Applications for the Environment: Real-Time Information Synthesis (AERIS)

Capstone Report: 2009 to 2014 Executive Summary

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Executive Summary — January 2016

U.S. Department of Transportation

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U.S. Department of Transportation
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Notice

Executive Summary

Introduction

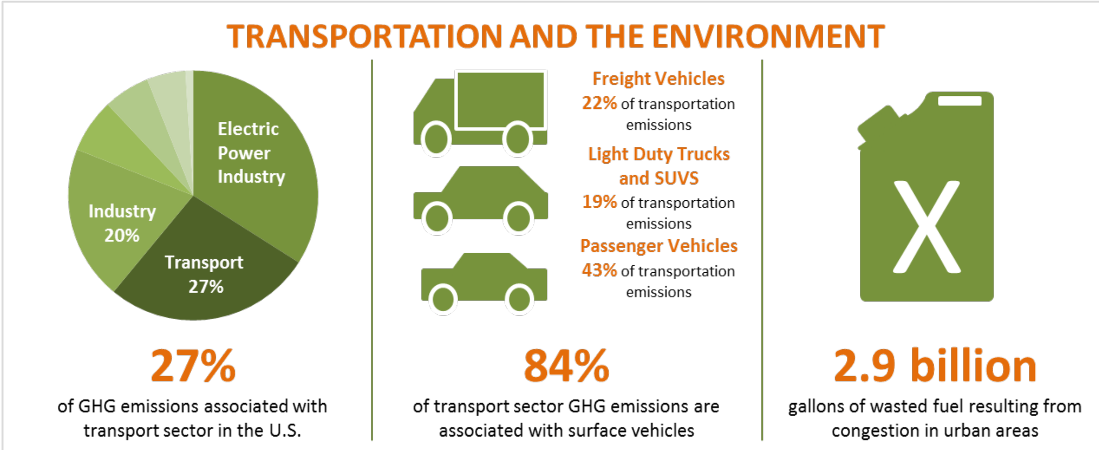
> *The AERIS Research Program advanced the state-of-the-practice in connected vehicle research by defining transformative applications; conducting advanced analysis, modeling and simulation; and developing a first of its kind connected automation GlidePath prototype application.*

The Applications for the Environment: Real-Time Information Synthesis (AERIS) Research Program advanced the state-of-the-practice in intelligent transportation systems (ITS) connected vehicle research that supports a more sustainable relationship between transportation and the environment. Over a five-year period, the AERIS Research Program engaged a diverse set of stakeholders in a dialogue about the potential of connected vehicle technologies to reduce fuel consumption and vehicle emissions. The AERIS Program defined transformative applications and conducted state-of-the-art modeling and analysis to better understand the potential environmental benefits offered by connected vehicle applications. The AERIS Program also developed the GlidePath prototype application—a first-of-its-kind connected automated vehicle that uses automated longitudinal control capabilities to determine the most environmentally efficient trajectory for a vehicle approaching a signalized intersection.

The United States Department of Transportation's (USDOT's) connected vehicle research program is comprehensive and engages a wide range of stakeholders including the federal government, state agencies, the private sector, and vehicle manufacturers. Connected vehicles have the potential to transform travel as we know it by combining leading edge technologies—advanced wireless communications, on-board computer processing, advanced vehicle-sensors, Global Positioning System (GPS) navigation, smart infrastructure, and others—to address safety, mobility, and environmental challenges.

The environmental component of the ITS Joint Program Office's (JPO's) connected vehicle research program 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.

From the start, the AERIS research team envisioned a transportation system in which all transportation users, regardless of mode, would have the information they needed to make better informed and greener transportation choices, whenever and wherever they chose. The AERIS research team asked its stakeholders to completely reimagine how a transportation system could operate to achieve a maximum environmental benefit by leveraging the new capabilities of connected vehicle and other emerging technologies. Assuming the full potential of these technologies existed, what would the transportation system look like? How could these technologies help reduce the 27% of greenhouse gas (GHG) emissions associated with transportation and the 2.9 billion gallons of wasted fuel resulting from congestion in urban areas? And what potential environmental benefits may these connected vehicle applications offer? These questions proved to be the central mission of the AERIS Research Program between 2009 and 2014.



ES Figure 1: Transportation and the Environment (*Source: USDOT, 2014)*

This document, the *AERIS Capstone Report (2009-2014)*, examines and summarizes the five years of research conducted by the ITS JPO. The report serves as a tool to transfer knowledge to a diverse set of stakeholders educating them on the program's objectives, key research findings, modeling results, and prototyping activities. As such, the AERIS Capstone Report (2009-2014) answers three questions:

1. What was the AERIS Research Program <u>supposed</u> to do and what <u>did</u> it do?
2. How did the AERIS Research Program advance connected vehicle and environmental research and move forward the state of the practice?
3. How are the AERIS Research Program's results being used and how might they support deployment in the near-term and in the long-term?

The *AERIS Capstone Report (2009-2014)* also provides recommendations for future research activities related to transportation, the environment, and connected vehicle technologies. The audience for this report includes: federal staff including USDOT leadership and researchers; practitioners including staff working for metropolitan planning organizations (MPOs) and state and local agencies; deployment enablers including vendors and application developers, the ITS standards community, and the automotive industry; researchers including public, private, and academic researchers; and other partners interested in how connected vehicle technologies can mitigate transportations negative impact on the environment.

Question 1: What was the AERIS Research Program <u>supposed</u> to do and what <u>did</u> it do?

The AERIS Research Program began in 2009 and was a five-year research program. The ITS JPO initiated the AERIS Program to investigate whether it was possible and feasible to:

- Identify connected vehicle applications that could provide environmental impact reduction benefits via reduced fuel use and efficiency impacts on emissions.
- Facilitate and incentivize "green choices" by transportation service consumers (i.e., system users, system operators, policy decision makers, etc.).

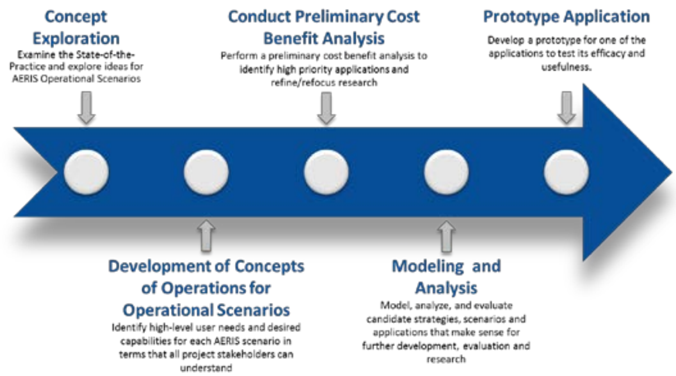
- Identify vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-grid (V2G) data (and other) exchanges via wireless technologies of various types.
- Model and analyze connected vehicle applications to estimate the potential environmental impact reduction benefits.
- Develop a prototype for one of the applications to test its efficacy and usefulness.

Over the course of the program, AERIS sought to promote the highest levels of collaboration and cooperation in the research and development of transformative environmental applications using connected vehicle technologies. AERIS applications were designed to work in a connected vehicle environment where vehicles and infrastructure communicate seamlessly with each other to transmit information that can be used for various purposes.

AERIS research activities focused on five Operational Scenarios or strategic bundles of applications. As depicted in ES Figure 2, these Operational Scenarios include Eco-Signal Operations, Eco-Lanes, Low Emissions Zones, Eco-Traveler Information, and Eco-Integrated Corridor Management (Eco-ICM). Each Operational Scenario encompassed a set of applications which individually achieved environmental benefits. However, by strategically bundling the applications, the AERIS Program saw that the Operational Scenarios could achieve additional environmental benefits above those of the individual applications.

ES Figure 2: AERIS Operational Scenarios and Applications *(Source: USDOT, 2014)*

The AERIS Research Program adopted a phased research approach. The first phase, Concept Exploration, examined the state-of-the-practice and explored ideas for AERIS research. Five state-of-the-practice reports were developed as part of this phase investigating (i) environmental applications, (ii) assessment of technologies to collect environmental data, (iii) environmental models, (iv) behavioral and activity-based models, and (v) evaluation of environmental ITS deployments. Additionally, AERIS sponsored seven Broad Agency Announcement (BAA) projects that were conducted to leverage cutting edge research activities from academia and private industry.



ES Figure 3: The AERIS Research Approach *(Source: USDOT, 2014)*

The next phase, Development of Concepts of Operations (ConOps) for Operational Scenarios, focused on the identification of environmental applications and the development of Concept of Operations for the Eco-Signal Operations, Eco-Lanes, Low Emissions Zones, Eco-Traveler Information, and Eco-ICM Operational Scenarios. Once the ConOps were developed, a preliminary benefit cost analysis (BCA) was performed to identify high priority applications and refine/refocus the research. The high priority applications brought to light by the BCA were then selected for more detailed Modeling and Analysis. Modeling and Analysis consisted of algorithm development and integrated modeling using transportation simulation models (e.g., VISSIM) and environmental models [e.g., the Environmental Protection Agency's (EPA's) MOVES model] to estimate environmental benefits. The results of the modeling effort were detailed modeling reports that document the potential benefits that may be possible by implementing AERIS connected vehicle applications.

Finally, the AERIS Program selected one of the high priority applications—the Eco-Approach and Departure at Signalized Intersections application—for *Prototyping* to test its efficacy and usefulness. AERIS conducted a field experiment in 2012 at Turner Fairbank Highway Research Center (TFHRC) to test efficacy and usefulness and more recently developed a more robust prototype application—the GlidePath prototype—that integrates automated longitudinal control capabilities into the application.

Question 2: How did the AERIS Research Program advance connected vehicle and environmental research and move forward the state of the practice?

The AERIS Research Program pioneered connected vehicle research related to the environment. When the program began in 2009, initial research in the field of ITS found limited documentation about environmental applications and their benefits. While ITS safety and mobility research was fairly mature, environmental ITS research related was basically in its infancy. At the same time, connected vehicle research activities were also in their early stages. Thus, establishing the foundation for the AERIS Research Program proved to be an initial challenge.

The AERIS Research Program Fostered Environmental Research Activities through State of the Practice and Broad Agency Announcement (BAA) Research Projects

Foundational research for AERIS included the development of five state-of-the-practice (SOP) reports along with seven broad BAA projects. Together these efforts helped identify opportunities for further research within the program to: (i) analyze and evaluate specific applications/strategies for improving environmental decisions by public agencies and consumers and (ii) to improve environmental outcomes using ITS and connected vehicle technologies. Outcomes from the SOP reports served as inputs for the next phase of the program focused on concept development and detailed modeling and analysis. The SOP reports were useful in identifying potential modeling tools to support evaluation of AERIS applications.

AERIS SOP Reports

- ***SOP Report #1.*** *Applications State of the Practice Assessment Report*
- ***SOP Report #2.*** *Techniques for Evaluating the Environmental Impacts of ITS Deployment*
- ***SOP Report #3.*** *State of the Practice Scan of Behavioral and Activity-Based Models*
- ***SOP Report #4.*** *State-of-the-Practice Scan of Environmental Models*
- ***SOP Report #5.*** *State-of-the-Practice Assessment of Technology to Enable Environmental Data Acquisition*

The BAA projects were useful in actively soliciting ideas from the research community—and were also used to fund new research efforts and allowed the AERIS team to learn from technical experts. The results from the foundational BAA research shaped the AERIS Research Program. As depicted in the table below, BAA research included modeling of connected vehicle applications (e.g., eco-routing, eco-driving, and eco-approach and departure applications). Many of these applications were later identified as strategic applications for additional modeling and analysis and eventually prototyping. Projects also investigated data capture and management strategies including detailed analysis of potential data elements available from commercial vehicles. Finally, one project provided a scan of international activities in Japan and Europe.

ES Table 1: AERIS Broad Agency Announcement (BAA) Research Projects

Project	Researcher	Summary
BAA Project #1. An Evaluation of Likely Environmental Benefits of Lowest Fuel Consumption Route Guidance	University at Buffalo	This project developed an integrated simulation modeling framework capable of calculating "green-routes" in the Buffalo-Niagara metropolitan area. Results indicated that 'green routing' could result in significant reductions in fuel consumption and emissions, but this may come at the expense of an increased travel time.
BAA Project #2. Developing and Evaluating Intelligent Eco-Drive Applications	Virginia Tech	The project developed a predictive eco-cruise control algorithm in state-of-the-art car-following models that integrates eco-cruise control, optimum vehicle acceleration and deceleration controllers with car-following models. The vehicle's eco-cruise control system generates an optimal control plan using roadway grade information obtained from a high resolution digital map to control the vehicle speed within a preset speed window in a fuel-saving manner.

Project	Researcher	Summary
BAA Project #3. Eco-Speed Control Using V2I Communication	Virginia Tech	This project investigated adjustments in vehicle speed approaching "smart" intersections to achieve fuel efficiency. Vehicles used signal phase and timing (SPaT) data to adjust their speeds when approaching intersections to save fuel by avoiding stops and maintaining speeds closer to its fuel-optimum speed. Results indicated that accelerating at minimum throttle levels, when approaching a signalized intersection, generally produced optimum fuel efficiencies.
BAA Project #4. Preliminary System Development Plan for an AERIS Data Capture and Management System	Mixon Hill	This project examined the relevance of the Federal Highway Administration's (FHWA's) Clarus initiative and Michigan Department of Transportation's (DOT's) Data Use Analysis and Processing (DUAP).Results indicated that the capabilities developed for and demonstrated by the Clarus and DUAP systems are directly applicable to an AERIS Data Capture and Management System.
BAA Project #5. Eco-Intelligent Transportation Systems (ITS)	UC-Riverside	This project developed a method for estimating emissions on arterial roads based on reconstructing vehicle speed profiles using travel time data from the wireless vehicle sensors. The estimated energy and emissions were within 5 - 10% of the actual, which is much better than the about 30 - 40% error using the average speed method.
BAA Project #6. Assessment, Fusion, and Modeling of Commercial Vehicle Engine Control Unit (ECU) Data	Calmar Telematics and UC-Riverside	This project investigated what data elements in the electronic control unit (ECU) could be useful and how they could be collected and integrated with the University of California at Riverside's Comprehensive Modal Emissions Model (CMEM). There are variables in the ECU that have not been previously explored that may be able to improve the accuracy of emission estimates by CMEM.
BAA Project #7. Engaging the International Community	California Partners for Advanced Transit and Highways (PATH)	This project built on the exposure that its participants have with the Japanese and Europeans. It found that Japan took on the leadership role in making carbon reduction central to ITS. Europe has set goals for the entire transportation sector to reduce its GHG relative to 1990 levels by 20% in 2030 and by 60% in 2050. It also identified several European research efforts underway that related to AERIS.

The AERIS Research Program Defined Innovative and Transformative Connected Vehicle Applications

AERIS developed innovative and transformative applications focused on connected vehicle applications that facilitate a more sustainable relationship between transportation and the environment. AERIS identified five Operational Scenarios with eighteen (18) unique connected vehicle applications that sought to reduce fuel consumption and vehicle emissions. The AERIS Research Program developed ConOps documents for each of the five AERIS Operational Scenarios to guide analysis, modeling, simulation, and prototyping. The documents also guided connected vehicle standards activities related to the environment. The AERIS ConOps documents describe the various applications; provide a description current ITS operations, communicate user needs and desired capabilities for and expectations of the applications; provide operational scenarios describing how the applications may operate; and identify goals, objectives, and potential performance measures for the Operational Scenario. AERIS Operational Scenario ConOps documents are available at the National Transportation Library (NTL).

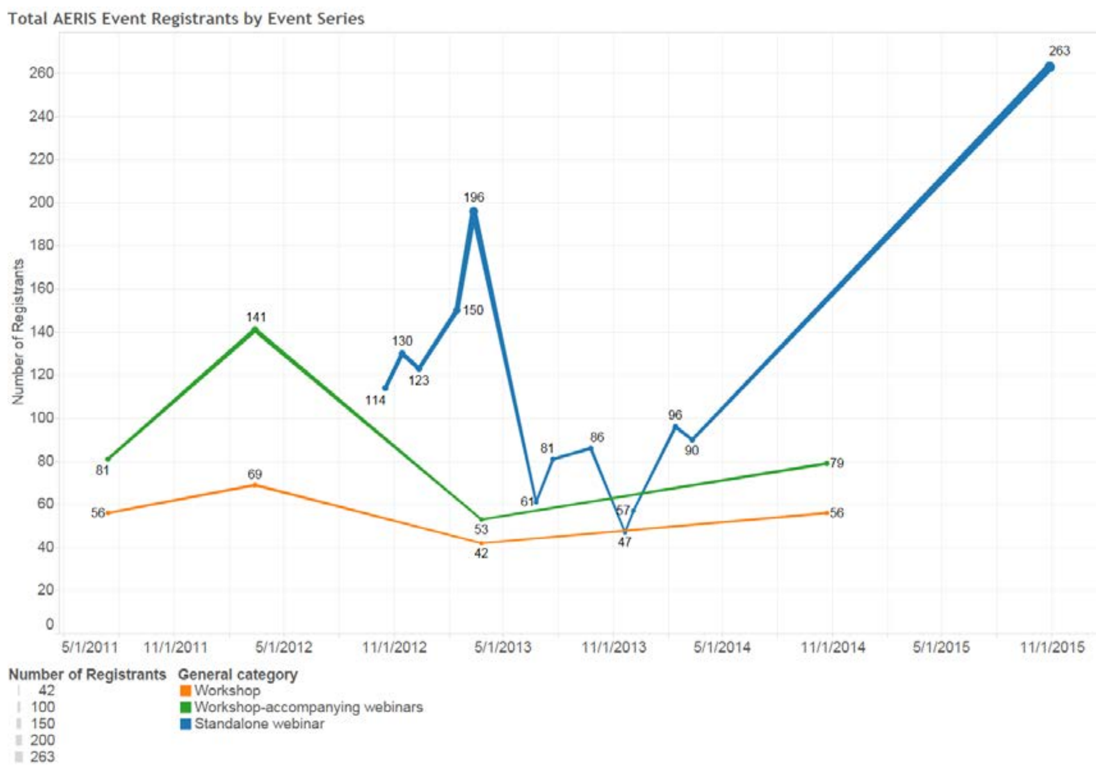
ES Table 2: AERIS Applications

Application	Description
Eco-Approach and Departure at Signalized Intersections	The application uses wireless data communications sent from a Roadside Equipment (RSE) unit to connected vehicles to encourage “green” approaches to signalized intersections. The application, located in a vehicle, collects SPaT and MAP messages using V2I communications and data from nearby vehicles using V2V communications. Upon receiving these messages, the application performs calculations to determine the vehicle’s optimal speed to pass the next traffic signal.
Eco-Traffic Signal Timing	This application optimizes the performance of traffic signals for the environment. The application collects data from vehicles, such as vehicle location, speed, and emissions data. It then processes these data to develop signal timing strategies focused on reducing fuel consumption and emissions.
Eco-Traffic Signal Priority	This application allows either transit or freight vehicles approaching a signalized intersection to request signal priority. The application considers the vehicle’s location, speed, vehicle type, and associated emissions to determine whether priority should be granted.
Connected Eco-Driving	This application provides customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions. Eco-driving advice includes recommended driving speeds and optimal acceleration/decelerations based on prevailing traffic, interactions with nearby vehicles, and upcoming road grades.
Wireless Inductive/Resonance Charging	This application enables wireless charging of electric vehicle batteries and supports static charging capable of transferring electric power to a vehicle stopped at a traffic signal or a stop sign.
Eco-Lanes Management	This application is used to manage the eco-lanes. Eco-lanes parameters may include the types of vehicles allowed in the eco-lanes, emissions parameters for entering the eco-lanes, the number of lanes, and the start and end of the eco-lanes.
Eco-Speed Harmonization	This application adjusts speed limits on links that approach areas of traffic congestion, bottlenecks, and incidents. Speed harmonization assists in maintaining flow, reducing unnecessary stops and starts, and maintaining consistent speeds, thus reducing fuel consumption and emissions.
Eco-Cooperative Adaptive Cruise Control (Eco-CACC)	Expanding on existing adaptive cruise control (ACC) systems, connected vehicle technologies can be used to collect the preceding vehicle’s speed, acceleration, and location and feed these data into the vehicle’s ACC. These data are transmitted from the lead vehicle to the following vehicle to support vehicle platooning. The Eco-CACC application also considers information, such as road grade, roadway geometry, and road weather information.
Eco-Ramp Metering	The application determines the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of entering vehicles.
Low Emissions Zone Management	This application supports the operation of a Low Emissions Zone that is responsive to real-time traffic and environmental conditions. The application would establish parameters including the types of vehicles permitted to enter the zone, exemptions for transit vehicles, emissions criteria for entering the zone, fees or incentives for vehicles, and geographic boundaries.
Connected Vehicle-Enabled Data Collection: Probe and Environmental Data	This application supports the collection of fuel consumption and emissions data from vehicles. Using these data, real-time air quality maps may be created for roadway segments.

Application	Description
Multimodal Traveler Information	This application provides pre-trip and en-route traveler information to travelers encouraging a more sustainable travel. The application collects multimodal data to support trip planning tools that provide travelers with information about multimodal travel options. The application also provides travelers with real-time traffic conditions so they can adjust departure time and mode choices or select an alternate.
Eco-Smart Parking	This application provides users with real-time location, availability, type (e.g., street, garage), and price of parking. Eco-Smart Parking applications also support dynamic pricing or incentives for parking based on vehicle type. Pricing and incentives may serve a traffic demand management strategy helping to reduce vehicle miles traveled in an area, or incentivize travel by eco-vehicles. The application also allows travelers to reserve parking spaces in advance, as well as pay for parking, using mobile devices and connected vehicle technologies.
AFV Charging/Fueling Information, Reservations, and Payment	This application informs travelers of the range of their alternative fuel vehicle (AFV) and provides locations and the availability of AFV charging and fueling stations. The application allows drivers to make reservations to use charging/fueling stations before they start their trip or while en-route. Additionally, the application supports electronic payment for fuel/energy using connected vehicle technologies. The vehicle would also learn from the driver's behavior providing accurate estimates of the vehicle's range, reducing the driver's fear of being stranded.
Dynamic Eco-Routing	This application determines the most eco-friendly route for individual travelers. The application leverages connected vehicle data to determine the eco-routes based on historical, real-time, predicted traffic and environmental data as well as road type (e.g., arterial or freeway) and road grade. The Dynamic Eco-Routing application takes into account a variety of different data, including: real-time traffic information, road type, and road grade.
Connected Eco-Driving – Gamified / Incentives-based Apps	This application uses advanced sensors, software, and telematics allowing vehicular systems to communicate information about the vehicle's performance directly to the driver—via the dashboard or wirelessly to a smartphone. Drivers receive eco-driving recommendations and post-trip feedback on their behavior adapted to them and to their vehicle's characteristics. Eco-driving information applications provide recommendations via an onboard unit to promote energy efficient driving techniques. These applications also leverage a social media component, where people can compete on leaderboards.
Gamified / Incentives-based Multimodal Traveler Information	This application allows travelers to opt-in to smartphone apps to earn points based on their travel choices. Travelers would earn points for green transportation choices including travel during off-peak hours, transit usage, bike usage, etc. These applications would allow system operators to collect data from travelers on their traveling behavior, would allow app users to receive customized traveler information, and would leverage a social media component where people would compete on leaderboards on how much fuel and emissions they save from making green transportation choices.
Eco-ICM Decision Support System (DSS)	This application seeks to assist managers in the process of collaboratively managing a multimodal transportation network. The DSS integrates multiple real-time data sources from a variety of systems – including arterial, freeway, transit, and other management systems. Expanding on existing ICM DSSs, the Eco-ICM DSS would also collect environmental, connected vehicle, and shared use mobility data. These data would be processed, modeled, and analyzed to support decisions for specific actions, strategies, and recommendations.

The AERIS Research Program Supported Discussion about Transportation and the Environment

Between 2009 and 2014, the AERIS Program created opportunities for discussion about connected vehicles and the environment among the stakeholder community. These discussions occurred during numerous AERIS events such as workshops and webinars. These events included 1,808 participants (see ES Figure 4) with 20.3% from academia; 49.1% from the private sector; and 30.6% from the public sector. These events were used to actively engage the community and keep them informed on the program's progress. The AERIS team shared interim and final results with stakeholders using webinars. Additionally, the AERIS team also engaged with other federal agencies (i.e., the U.S. Department of Energy) and the automotive industry. The AERIS team also presented at numerous venues including ITS America Annual Meetings, ITS America State Chapter Meetings, ITS World Congresses, Transportation Research Board (TRB) Annual Meetings, TRB Automated Vehicle Symposia, Institute of Transportation Engineers (ITE) Annual Meetings, and American Public Transportation Association (APTA) Sustainability Meetings. Through these events, AERIS engaged with numerous domestic and international partners familiarizing them with the research and findings of the program.



ES Figure 4: Registrants for AERIS Workshops and Webinars *(Source: ITSA, 2015)*

The AERIS Research Program Advanced Research in Connected Vehicle and Environmental Modeling

A major objective of the AERIS Research Program was to model and analyze connected vehicle applications to estimate the potential environmental impact reduction benefits. Modeling and analysis consisted of an initial benefit-cost analysis (BCA) used to prioritize AERIS applications for more detailed modeling and analysis. AERIS was the first program in the ITS JPO to conduct such an analysis and it engaged other ITS JPO Programs in discussions about underlying assumptions in the determination of benefits and costs of connected vehicle applications. These discussions between AERIS and other ITS JPO programs vetted variables such as onboard equipment (OBE) and roadside equipment (RSE) unit deployment rates, driver compliance, vehicle fuel efficiency projections, and fuel prices. The BCA assisted the AERIS team in selecting three priority Operational Scenarios—Eco-Signal Operations, Eco-Lanes, and Low Emissions Zones—for more detailed modeling. Additionally, the AERIS variables and results served as inputs to future BCA conducted by the Dynamic Mobility Applications (DMA) and Road Weather Management (RWM) Programs.

To assess the potential benefits of connected vehicle applications, highly complex transportation models were integrated with the EPA's Motor Vehicle Emission Simulator (MOVES) model. Since many of the AERIS applications were truly new and transformative, new algorithms needed to be developed to support modeling. Another challenge was that the modeling was intended to represent a future with connected vehicles. Because of uncertainties associated with predicting the future, sensitivity analysis was conducted to consider variability in connected vehicle deployment rates, driver compliance rates, fleet composition, traffic demands, and other variables. The modeling efforts are summarized below.

- **Eco-Signal Operations Modeling and Analysis.** A twenty-seven intersection, 6.5 mile segment of El Camino Real in Northern California was modeled using VISSIM. Modeling was conducted under different traffic conditions, network conditions, connected vehicle penetration rates, and other variables. Modeling was conducted for individual applications to understand the potential benefits of each application. Additionally, combined modeling was performed to understand potential synergies of the Eco-Signal Operations applications.
- **Eco-Lanes Modeling and Analysis.** The Eco-Speed Harmonization and Eco-Cooperative Adaptive Cruise Control applications were modeled for a segment of roadway on State Route 91 Eastbound (SR-91 E) in Southern California using VISSIM. An Eco-Cooperative Adaptive Cruise Control (Eco-CACC)-reserved "Eco-Lane" was developed from an existing high occupancy vehicle (HOV) lane on the corridor, while the remaining lanes were used for Eco-Speed Harmonization.
- **Low Emissions Zones Modeling and Analysis.** Analysis, modeling, and simulation were conducted for a low emissions zone in the Phoenix, AZ metropolitan area using the SimTRAVEL (Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land) integrated model system.

Detailed modeling reports were created for each of the three Operational Scenarios. The results of the modeling effort are summarized in ES Table 3. In general, the AERIS applications showed environmental benefits ranging from 2% to 19%. Additional findings also showed that while mobility improvements generally lead to environmental benefits, optimizing for the environment is not always the same as optimizing for mobility. In some cases, optimizing the transportation system for the environment instead of for mobility provided additional benefits in fuel use reductions and carbon dioxide (CO_2) reductions. Modeling also showed that there were synergistic benefits from non-equipped vehicles following equipped vehicles for some applications. Individual applications worked well together and offered synergistic benefits.

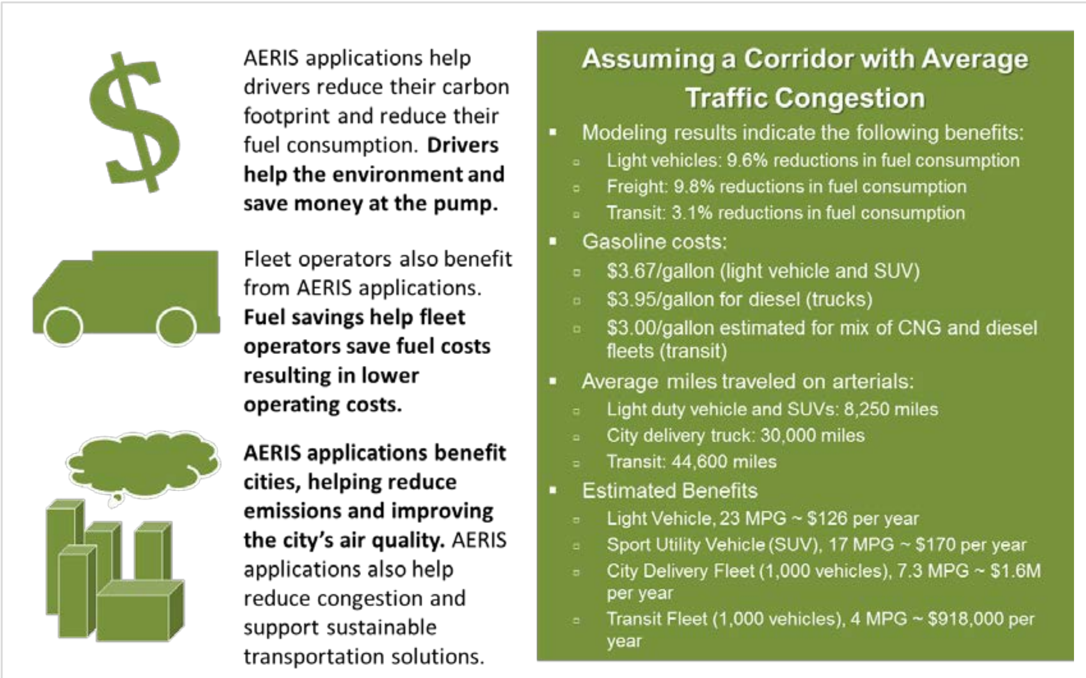
ES Table 3: Summary of AERIS Modeling Results

Application	Modeling Results

Eco-Approach and Departure at Signalized Intersections	• The application provided 5-10% fuel reduction benefits for an uncoordinated corridor
	• For a coordinated corridor, the application provided up to 13% fuel reduction benefits
	  o 8% of the benefits were attributable to signal coordination
	  o 5% attributable to the application

Eco-Traffic Signal Timing	• When applied to a signalized corridor that was fairly well optimized, the application provided an additional 5% fuel reduction benefit at full connected vehicle penetration.
Eco-Traffic Signal Priority	• The Eco-Transit Signal Priority application provided up to 2% fuel reduction benefits for transit vehicles. • The Eco-Freight Signal Priority application provided up to 4% fuel reduction benefits for freight vehicles.
Connected Eco-Driving	• When implemented along a signalized corridor, the application provided up to 2% fuel reduction benefits at full connected vehicle penetration. • The application provided up to 2% dis-benefit in mobility (e.g., travel time) due to smoother and slower accelerations to meet environmental optimums.
Combined Eco-Signal Operations Modeling	• Together the Eco-Signal Operations applications provided up to 11% improvement in CO_2 and fuel consumption reductions at full connected vehicle penetration.
Eco-Speed Harmonization	• The application provided up to 4.5% fuel reduction benefits 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.
Eco-Cooperative Adaptive Cruise Control (Eco-CACC)	• Eco-CACC provided up to 19% fuel savings on a real-world freeway. • Vehicles using a dedicated “eco-lane” experienced 7% more fuel savings when compared to vehicles in the general lanes. • Eco-CACC has the potential to provide up to 42% travel time savings on a real-world freeway corridor for all vehicles.
Combined Eco-Lanes Modeling	• Together the Eco-Lanes applications provided up to 22% fuel savings on a real-world freeway corridor for all vehicles. • Vehicles using the dedicated “eco-lane” experienced 2% more fuel savings when compared to vehicles in the general traffic lanes. • The scenario provided up to 33% travel time savings for all vehicles.
Low Emissions Zones	• A Low Emissions Zone modeled in the Phoenix Metropolitan Area resulted in up to 4.5% reduction in fuel consumption when both eco-vehicle incentives and transit incentives were offered. • The modeling indicated that the Low Emissions Zone has the potential to reduce vehicle miles traveled by up to 2.5% and increase by up to 20% in to the Low Emissions Zones.

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. In particular, drivers help the environment and save money at the pump. Fleet operators (e.g., transit and freight operators) 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 in a city. AERIS applications also help reduce congestion and support sustainable transportation solutions.



ES Figure 5: Conveying AERIS Benefits to Stakeholders *(Source: USDOT, 2014)*

The AERIS Research Program Advanced Prototyping of Environmental Connected Vehicle Applications

While the AERIS Research Program was not initially charged with developing prototypes, foundational activities from the BAA Project and modeling proved to be promising. In particular, the Eco-Approach and Departure at Signalized Intersections application appeared to be a near-term application that had potential to yield significant environmental benefits. In 2012, AERIS 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 CO_2 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 (driver advisory feedback). While the results were promising, the experiment also identified potential driver distraction issues. As such, in 2014 AERIS 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 algorithms. In 2015, the USDOT engaged researchers from the automotive industry (i.e., CAMP) to investigate further research activities and develop a roadmap of activities to support near-term deployment of the application.

AERIS Prototyping

- *A 2012 Field Experiment of the Eco-Approach and Departure at Signalized Intersection application yielded up to 18% benefits for a single vehicle at a single signalized intersection.*
- *The 2014 GlidePath prototype application is building on the 2012 field experiment, integrating automated longitudinal control capabilities.*
- *The Crash Avoidance Metrics Partnership (CAMP) is developing a roadmap of activities to support near-term deployment of the application.*

ES Figure 6: GlidePath Vehicle (left) and Driver Vehicle Interface (right) *(Source: FHWA, 2014)*

Data collected in the tests revealed that average fuel consumption was improved in vehicles equipped with the Eco-Approach and Departure application. As shown in ES Table 3-24, the average improvement percentages varied as different speeds were analyzed. 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 initial 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 for minimal environmental impact.

ES Table 4: 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
DVI vs. Uniformed	-11.8	-11.8	7.6	5.2	7.6	12.1	25.1	37.8	-18.3	21.7	-0.6	13.5	**7.3**
Automated vs. Uninformed	4.7	7.6	35.3	20.9	20.3	31.7	32.7	47.9	-3.9	26.5	20.1	22.9	**22.2**
Automated versus DVI	14.7	17.3	29.9	16.6	13.8	22.4	10.1	16.3	12.2	6.1	20.5	10.8	**15.9**

Question 3: How are the AERIS Research Program's results being used and how are they supporting deployment in the near-term and in the long-term?

Over the course of five years, the AERIS Research Program produced numerous products and deliverables that advanced environmental connected vehicle research including SOP Reports, BAA Research Projects, a BCA Report, ConOps documents for each of the five Operational Scenarios, Modeling Reports for three high-priority Operational Scenarios, systems engineering documentation for the GlidePath Prototype Application, a working GlidePath prototype, US-EU Sustainability Working Group White Papers, and several other products. While these products were valuable, perhaps even more valuable was the dialogue with stakeholders—including a core group engaged throughout the lifecycle of the program—that occurred between 2009-2014 and continues today.

The AERIS Research Program Inspired Additional Research

AERIS inspired new environmental research from other sources. The BAA Research Projects supported initial research that in some cases have continued after federal funding for the BAA projects ended. AERIS provided a framework for academia and the private sector to guide research in connected vehicles and the environment. For example, the Virginia Tech Transportation Institute (VTTI)—a BAA research partner—has continued its environmental modeling efforts and continues to conduct groundbreaking research. Other institutions continue to leverage the framework as well to guide their research.

At the federal level, the Federal Highway Administration (FHWA) engaged in an Exploratory Advanced Research (EAR) project to advance prototyping of the Eco-Approach and Departure at Signalized Intersections application. The project builds on the AERIS prototype from 2012 to evaluate the performance of the application along a real-world corridor in California operating actuated traffic signals. Advances to the algorithm were made to consider actuated traffic signals. Testing and experimentation is building off the foundational research conducted by AERIS and helping move this application toward deployment. At the same time, AERIS is engaging the automotive industry in further discussions about the Eco-Approach and Departure at Signalized Intersections application. A project was initiated between FHWA and the Crash Avoidance Metrics Partnership (CAMP) to review AERIS documentation and demos of the GlidePath vehicle and determine a roadmap for future research activities.

Finally, the Department of Energy (DOE) has actively engaged with the AERIS team and is using AERIS results to advance research being carried out by DOE and their national laboratories to better understand the potential impacts of connected and automated vehicles. Their work is based on the foundational work conducted by AERIS. Moving forward, plans are in place to continue coordination between the ITS JPO and DOE. There is a need to support the development of new integrated models (both traffic models and emissions models) and modeling algorithms that incorporate the stream of connected vehicle data and incorporate connected vehicle operations/applications. AERIS has been a good start, but additional opportunities exist to further advance the state-of-the-practice.

The AERIS Research Program Contributed to Connected Vehicle Standards Activities

Standards are an essential component of achieving interoperability and successful implementation of connected vehicle technologies and applications. Standards help to ensure interoperability focuses on enabling ITS elements in vehicles, devices, infrastructure, and applications to effectively communicate with other parts of the system as needed regardless of where they are built and where and when they are used. Throughout the five-year research program, AERIS was involved with the ITS Standards work contributing inputs to various activities including efforts on the Connected Vehicle Reference Implementation Architecture (CVRIA), J2735 Systems Engineering Project, ISO 190091, J2945 Framework, and NTCIP 1204: Environmental Sensor Station Interface Standard. AERIS contributions to these standards were and continue to be important since when many of the standards were first developed they did not consider environmental data needs. The AERIS ConOps documents proved to be useful tools in conveying detailed user needs and desired capabilities to the standards community. While much progress has been made, continued efforts are needed to continue an open dialogue with the standards community to ensure that environmental needs are considered in relevant connected vehicle standards to help ensure the successful deployment of AERIS (or other environmental) applications.

The AERIS Research Program is Moving Connected Vehicle Research toward Deployment

There was an effort to reach out to parties particularly interested in deploying environmental applications. AERIS engaged in several meetings with state and local agencies interested in deploying environmental applications. As an example, in February 2013 the AERIS team met with ITS California members to provide an update on AERIS research activities and engage in a discussion about deploying ITS strategies targeted at reducing fuel use consumption and emissions. More recently, the AERIS team conducted a public workshop in October 2014 to share information and lessons learned. The workshop was used to: inform stakeholders on the potential fuel use and emissions reduction benefits that may be achieved from deploying connected vehicle applications; share information about real-world environmental projects currently deployed and research activities underway targeted at reducing transportation's negative impact on the environment; and engage the adopter community in discussion of environmental connected vehicle applications that may be good candidates for near-term deployment.

As initial research is ending, the AERIS Research Program is focused on near-term deployment of connected vehicle applications relevant to environmental outcomes and focused on environmental performance measures. As depicted in ES Figure 7, AERIS articulated a three step process to deployment—beginning with identifying local needs or challenges stakeholders are trying to address, followed by setting performance goals (e.g., reductions in fuel use and emissions), and then selecting connected vehicle applications that work together to meet those goals.

ES Figure 7: Moving AERIS Applications toward Deployment *(Source: USDOT, 2014)*

As agencies begin to think about deploying applications, AERIS notes that there are many paths to deployment—the Connected Vehicle Pilot Demonstrations are one, but not the only path to near-term deployment. As such, Metropolitan Planning Organizations (MPOs), local public agencies, transit operators, and states should begin considering connected vehicle strategies in their long range planning. To assist the adopter community in moving environmental applications toward deployment, AERIS developed several tools:

- ConOps Documents for each of the five Operational Scenarios

- Simulation, Modeling, and Benefit-Cost Analysis Results for Eco-Signal Operations, Eco-Lanes, and Low Emissions Zones
- Algorithms (primarily developed for modeling and analysis)
  - Eco-Approach and Departure at Signalized Intersections
  - Eco-Traffic Signal Timing
  - Eco-Traffic Signal Priority (Transit and Freight)
  - Connected Eco-Driving
  - Eco-Speed Harmonization
- Eco-Approach and Departure at Signalized Intersections Prototype Application Documents
  - Requirements Documentation
  - System Architecture and Design Documentation

Additional work is needed to support knowledge transfer. The AERIS Research Program developed an extensive communications and outreach plan focused on sharing key research findings with a diverse set of stakeholders. Preliminary AERIS communications and outreach goals include continuing to build relationships with stakeholders through open dialogue and idea exchange. A key component of AERIS outreach is educating transportation professionals on AERIS research and key findings and sharing research results. Providing real world examples of proven ITS solutions and connected vehicle technologies has been a powerful tool to illustrate how these applications are providing benefits to citizens, fleets, and jurisdiction today. The AERIS team currently maintains a database of real-world examples that it can draw from. In general, knowledge transfer assists decision makers in learning how AERIS applications might help them address their problems/issues and builds a network of champions with a focus on the early adopter community.

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