ITS4US Deployment program is focused on solving mobility challenges for all travelers, with a specific focus on underserved communities. For example, the Complete Trip Deployment in Buffalo, NY will improve mobility within and around the Buffalo Niagara Medical Campus by deploying technologies such as an accessible trip planning tool, community-based on-demand shuttles, and intersection pedestrian safety technologies. Learn more about this deployment and other ITS4US initiatives here.

AIR QUALITY AND HEALTH

V2X technologies can help smooth the drive cycle and reduce frequent accelerations, decelerations, and idling, which in turn reduces emissions (TNO, 2020). V2X deployments may be particularly beneficial in port regions with poor air quality and along congested freight corridors.

A study evaluating audio- and image-based in-vehicle warning messages in work zones showed considerable reductions in air pollutants, including a 19% reduction in NOx emissions and 16% reduction in CO emissions (Li et al., 2018).

RURAL COMMUNITIES

Infrastructure for pedestrians in rural areas may be limited; V2X technologies can improve safety and walkability. For example, rectangular rapid flashing beacons (RRFBs) were installed at crosswalks in small and rural communities in Vermont in 2021. When the RRFBs were active, drivers were 2.6 times more likely to yield to pedestrians and pedestrian wait time was not significantly impacted (Rowangould et al., 2023).

COST CONSIDERATIONS

The ITS JPO maintains a Costs Database with cost estimates for ITS deployments. Cost data can be used to develop project cost estimates during the planning or preliminary design phases. Both capital and operating & maintenance costs are provided where possible.

Maryland DOT installed and tested roadside units at a single intersection to evaluate crosswalk safety. The dual-mode units had two communication capabilities: dedicated short-range communication (DSRC) and cellular-vehicle to everything (C-V2X). The total project cost, including one year of maintenance was $84,000 (Maryland DOT, 2023).

Connected vehicle technology was deployed on school buses in Fulton County, CA for approximately $5,000 per bus and $5,000 per intersection. These costs covered connected-V2X technology and allowed for traffic signal priority (Descant, 2022).

The estimated costs for implementing adaptive signal control systems on 3,280 intersections in the Twin Cities metro area (Minnesota) was approximately $70 million or $21,300 per intersection (University of Minnesota, 2021).

The Utah Autonomous Shuttle Pilot provided passenger service at eight locations across Utah over a 17-month project period in 2019. The shuttle was a Level 4 (High Driving Automation) vehicle that could operate at 8-11 mph on fixed, repeated routes. The shuttle cost $400,000 to lease and operate, with an additional $227,000 in UDOT staff time and engineering support (WSP/UDOT, 2021).

FUNDING OPPORTUNITIES

Strengthening Mobility and Revolutionizing Transportation (SMART): This USDOT grant program funds demonstration projects focused on advanced smart community technologies and systems that improve transportation efficiency and safety. Eligible projects include connected vehicles, aviation innovation, smart grid, and traffic signal innovation.

Safe Streets and Roads for All (SS4A) Grant Program: USDOT's SS4A program was established by BIL to support regional, local, and Tribal initiatives to prevent roadway deaths and serious injuries through the safe system approach. Similar to the Zero Deaths and Safe System Program, safety improvements from SS4A will encourage mode choice by removing safety barriers to active transportation.

Clean Ports Program: This EPA program provides for investment in clean, zero emission port equipment and technology; to conduct relevant planning or permitting in connection with the purchase or installation of such equipment or technology; and to help ports develop climate action plans to reduce air pollutants at U.S. ports. Funding may be used for ITS deployments that support zero emission technology and infrastructure.

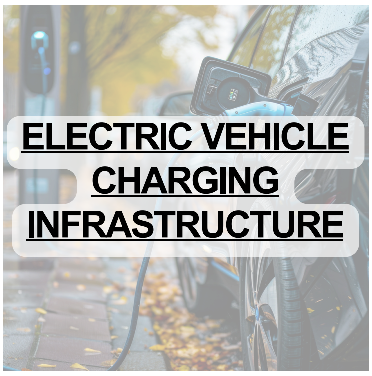
Truck Emissions at Port Facilities (RTEPF) Grant Program: FHWA's RTEPF program provides funding to test, evaluate, and deploy projects that reduce port-related emissions from idling trucks. Eligible projects include port electrification and efficiency improvements, focusing on heavy-duty commercial vehicles, and other related projects.

Exploratory Advanced Research (EAR) Program is exploring the development of artificial intelligence (AI) and machine learning technology within the surface transportation sector. FHWA's EAR program has also funded several computer vision research projects to enhance the safety and efficiency of surface transportation.

Congestion Mitigation and Air Quality Improvement (CMAQ) Program: FHWA's CMAQ program supports surface transportation projects and other related efforts that contribute to air quality improvements and provide congestion relief. CMAQ-eligible projects include V2X technologies such as adaptive traffic control systems, electronic and open road tolling, and variable speed limit/variable message signs.

Advanced Transportation and Innovative Mobility Development (ATTIMD)/Advanced Transportation Technology and Innovation (ATTAIN): FHWA's ATTIMD and ATTAIN programs support the deployment, installation, and operation of advanced transportation technologies. Eligible activities under this program that advance V2X include integrated corridor management systems, electronic pricing and payment systems, and retrofitting DSRC technology deployed as part of an existing pilot program to C-V2X technology.

COMPLEMENTARY STRATEGIES



Smart charging systems using V2X technology to monitor, manage, and restrict the use of charging devices to optimize power grid conditions and battery health.

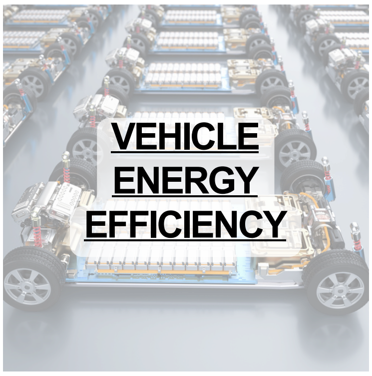
CAV and V2X technologies are seeing increased applications in freight transport, from drone delivery to various curb management strategies.

Cargo bikes, small autonomous vehicles, and other micromobility devices may use V2X technology to improve the efficiency and safety of deliveries. Technology can be installed on devices, cellular phones, and roadside.

V2X technology can support parking reforms through data collection to better predict parking demand and Smart Parking systems.

V2X technology enables implementation of road usage charges, including congestion pricing and cordon pricing programs. In-vehicle transponders communicate with overhead gantries and data collected from roadside monitors can be use to adjust tolls depending on traffic conditions.

V2X can enable monitoring and management of travel demand for shared micromobility devices. Safety features can also allow vehicles to communicate directly with scooters and bikes, for example, by warning them of an approaching or turning vehicle.



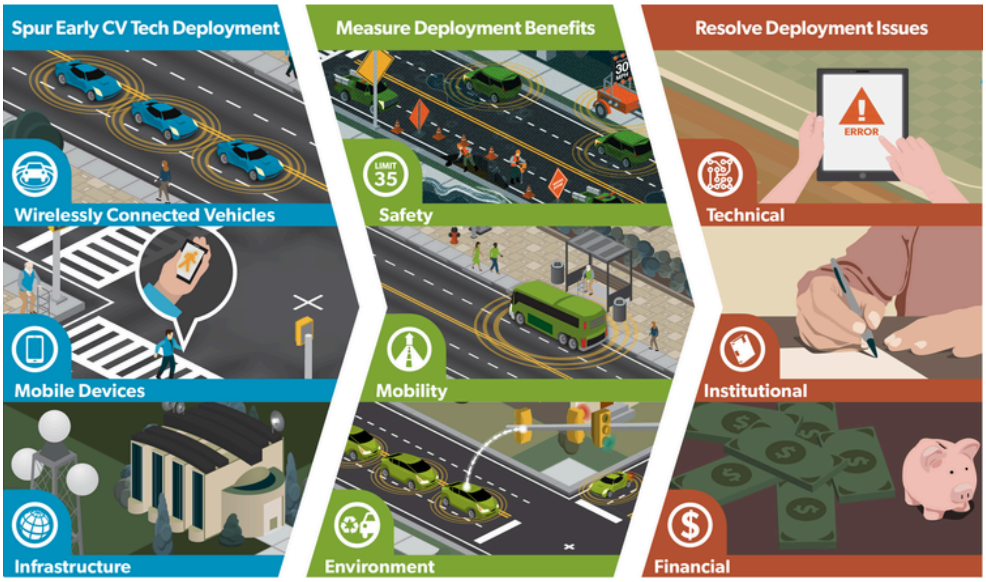
Eco-driving, cooperative adaptive cruise control, and other V2X technologies contribute to improved energy efficiency. They can be installed in any vehicles, from small passenger vehicles up to the largest Class 8 trucks.

View All Strategies

CASE STUDIES

NEW YORK CITY DOT (NYCDOT) CONNECTED VEHICLE PILOT

NYCDOT led a CV deployment in 2021 with the aim of improving the safety of travelers and aligning with the city's Vision Zero initiative to reduce the number of fatalities and injuries due to traffic crashes. The pilot involved a fleet of approximately 3,000 CVs, installing 470 roadside units at signalized intersections, along a major thoroughfare (FDR Drive), and at other strategic locations, and pushing in-vehicle pedestrian warnings. Although improving safety was the primary objective of the NYC pilot, simulations showed that reducing crashes in the deployment area also decreased crash-related congestion, fuel consumption, and GHG emissions.



(Source: NYCDOT)

SCHOOL BUS SIGNAL PRIORITY IN FULTON COUNTY

A pilot study conducted in Alpharetta, GA equipped school buses with cellular connected-vehicle technology and installed CV-enabled roadside units at 62 signalized intersections along the school bus routes. These technologies provided transit signal priority to buses as they approached each traffic signal. Results of the pilot showed a 13.3% decrease in travel time and 7.4% and 12.4% decreases in fuel consumption for a propane bus and diesel bus, respectively.

TEXAS: CARBON REDUCTION STRATEGY V2I TECHNOLOGY

The Texas Carbon Reduction Strategy includes the installation of vehicle-to-infrastructure (V2I) technology on key freight corridors to improve communication and traffic flow along the highway network. The technology upgrade aims to improve the safety and efficiency of current systems and support strategies related to reduced transportation emissions.

IMPLEMENTING INTELLIGENT TRANSPORTATION SYSTEMS: **WHAT TO READ NEXT**

ITS JPO Resources: The USDOT's ITS Joint Program Office supports development and implementation of ITS. The ITS JPO maintains an extensive database with benefits, costs, and lessons learned from over 3000 ITS deployments across the country, including findings related to safety, efficiency, mobility, and environmental benefits. For more information, see the ITS Deployment Evaluation website, detailed Benefit Data, and Benefits and Costs Map.

V2X Deployment Plan: Successfully developing and deploying V2X technologies requires close coordination across USDOT, state and local governments, and Tribes, researchers, OEMS, automotive suppliers, transit and freight operators, communication providers, and standards development organizations, among others. See USDOT's National V2X Deployment Plan for more information.

V2X Community Stakeholder Groups (Source USDOT).

V2X connectivity is envisioned as a cooperative system where technology operates as a single system despite various stakeholders, owners, operators, and equipment. Achieving interoperability requires close coordination across government and industry. The USDOT's standards and architecture includes the National ITS Reference Architecture, a resource that provides a framework for safe, secure, and effective interoperable systems (USDOT 2023).

Adaptive Signals: At a high level, adaptive signals require planning, equipment, maintenance, and technical skills. Before implementing adaptive signals, agencies should use the FHWA's Systems Engineering Process for ASCT Systems to identify needs and requirements and determine if adaptive signals are appropriate. For more information, see FHWA's ASCT Resources and WSDOT's Resources on Adaptive Signals – Coordination, Integration, and Timing.

RESOURCES

GENERAL RESOURCES

USDOT ITS Joint Program Office. Since its formation in 1994, the ITS JPO has led collaborative research to support the development and implementation of ITS. The JPO maintains a library of resources to support ITS demonstrations, ITS Deployment Evaluations, Benefits, and Costs, ITS CodeHub, and ITS DataHub.

WSDOT TSMO Resources. Washington State DOT (WSDOT) has developed an interactive website for transportation professionals to learn more about Transportation Systems Management and Operations (TSMO). Strategies include CAV, ITS, and transportation demand management with ratings based on cost, technology, and level of collaboration required.

Saving Energy with Connectivity. In collaboration with USDOT, DOE announced a Notice of Intent for a FY24 Funding Opportunity Announcement for Saving Energy with Connectivity. Projects will develop and deploy approaches using vehicle-to-everything (V2X) high-speed, low latency communication to improve the efficiency and convenience of the mobility-system. Projects could include but are not limited to eco-driving along connected corridors, transit priority, intermodal optimization, or freight priority. Projects under this program will culminate in the deployment of hardware in real-world settings, serving as a model for future deployment.

Cooperative Driving Automation.

- FHWA's CARMA Program is leading research on cooperative driving automation (CDA) which would enable communication and cooperation between properly equipped vehicles and infrastructure.
- DOE also supports CDA research through research funding through the ARPA-E NEXTCAR Program and research funding for New Mobility Systems. DOE's portfolio of work includes defining and developing communication requirements to implement energy centric CDA applications, including information messages exchanged, required communication latency, frequency, bandwidth, and other state-of-the-art requirements as well as evaluate their impacts on energy efficiency over a range of scenarios. DOE's CDA research includes optimizing the signal phase and timing of traffic signals and connected vehicle/connected and automated vehicle (CV/CAV) trajectory planning along multi-intersection arterials and highways.

Smart Community Resource Center. The SCRC, maintained by USDOT and ITS JPO, is designed to connect States, Tribal governments, and local communities with resources that can be used to develop intelligent transportation systems and smart community transportation programs. It is a comprehensive central resource for ITS-related information.

ITS JPO's ITS Standards Program. Established by USDOT in 1996, the ITS Standards Program helps encourage widespread use of ITS technologies. To date, 99 standards have been published and are ready for use in ITS deployments, such as Dynamic Message Signs and Connected Intersections.

Architecture Reference for Cooperative and Intelligent Transportation (ARC-ITS). ACR-IT provides a common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross-section of the ITS community. Service packages address specific services like traffic signal control and provide a straightforward entry into ARC-IT content.

USDOT's Safety Band Website. This site provides many resources related to the radio spectrum (5.9 GHz) reserved for transportation safety. These resources include an interactive map showing CV deployment locations across the country and state-by-state crash data that could potentially be mitigated through deployment of Safety Band technology.

FHWA's Planning and Implementing Multimodal, Integrated Corridor Management: Guidebook. Integrated Corridor Management (ICM) is an operational concept that seeks to reduce congestion and improve performance by maximizing the use of available multimodal capacity across a corridor, including highways, arterial roads, and transit systems. The NCHRP Web-Only Document 287: Planning and Implementing Multimodal, Integrated Corridor Management: Guidebook provides an overview of current recommended practices and outlines critical components for the planning, design and development, and operations and maintenance of an ICM system.

TOOLKITS AND MODELING APPROACHES

FHWA's Congestion Mitigation and Air Quality Improvement Program (CMAQ) Emissions Calculator Toolkit: The CMAQ Toolkit includes a tools specifically designed to estimate the air quality and greenhouse gas reduction benefits of V2X projects, including Adaptive Traffic Control Systems, Travel Advisories, Electronic and Open Road Tolling.

DOE's Energy Efficiency Mobility Systems: The EEMS Program supports the DOE Vehicle Technology Office's mission to improve transportation energy efficiency through low-cost, secure, and clean energy technologies. The SMART Mobility 2.0 Laboratory Consortium supports a range of research on advanced mobility solutions, including CAV, curb management, and micromobility.

DOE's POLARIS: This tool allows for advanced travel and freight demand modeling and simulations for multi-modal systems. It can be used to analyze transportation systems involving CAV and V2I technologies and conduct systems level optimization on parameters including travel time and energy usage.

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