



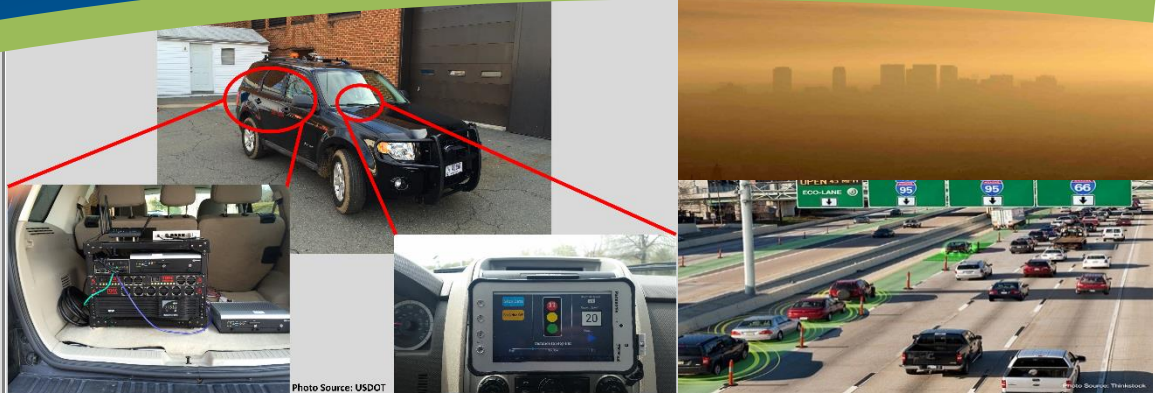
# Connected Vehicles – Environmental Applications

## ITS Benefits, Costs, and Lessons Learned: 2017 Update Report

### Connected Vehicle – Environmental Applications

#### Highlights

- Employing a multi-modal approach, the AERIS Research Program aims to encourage the development of technologies and applications that support a more sustainable relationship between transportation and the environment chiefly through fuel use reductions and resulting emissions reductions.
- Together the Eco-Signal Operations applications provided **up to 11% improvement** in CO<sub>2</sub> and fuel consumption reductions at full connected vehicle penetration.



### Introduction

*This factsheet is based on past evaluation data contained in the ITS Knowledge Resources database at: [www.itskrs.its.dot.gov](http://www.itskrs.its.dot.gov). The database is maintained by the U.S. DOT's ITS JPO Evaluation Program to support informed decision making regarding ITS investments by tracking the effectiveness of deployed ITS. The factsheet presents benefits, costs and lessons learned from past evaluations of ITS projects.*

The U.S. Department of Transportation's (USDOT's) 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're 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 and projects are being deployed in each of these areas. Environmental applications developed through the Applications for the Environment: Real-time Information Synthesis (AERIS) program envisioned a transportation system in which all transportation users, regardless of mode, would have the information needed to make better and greener transportation choices, at any time and in any place.

The environmental component of the ITS Joint Program Office's (JPO's) connected vehicle research program, AERIS, officially kicked off in 2009 with a vision of "Cleaner Air through Smarter Transportation". Employing a multimodal approach, the AERIS Research Program aimed to encourage the development of technologies and applications that support a more sustainable relationship between transportation and the environment chiefly through fuel use reductions and resulting emissions reductions.

**AERIS Applications Benefit Drivers, Fleet Operators and Cities: Drivers help the environment and save money at the pump, fuel savings help fleet operators reduce operating costs and cities benefit from reduced emissions and improving the air quality.**

The AERIS Program investigated five operational scenarios, each made up of several applications. The operational concepts were: Eco-Signal Operations, Eco-Lanes, Low Emissions Zones, Eco-Traveler Information, and Eco-Integrated Corridor Management.

## Eco-Signal Operations

The Eco-Signal Operations Operational Scenario includes the use of connected vehicle technologies to decrease fuel consumption and decrease greenhouse gases (GHGs) and criteria air pollutant emissions on arterials by reducing idling, reducing the number of stops, reducing unnecessary accelerations and decelerations, and improving traffic flow at signalized intersections. The Eco-Signal Operations Operational Scenario includes five applications: (1) Eco-Traffic Signal Timing, (2) Eco-Traffic Signal Priority, (3) Eco-Approach and Departure at Signalized Intersections, (4) Connected Eco-Driving, and (5) Wireless Inductive/Resonance Charging.

## Eco-Lanes

The Eco-Lanes Operational Scenario includes dedicated lanes optimized for the environment, referred to as Eco-Lanes. Eco-Lanes are similar to HOV and HOT lanes; however these lanes are optimized for the environment using connected vehicle data and can be responsive to real-time traffic and environmental conditions. Eco-Lanes allow an operating entity to change the location of the eco-lanes, the duration of the eco-lanes, the number of lanes dedicated as eco-lanes, the rules for vehicles entering the eco-lanes, and other parameters. These lanes would be targeted towards low emission, high occupancy, freight, transit, and alternative fuel vehicles. Drivers would be able to opt-in to these dedicated eco-lanes to take advantage of eco-friendly applications such as eco-cooperative adaptive cruise control, connected eco-driving, and wireless inductive/resonance charging applications.

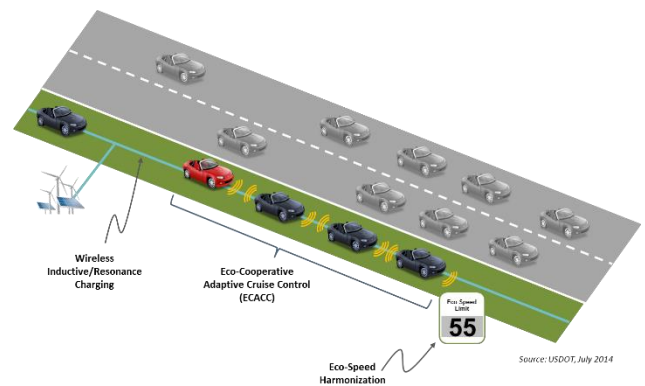


Figure 1: Eco-Lanes Concept (Source: USDOT)

## Low Emissions Zones

Low Emissions Zones would be used to encourage decisions by travelers that help reduce transportation's negative impact on the environment. The Low Emissions Zones Operational Scenario envisions entities responsible for the operations of the transportation network to have the ability to define geographic areas that seeks to restrict or deter access by specific categories of high-polluting vehicles into the area for the purpose of improving the air quality within the geographic area. Alternatively, the Operational Scenario may incentivize traveler decisions that are determined to be environmentally friendly such as the use of alternative fuel vehicles or transit. Low emissions zones in a connected vehicle environment would be similar to existing low emissions zones; however they would leverage connected vehicle technologies allowing the systems to be more responsive to real-time traffic and environmental conditions.

## Eco-Traveler Information

The Eco-Traveler Information Operational Scenario enables development of new, advanced traveler information applications through integrated, multisource, multimodal data. Although the AERIS Program may not directly develop specific traveler information applications, an open data/open source approach is intended to engage researchers and the private sector to spur innovation and environmental applications. This Operational Scenario includes six applications: (1) Dynamic Eco-Routing, (2) Dynamic Eco-Transit Routing, (3) Dynamic Eco-Freight Routing, (4) Eco-Smart Parking, (5) Connected Eco-Driving, (6) Multi-Modal Traveler Information, and AFV Charging / Fueling Information.

## Eco-Integrated Corridor Management

The Eco-Integrated Corridor Management (Eco-ICM) Operational Scenario includes the integrated operation of a major travel corridor to reduce transportation-related emissions on arterials and freeways. Integrated operations means partnering among operators of various surface transportation agencies to treat travel corridors as an integrated asset, coordinating their operations simultaneously with a focus on decreasing fuel consumption, GHG emissions, and criteria air pollutant emissions. At the heart of this Operational Scenario is a real-time data-fusion and decision support system that involves using multisource, real-time V2I data on arterials, freeways, and transit systems to determine which operational decisions have the greatest environmental benefit to the corridor. This Operational Scenario includes a combination of multimodal applications that together provide an overall environmental benefit to the corridor as well as a decision support system.

# Benefits

The AERIS Capstone report summarizes all of the modeling benefits for the environmental applications that were being researched.

**Table 1: Summary of AERIS Modeling Results**

Application	Modeling Results
<b>Eco-Approach and Departure at Signalized Intersections</b>	<ul style="list-style-type: none"> <li>The application provided <b>5-10% fuel reduction benefits</b> for an uncoordinated corridor</li> <li>For a coordinated corridor, the application provided up to <b>13% fuel reduction benefits</b> <ul style="list-style-type: none"> <li>8% of the benefits were attributable to signal coordination</li> <li>5% attributable to the application</li> </ul> </li> </ul>
<b>Eco-Traffic Signal Timing</b>	<ul style="list-style-type: none"> <li>When applied to a signalized corridor that was fairly well optimized, the application provided an <b>additional 5% fuel reduction benefit</b> at full connected vehicle penetration.</li> </ul>
<b>Eco-Traffic Signal Priority</b>	<ul style="list-style-type: none"> <li>The Eco-Transit Signal Priority application provided <b>up to 2% fuel reduction benefits</b> for transit vehicles.</li> <li>The Eco-Freight Signal Priority application provided <b>up to 4% fuel reduction benefits</b> for freight vehicles.</li> </ul>
<b>Connected Eco-Driving</b>	<ul style="list-style-type: none"> <li>When implemented along a signalized corridor, the application provided <b>up to 2% fuel reduction benefits</b> at full connected vehicle penetration.</li> <li>The application provided <b>up to 2% dis-benefit in mobility</b> (e.g., travel time) due to smoother and slower accelerations to meet environmental optimums.</li> </ul>
<b>Combined Eco-Signal Operations Modeling</b>	<ul style="list-style-type: none"> <li>Together the Eco-Signal Operations applications provided <b>up to 11% improvement</b> in CO<sub>2</sub> and fuel consumption reductions at full connected vehicle penetration.</li> </ul>
<b>Eco-Speed Harmonization</b>	<ul style="list-style-type: none"> <li>The application provided <b>up to 4.5% fuel reduction benefits</b> for a freeway corridor. It assisted in maintaining the flow of traffic, reducing unnecessary stops and starts, and maintaining consistent speeds near bottleneck and other disturbance areas.</li> </ul>
<b>Eco-Cooperative Adaptive Cruise Control (Eco-CACC)</b>	<ul style="list-style-type: none"> <li>Eco-CACC provided <b>up to 19% fuel savings</b> on a real-world freeway.</li> <li>Vehicles using a dedicated “eco-lane” experienced <b>7% more fuel savings</b> when compared to vehicles in the general lanes.</li> <li>Eco-CACC has the potential to provide <b>up to 42% travel time savings</b> on a real-world freeway corridor for all vehicles.</li> </ul>
<b>Combined Eco-Lanes Modeling</b>	<ul style="list-style-type: none"> <li>Together the Eco-Lanes applications provided <b>up to 22% fuel savings</b> on a real-world freeway corridor for all vehicles.</li> <li>Vehicles using the dedicated “eco-lane” experienced <b>2% more fuel savings</b> when compared to vehicles in the general traffic lanes.</li> <li>The scenario provided <b>up to 33% travel time savings</b> for all vehicles.</li> </ul>
<b>Low Emissions Zones</b>	<ul style="list-style-type: none"> <li>A Low Emissions Zone modeled in the Phoenix Metropolitan Area resulted in <b>up to 4.5% reduction in fuel consumption</b> when both eco-vehicle incentives and transit incentives were offered.</li> <li>The modeling indicated that the Low Emissions Zone has the potential to <b>reduce vehicle miles traveled by up to 2.5%</b> and <b>increase by up to 20%</b> in to the Low Emissions Zones.</li> </ul>

One lesson the AERIS team learned from modeling is that converting results to meaningful numbers (e.g., fuel savings for individuals and/or fleet operators) helped stakeholders understand the potential benefits in ways they could visualize the results. Fleet operators, including transit, freight and others, also benefit from AERIS applications. Fuel savings help fleet operators save fuel costs resulting in lower operating costs. Finally, cities benefit from AERIS applications which help to reduce emissions and improving the air quality. AERIS applications also help reduce congestion and support sustainable transportation solutions.



AERIS applications help drivers reduce their carbon footprint and reduce their fuel consumption. **Drivers help the environment and save money at the pump.**



Fleet operators also benefit from AERIS applications. **Fuel savings help fleet operators save fuel costs resulting in lower operating costs.**



**AERIS applications benefit cities, helping reduce emissions and improving the city's air quality.** AERIS applications also help reduce congestion and support sustainable transportation solutions.

### Assuming a Corridor with Average Traffic Congestion

- Modeling results indicate the following benefits:
  - Light vehicles: 9.6% reductions in fuel consumption
  - Freight: 9.8% reductions in fuel consumption
  - Transit: 3.1% reductions in fuel consumption
- Gasoline costs:
  - \$3.67/gallon (light vehicle and SUV)
  - \$3.95/gallon for diesel (trucks)
  - \$3.00/gallon estimated for mix of CNG and diesel fleets (transit)
- Average miles traveled on arterials:
  - Light duty vehicle and SUVs: 8,250 miles
  - City delivery truck: 30,000 miles
  - Transit: 44,600 miles
- Estimated Benefits
  - Light Vehicle, 23 MPG ~ \$126 per year
  - Sport Utility Vehicle (SUV), 17 MPG ~ \$170 per year
  - City Delivery Fleet (1,000 vehicles), 7.3 MPG ~ \$1.6M per year
  - Transit Fleet (1,000 vehicles), 4 MPG ~ \$918,000 per year

Figure 2: AERIS Benefits

## Case Study GlidePath – Eco-Approach and Departure at Signalized Intersections

Together the Intelligent Transportation Systems (ITS) Joint Program Office (JPO) and Federal Highway Administration's (FHWA's) Turner Fairbank Highway Research Center (TFHRC) Office of Operations, Research and Development (HRDO) implemented and successfully demonstrated the automated GlidePath prototype application. GlidePath is the Nation's first application of a Cooperative Adaptive Cruise Control (CACC) system that automatically communicates wirelessly with a traffic signal and controls a vehicle's speed in an eco-friendly manner. The application leverages vehicle-to-infrastructure (V2I) communications to enable an equipped vehicle to communicate wirelessly with a traffic signal.

In 2012, the Applications for the Environment: Real-Time Information Synthesis (AERIS) team conducted a field experiment at TFHRC for the Eco-Approach and Departure at Signalized Intersections application. Successful experimentation showed up to 18% reductions in fuel consumption and carbon dioxide (CO<sub>2</sub>) emissions for a single vehicle at a single fixed timed intersection. Drivers were provided with speed recommendations using a driver-vehicle interface (DVI) incorporated into the speedometer. Recommendation speeds were calculated based on the vehicle's location and signal phase and timing (SPaT) messages collected from the traffic signal. While the results were promising, the experiment identified potential driver distraction issues. As such, in 2014 the AERIS team undertook the GlidePath prototype application project—a first of its kind prototype—which incorporated automated longitudinal control capabilities along with the eco-approach and departure algorithm.



Figure 3: Vehicle Used for Testing at TFHRC (Source: USDOT)

FHWA Office of Operations Research and Development (R&D) staff, in cooperation with partners, built the onboard application and control software that provides a tablet-based driver interface and computes an optimum speed trajectory through TFHRC's intelligent intersection. Upon computing this trajectory and activation by the driver, the software takes control of the vehicle's accelerator and brakes to safely and smoothly drive it through the intersection while respecting the



traffic signal and local speed limit. As with any cruise control, the human driver is always in control of the vehicle and can disengage the automation by stepping on the brake or turning the cruise control feature off.

When the vehicle approaches an intelligent intersection, it receives two distinct standard dedicated short range communications (DSRC) messages describing the SPaT and intersection geometry. With this information, and its current position and speed, the onboard computer computes its travel distance to the stop bar.

DSRC messages also provide the driver with SPaT data in illustration form, which indicates signal activity (i.e., when the signal will turn from green to yellow to red). With these data, the vehicle can then compute a speed profile that maximizes fuel economy by adjusting speed either up or down to avoid coming to a full stop at the intersection, if possible. In cases where a full stop is necessary, the software holds the vehicle at the stop bar until the signal turns green and the driver issues a “Resume” command, thus ensuring that it is safe to resume forward motion. The software then accelerates the vehicle to its desired cruise speed as it leaves the intersection. The software will work on any properly configured intersection and has many configurable parameters, some of which include cruise speed, roadway speed limit, decision point distances, and acceleration limits.

## Results

Data collected in field experiments revealed that average fuel consumption was improved in vehicles equipped with the Eco-Approach and Departure application. As shown in the table below, results from August 2015 indicate that a driver with a DVI saw 7% fuel savings over un-informed drivers, while a driver with partial automation and the GlidePath application saw 22% fuel savings over the un-informed driver. These results show a 15% fuel improvement from a driver trying to follow a DVI speed recommendation to the partial automated GlidePath application. These improvements are due to minimizing the lag in speed changes to keep the optimal speed and approach.

**Table 2: Relative Savings in Fuel Consumption (%) between Different Driving Modes for the GlidePath Prototype Application**

Phase	2	7	12	17	22	27	2	7	12	17	22	27	Average
<b>DVI vs. Uniformed</b>	-11.8	-11.8	7.6	5.2	7.6	12.1	25.1	37.8	-18.3	21.7	-0.6	13.5	<b>7.3</b>
<b>Automated vs. Uninformed</b>	4.7	7.6	35.3	20.9	20.3	31.7	32.7	47.9	-3.9	26.5	20.1	22.9	<b>22.2</b>
<b>Automated versus DVI</b>	14.7	17.3	29.9	16.6	13.8	22.4	10.1	16.3	12.2	6.1	20.5	10.8	<b>15.9</b>

## Future Research Opportunities

This pioneering work has established a solid foundation for continued research and innovation involving variable signal timing, accommodating other vehicles in the intersection, and investigating multi-signal applications. The project will continue through the Crash Avoidance Metrics Partnership (CAMP), a consortium of twelve vehicle manufacturers who will first further investigate the feasibility of this application. Opportunities for future research with the GlidePath Prototype include consideration of: testing with multiple equipped vehicles—including integration of CACC capabilities between multiple vehicles, testing at multiple intersections (i.e., a corridor), testing on a real-world corridor with traffic, and testing with an enhanced algorithm that considers actuated traffic signal timing plans and queues at intersection.

## References

Data referenced in this factsheet is available from the AERIS Capstone report and Executive Summary:

Applications for the Environment Real-Time Information Synthesis Capstone Report: 2009 to 2014 Executive Summary. USDOT. [http://www.its.dot.gov/research\\_archives/aeris/pdf/AERIS\\_Capstone\\_ExecSummary.pdf](http://www.its.dot.gov/research_archives/aeris/pdf/AERIS_Capstone_ExecSummary.pdf)