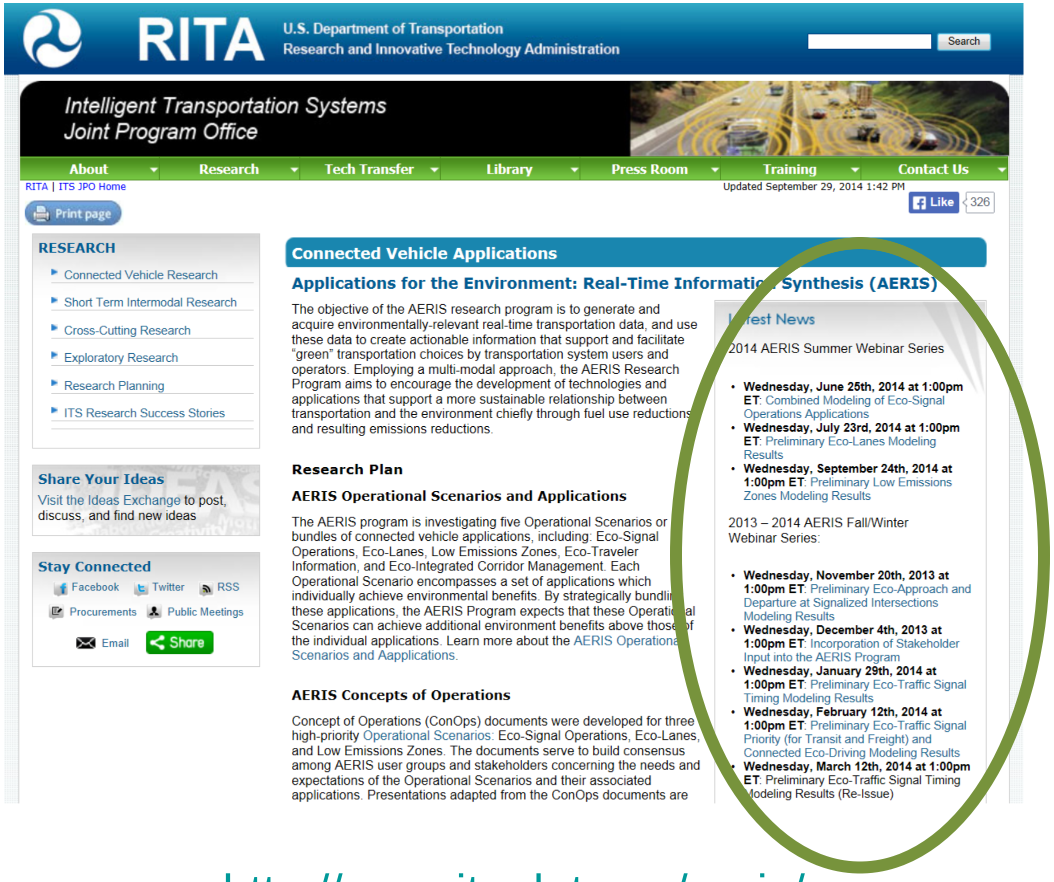
Environmental Benefits from AERIS Modeling

- For the adopter community to make a decision for near-term deployment, or to even begin planning an effort, they need information on the potential benefits to make sure the application can solve their problem
- Simulation, modeling, and analysis allows stakeholders to understand the potential benefits of connected vehicle applications
- AERIS Modeling Results
  - High-level overview – today
  - AERIS Fall Webinar Series presentations contain more details and are available on-line



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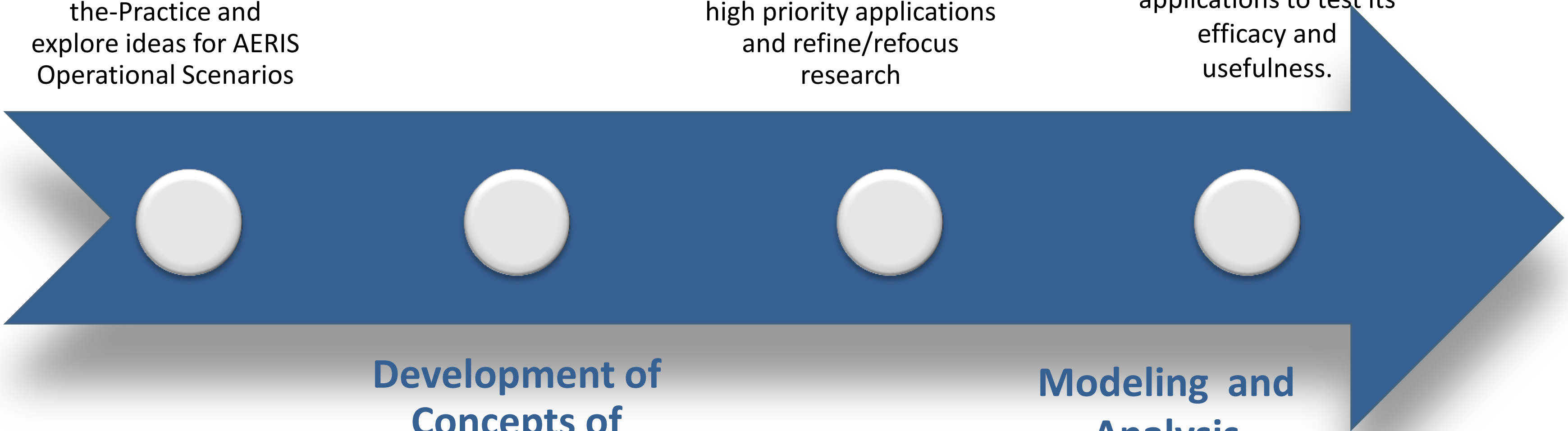
Environmental Benefits from AERIS Modeling

Sean Fitzgerel, Booz Allen Hamilton

AERIS Applications

From Concept, to Modeling, to Deployment



Concept Exploration

Examine the State-of-the-Practice and explore ideas for AERIS Operational Scenarios

Development of Concepts of Operations for Operational Scenarios

Identify high-level user needs and desired capabilities for each AERIS scenario in terms that all project stakeholders can understand

Conduct Preliminary Cost Benefit Analysis

Perform a preliminary cost benefit analysis to identify high priority applications and refine/refocus research

Modeling and Analysis

Model, analyze, and evaluate candidate strategies, scenarios and applications that make sense for further development, evaluation and research

Prototype Application

Develop a prototype for one of the applications to test its efficacy and usefulness.

AERIS Operational Scenario Modeling

ECO-SIGNAL OPERATIONS

Uses connected vehicle technologies to decrease fuel consumption and emissions at signalized intersections.

ECO-LANES

Dedicated freeway lanes – similar to managed lanes – optimized for the environment that encourage use from vehicles operating in eco-friendly ways.

LOW EMISSIONS ZONES

Geographically defined areas that seek to incentivize "green transportation choices" or restrict high-polluting vehicles from entering the zone.

ECO-TRAVELER INFORMATION

Enables development of new, advanced "green" traveler information applications through integrated, multisource, multimodal data.

ECO-ICM

Considers treating travel corridors as an integrated asset with a focus on decreasing fuel consumption and emissions.

- The AERIS Program identified five Operational Scenarios or bundles of connected vehicle applications
- Each Operational Scenario encompasses a set of applications which individually achieve environmental benefits. AERIS research is interested in these individual benefits, as well as, the benefits when applications are deployed together
- Three of the Operational Scenarios were chosen for detailed modeling and analysis:
  - Eco-Signal Operations
  - Eco-Lanes
  - Low Emissions Zones

AERIS Modeling of Applications

- Traffic simulation models – both micro and regional models – were combined with emissions models (e.g., EPA's MOVES model) to estimate the potential environmental benefits of connected vehicle applications for real-world corridors and regions
- Application algorithms were developed by the AERIS team and implemented as new software components in the traffic simulation models
- Results were compared against a "do nothing" scenario to determine the impact of each individual application, as well as, the impacts of strategically combining the applications in a scenario
- Modeling results indicate a possible outcome – results may vary depending on the baseline conditions, geographic characteristics of the corridor, etc.
- Detailed presentations on AERIS modeling results are available at: http://www.its.dot.gov/aeris/

AERIS Modeling of Applications

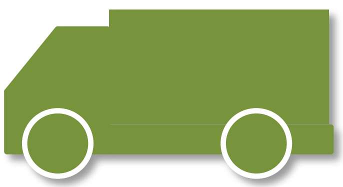
- **Eco-Signal Operations Modeling**
  - Tested on a signalized, urban arterial (27 signalized intersections) using the El Camino Real Paramics micro-simulation model
  - Modeled the interactions between vehicles, vehicle approaches to the intersection, and optimization of traffic signal timing plans

- **Eco-Lanes Modeling**
  - Tested on an urban freeway corridor using the State Route 91 (Southern California) Paramics micro-simulation model
  - Modeled interactions between individual vehicles

- **Low Emissions Zones Modeling**
  - Tested on a regional scale model (entire city and suburbs) using the Maricopa Area Governments (Phoenix metro) macro model
  - Modeled regional impacts of policy changes, shifts in driving patterns, and changes in vehicle/mode choice

Explaining Potential Benefits to Users

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



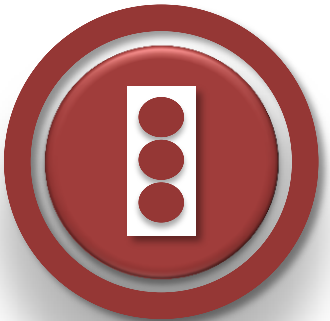
Fleet operators also benefit from AERIS applications. **Fuel savings help fleet operators save fuel costs resulting in lower operating costs.**

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**

Eco-Signal Operations



ECO-SIGNAL OPERATIONS

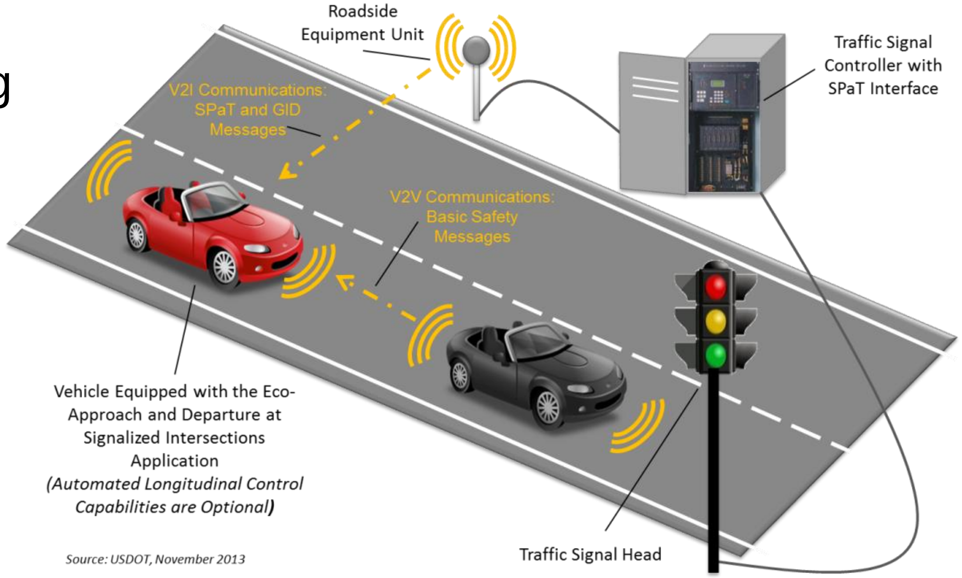
Uses connected vehicle technologies to decrease fuel consumption and emissions on arterials by reducing idling, reducing the number of stops, reducing unnecessary accelerations and decelerations, and improving traffic flow at signalized intersections.

The Operational Scenario includes five applications:

- Eco-Approach and Departure at Signalized Intersections
- Eco-Traffic Signal Timing
- Eco-Traffic Signal Priority
  - Eco-Transit Signal Priority
  - Eco-Freight Signal Priority
- Connected Eco-Driving
- *Wireless Inductive/Resonance Charging (not modeled)*

Eco-Approach and Departure at Signalized Intersections Application

Application Overview



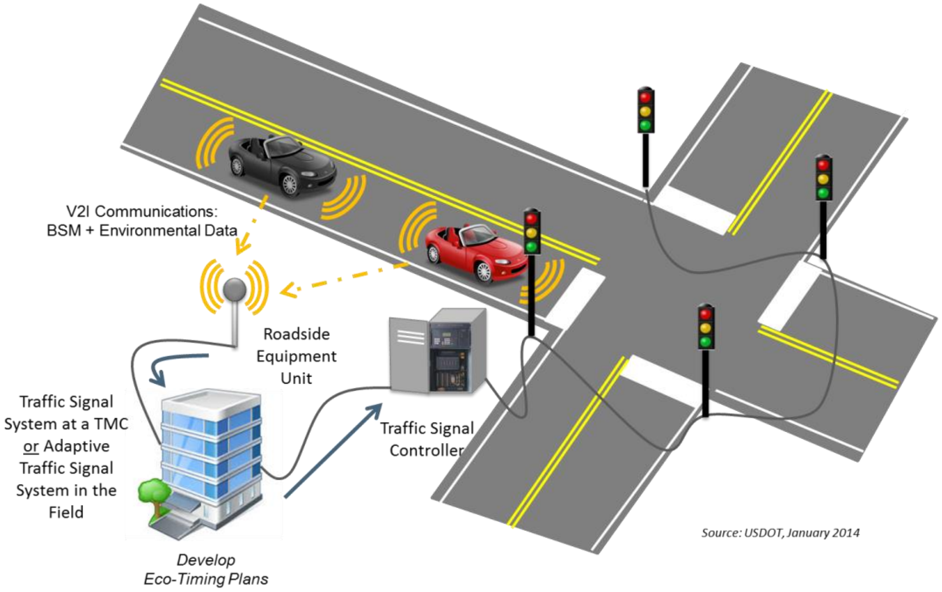
- Collects signal phase and timing (SPaT) and Geographic Information Description (GID) messages using vehicle-to-infrastructure (V2I) communications
- Collects basic safety messages (BSMs) from nearby vehicles using vehicle-to-vehicle (V2V) communications
- Receives V2I and V2V messages, the application performs calculations to determine the vehicle's optimal speed to pass the next traffic signal on a green light or to decelerate to a stop in the most eco-friendly manner
- Provides speed recommendations to the driver using a human-machine interface or sent directly to the vehicle's longitudinal control system to support partial automation

Eco-Approach and Departure at Signalized Intersections Application: Modeling Results

- **Summary of Preliminary Modeling Results**
  - 5-10% fuel reduction benefits for an uncoordinated corridor
  - Up to 13% fuel reduction benefits for a coordinated corridor
    - 8% of the benefit is attributable to signal coordination
    - 5% attributable to the application
- **Key Findings and Takeaways**
  - The application is less effective with increased congestion
  - Close spacing of intersections resulted in spillback at intersections. As a result, fuel reduction benefits were decreased somewhat dramatically.
  - Preliminary analysis indicates significant improvements with partial automation
  - Results showed that non-equipped vehicles also receive a benefit – a vehicle can only travel as fast as the car in front of it
- **Opportunities for Additional Research**
  - Evaluate the benefits of enhancing the application with partial automation

Eco-Traffic Signal Timing Application

Application Overview



- Similar to current traffic signal systems; however the application's objective is to optimize the performance of traffic signals for the environment
- Collects data from vehicles, such as vehicle location, speed, vehicle type, and emissions data using connected vehicle technologies
- Processes these data to develop signal timing strategies focused on reducing fuel consumption and overall emissions at the intersection, along a corridor, or for a region
- Evaluates traffic and environmental parameters at each intersection in real-time and adapts the timing plans accordingly

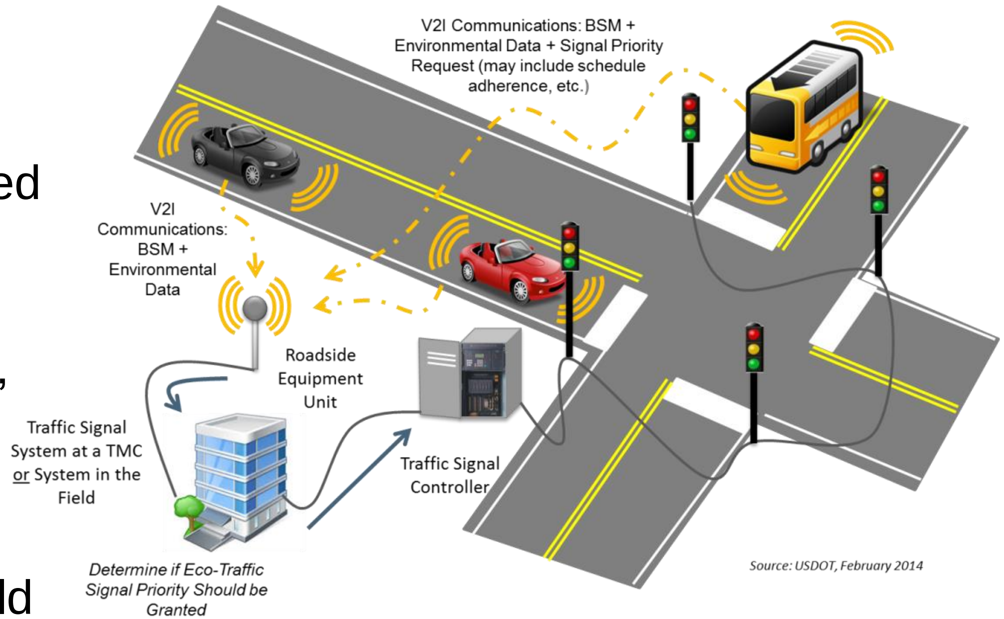
Eco-Traffic Signal Timing Application: Modeling Results

- **Summary of Preliminary Modeling Results**
  - Up to 5% fuel reduction benefits at full connected vehicle penetration
    - 5% fuel reduction benefits when optimizing for the environment (e.g., CO_2)
    - 2% fuel reduction benefits when optimizing for mobility (e.g., delay)
- **Key Findings and Takeaways**
  - Optimization of signal timings using environmental measures of effectiveness resulted in mobility benefits in addition to environmental benefits
  - For the El Camino corridor, modeling results indicated that shorter cycle lengths (60 seconds) produce greater benefits than longer cycle lengths (130 seconds)
- **Opportunities for Additional Research**
  - Consider analysis for different geometries (e.g., grid network) and traffic demands (e.g., a corridor with higher volumes on the side streets)
  - Investigate adaptive or real-time traffic signal timing optimization algorithms

Eco-Traffic Signal Priority Application

Application Overview

- Allows either transit or freight vehicles approaching a signalized intersection to request signal priority
- Considers the vehicle's location, speed, vehicle type (e.g., alternative fuel vehicles), and associated emissions to determine whether priority should be granted



- Information collected from vehicles approaching the intersection, such as a transit vehicle's adherence to its schedule, the number of passengers on the transit vehicle, or weight of a truck may also be considered in granting priority
- If priority is granted, the traffic signal would hold the green on the approach until the transit or freight vehicle clears the intersection

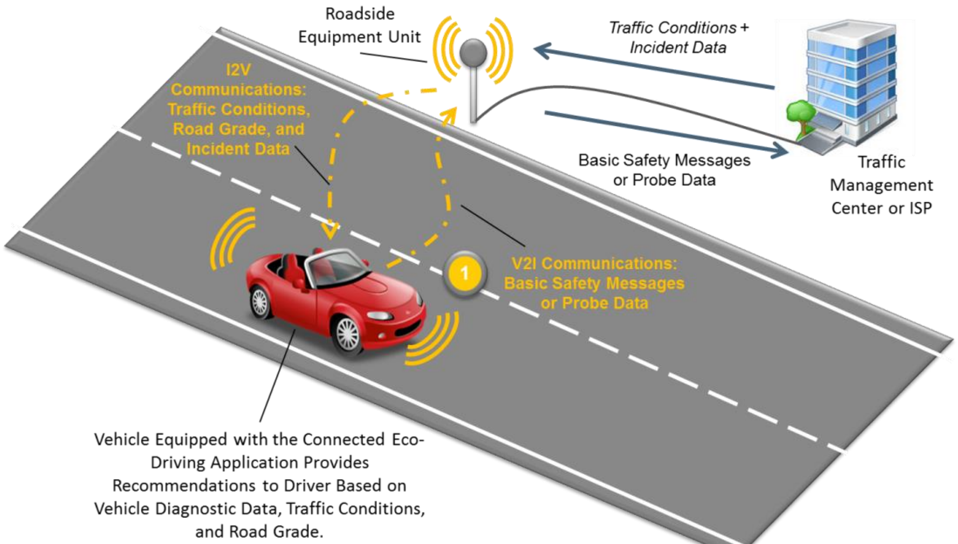
Eco-Traffic Signal Priority Application: Modeling Results

- **Summary of Preliminary Modeling Results**
  - Eco-Transit Signal Priority provides up to 2% fuel reduction benefits for transit vehicles → Up to $669,000 annual savings for fleet of 1,000 transit vehicles driving 44,600 miles each on arterials a year
  - Eco-Freight Signal Priority provides up to 4% fuel reduction benefits for freight vehicles → Up to $649,000 annual savings for fleet of 1,000 city delivery vehicles driving 30,000 miles on arterials each year
- **Key Findings and Takeaways**
  - Eco-Transit Signal Priority
    - Reduced emissions for buses; however in some cases, signal priority was detrimental to the overall network
    - Provided greater overall environmental benefits when the bus' adherence to its schedule was considered by the algorithm
  - Eco-Freight Signal Priority
    - Passenger vehicles and unequipped freight vehicles also saw reductions in emissions and fuel consumption, benefiting from the additional green time
- **Opportunities for Additional Research**
  - Investigate advanced algorithms that collect data from all vehicles and evaluate impacts of granting priority in real-time

Connected Eco-Driving Application

Application Overview

- Connected Eco-Driving provides customized real-time driving advice so drivers can adjust their driving behavior to save fuel and reduce emissions
- Driving advice includes recommended driving speeds, optimal acceleration, and optimal deceleration profiles



Source: USDOT, February 2014

- Receives V2I and V2V messages, the application determines the vehicle's optimal acceleration and deceleration profiles to navigate the corridor in the most eco-friendly manner
- Provides these recommendations to the driver using a human-machine interface or sent directly to the vehicle's longitudinal control system to support partial automation

Connected Eco-Driving Application: Modeling Results

- **Summary of Preliminary Modeling Results**
  - Up to 2% fuel reduction benefits at full connected vehicle penetration
  - Up to 2% dis-benefit in mobility due to smoother and slower accelerations to meet environmental optimums
- **Key Findings and Takeaways**
  - The application is much more amenable to different levels of congestion than the other Eco-Signal Operations applications
  - Results showed that non-equipped vehicles also receive a benefit – a vehicle can only travel as fast as the car in front of it
- **Opportunities for Additional Research**
  - The decision module could be further improved, taking into account the real-time information of the preceding vehicle
  - Automated longitudinal control could be integrated to further improve compliance with the speed, acceleration, and decelerations
  - Future research could consider could consider roadway grade and downstream traffic conditions, which were not modeled

Eco-Signal Operations Combined Modeling Results

- **Overview**
  - After the individual applications were thoroughly tested and completed, the five applications were combined and modeled together on the same corridor
  - This modeling helped to understand the total impact of the Eco-Signal Operations Concept and determine if any application would conflict with each other
- **Combined Modeling Results**
  - Up to 11% improvement in CO_2 and fuel consumption at full connected vehicle penetration
  - While the results are not additive of individual application improvements, it can be seen that the applications do not conflict with each other, but rather complement each other
  - Combined applications have limited effect in saturated, congested conditions, as there is little room for capacity improvement

Eco-Lanes

ECO-LANES

Dedicated freeway lanes – similar to managed lanes – optimized for the environment that encourage use from vehicles operating in eco-friendly ways.

The Operational Scenario supports the following applications:

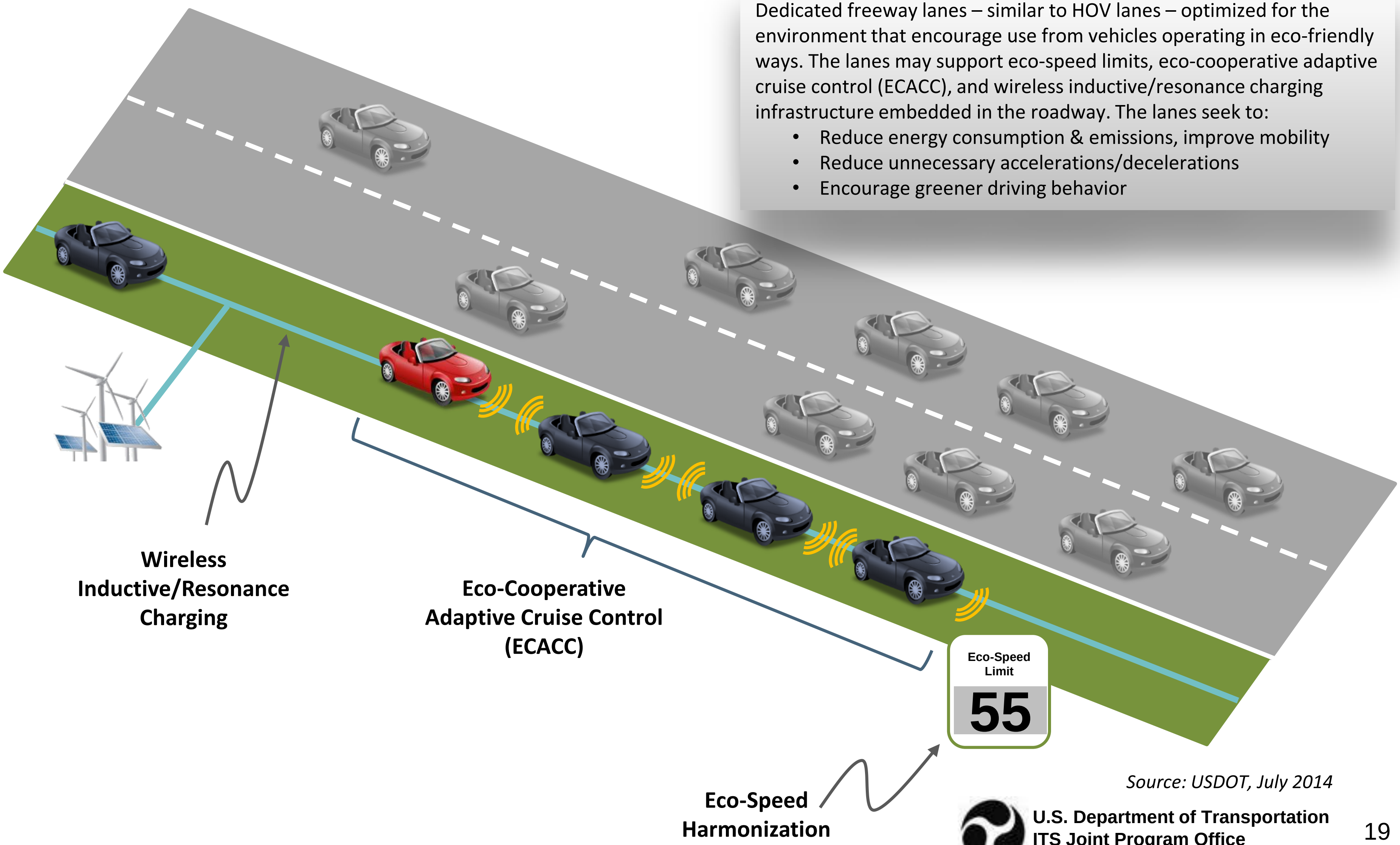
- Eco-Lanes Management
- Eco-Speed Harmonization
- Eco-Cooperative Adaptive Cruise Control
- *Eco-Ramp Metering (Not Modeled)*
- *Connected Eco-Driving (Not Modeled)*
- *Wireless Inductive/Resonance Charging (Not Modeled)*
- *Eco-Traveler Information Applications (Not Modeled)*

Eco-Lanes Operational Scenario

Eco-Lanes

Dedicated freeway lanes – similar to HOV lanes – optimized for the environment that encourage use from vehicles operating in eco-friendly ways. The lanes may support eco-speed limits, eco-cooperative adaptive cruise control (ECACC), and wireless inductive/resonance charging infrastructure embedded in the roadway. The lanes seek to:

- Reduce energy consumption & emissions, improve mobility
- Reduce unnecessary accelerations/decelerations
- Encourage greener driving behavior

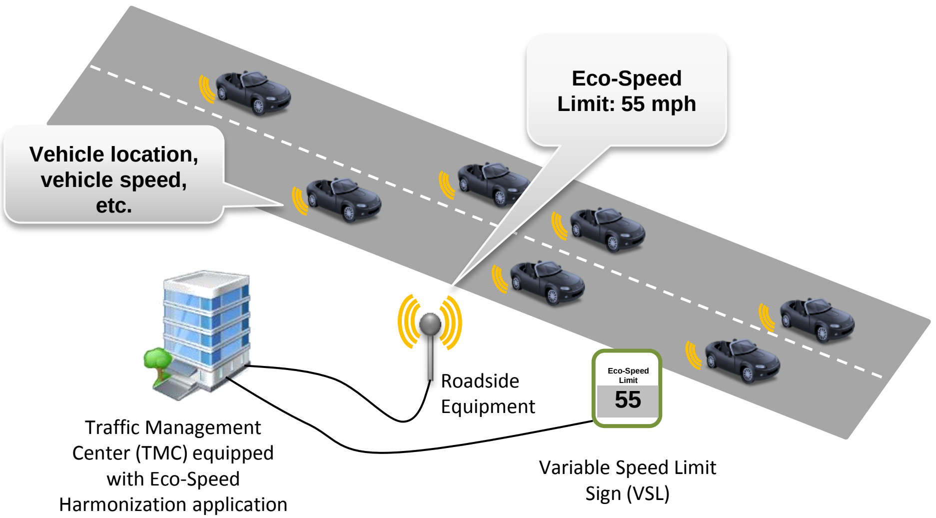


Source: USDOT, July 2014

Eco-Speed Harmonization Application

Application Overview

- Collects traffic information and pollutant information using V2I communications
- Assists in maintaining the flow of traffic, reducing unnecessary stops and starts, and maintaining consistent speeds near bottleneck and other disturbance areas



Source: USDOT, July 2014

- Receives V2I messages (e.g., BSMs), and uses these messages as inputs to determine the optimal eco-speed limit for the segment of freeway where the bottleneck, lane drop, or disturbance is occurring
- Broadcasts the optimal eco-speed limit to connected vehicles using V2I messages from roadside equipment

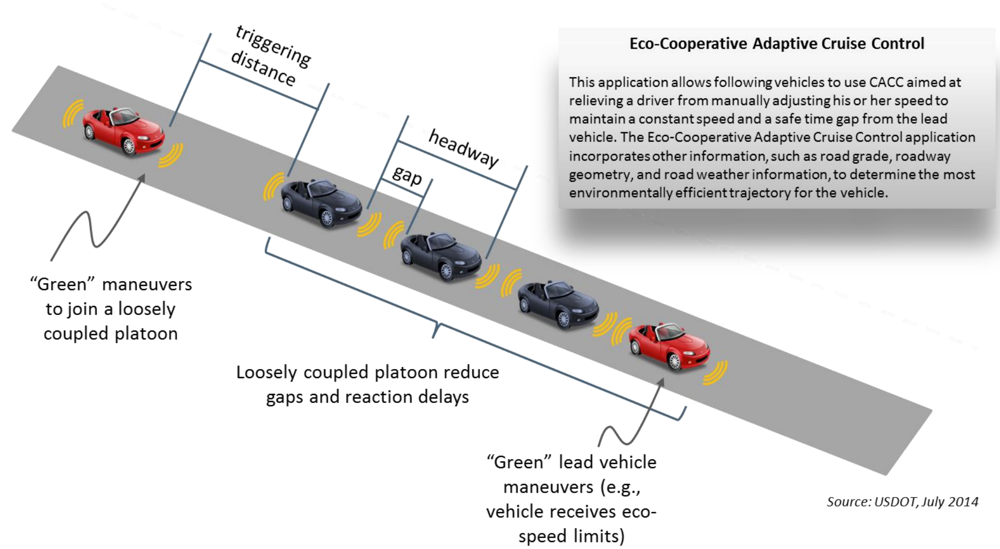
Eco-Speed Harmonization Application: Modeling Results

- **Summary of Preliminary Modeling Results**
  - Up to 4.5% fuel reduction benefits for a real-world freeway corridor
  - Corresponding mobility “dis-benefits” resulting from reducing the free-flow speed along the corridor
- **Key Findings and Takeaways**
  - The application provides more fuel consumption improvements with higher volumes of traffic along the freeway corridor
  - The application is less effective in low traffic conditions
  - The application benefits significantly from higher connected vehicle penetration rates
- **Opportunities for Additional Research**
  - To develop a scenario-based (with real-time monitoring) system that determines when to activate the application and the effective region to maximize the benefits

Eco-Cooperative Adaptive Cruise Control (ECACC) Application

Application Overview

- Considers automated longitudinal control of vehicles while considering eco-driving strategies
- Leverages V2V communications and messages (e.g., vehicle location, speed, and acceleration) as inputs to a vehicle's adaptive cruise control (ACC) system
- Allows for the possibility of vehicles traveling in platoons with shorter gaps/headways
- Reduces oscillations in traffic flow caused by human reaction time (or existing ACC systems) to accelerate or decelerate the vehicle



Source: USDOT, July 2014

Eco-Cooperative Adaptive Cruise Control (CACC) Application: Modeling Results

- **Summary of Key Modeling Results**
  - Up to 19% fuel savings on a real-world freeway corridor for all vehicles
  - Vehicles using the dedicated “eco-lane” experience 7% more fuel savings when compared to vehicles in the general traffic lanes
  - Up to 42% travel time savings on a real-world freeway corridor for all vehicles
- **Key Findings and Takeaways**
  - The presence of a single dedicated “eco-lane” leads to significant increases in overall network capacity
  - Drivers may maximize their energy and mobility savings by choosing to the dedicated “eco-lane”
- **Opportunities for Additional Research**
  - Increasing the number of dedicated lanes will likely further improve results
  - Quantifying relationship between platoon headway and increased network capacity is also of interest

Eco-Lanes
Combined Modeling Results

- **Overview**
  - After the individual applications were thoroughly tested, the two applications were combined and modeled together on the same freeway, including a dedicated “eco-lane”
  - Dedicated lane was reserved for ECACC and the remaining lanes used Eco-Speed Harmonization
  - This “Eco-Lane” was developed utilizing the existing HOV lane on the corridor, much like a real-life scenario would do
  - Due to the functional requirements of an “eco-lane,” only connected vehicles were allowed to use this lane
  - Modeling helped to understand the total impact of the Eco-Lanes Operational Scenario and determine if greater improvements could be obtained together

Eco-Lanes
Combined Modeling Results

- **Summary of Key Modeling Results**
  - Up to 22% fuel savings on a real-world freeway corridor for all vehicles
  - Vehicles using the dedicated “eco-lane” experience 2% more fuel savings when compared to vehicles in the general traffic lanes
  - Up to 33% travel time savings on a real-world freeway corridor for all vehicles
- **Key Findings and Takeaways**
  - The addition of ESH with ECACC leads to additional energy savings than just ECACC
  - Eco-Speed Harmonization and ECACC complement each other, providing drivers in every lane with energy benefits (relative to the baseline)
- **Opportunities for Additional Research**
  - Increasing the number of dedicated lanes will likely further improve results
  - Further improvement of the Eco-Speed Harmonization portion of the application may also yield higher energy and mobility benefits

Low Emissions Zones

LOW EMISSIONS ZONES

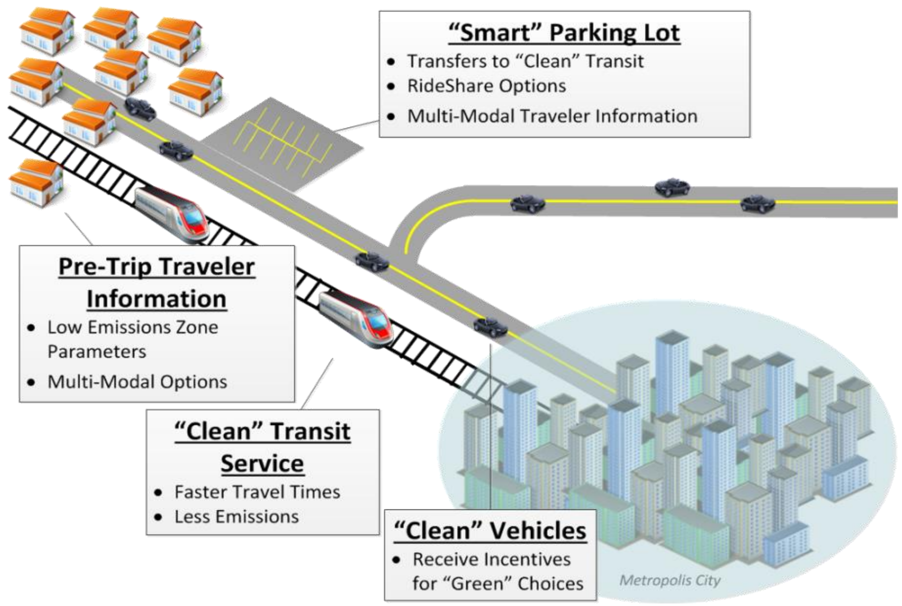
Geographically defined areas that seek to incentivize “green transportation choices” or restrict specific categories of high-polluting vehicles from entering the zone to improve the air quality within the geographic area. Geo-fencing the boundaries allows the possibility for these areas to be responsive to real-time traffic and environmental conditions.

- Low Emissions Zones Management
- *Connected Eco-Driving (Not Modeled)*
- *Eco-Traveler Information Applications (Not Fully Modeled)*

Low Emissions Zones

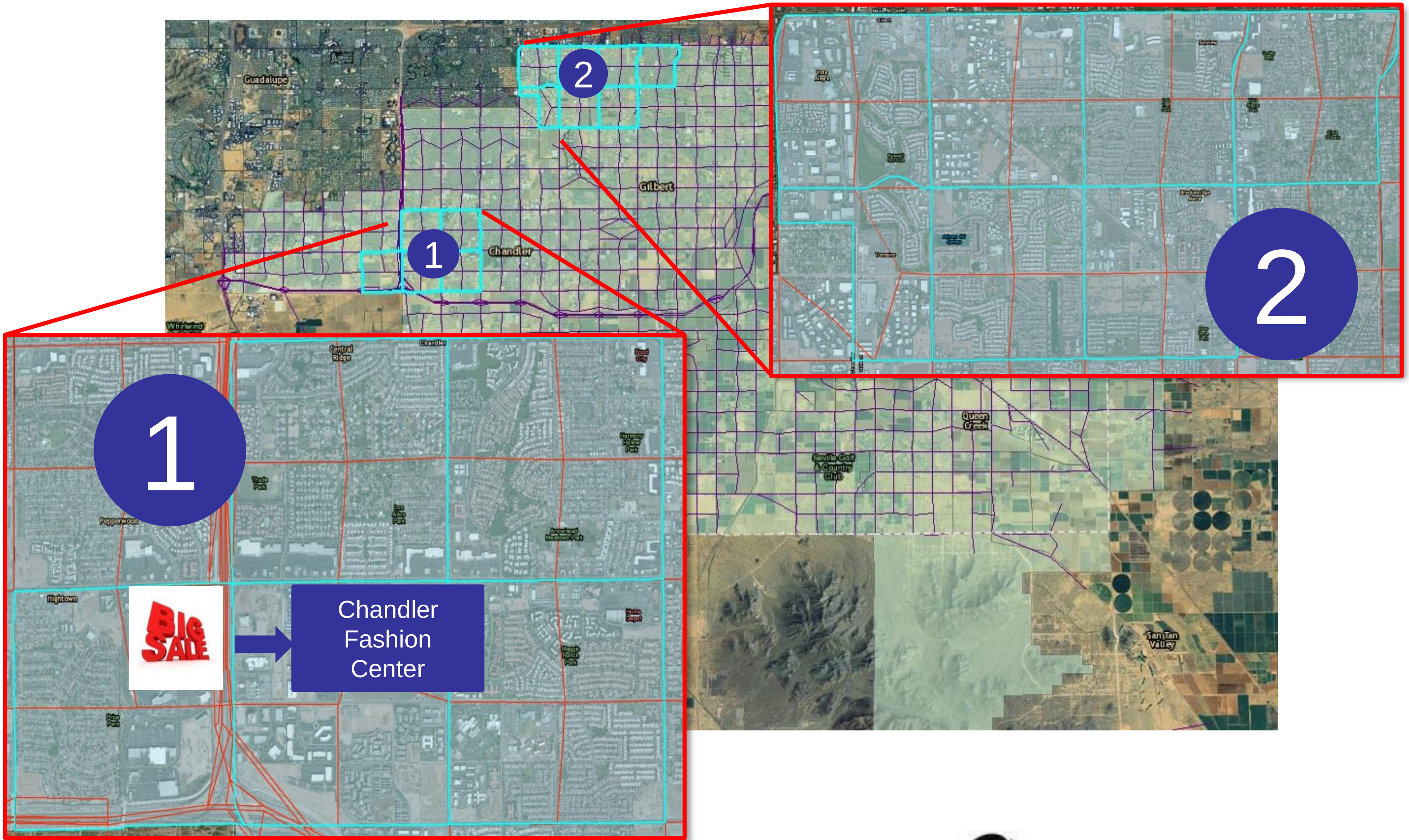
Application Overview

- Individual drivers are provided with pre-trip information about Low Emissions Zone locations, incentive policy, transit information, etc., to make trip decisions
- Driving eco-vehicles or taking transit is incentivized to encourage more eco-friendly driving choices



- Cordon zones are established around a defined area, such as the downtown central business district (CBD) of a major city, and connected vehicle technologies are leveraged for interaction with geo-fenced boundaries
- Non-eco vehicle drivers can switch to transit to enter the Low Emissions Zone to receive incentives

Low Emissions Zones



Source: Google Maps (https://www.google.com/maps)

Low Emissions Zones Modeling Results

- **Summary of Preliminary Modeling Results**
  - Up to 2.5% reduction in fuel consumption with only eco-vehicle incentives offered
  - Up to 4.5% reduction in fuel consumption on with both eco-vehicle incentives and transit incentives to non-eco vehicle drivers
  - VMT reductions of up to 2.5%, with a 20% increase in transit use to trips in to the Low Emissions Zones
- **Key Findings and Takeaways**
  - Offering incentives for transit greatly increases mode shift
  - An effective Low Emissions Zone includes a combination of incentives to eco-vehicles as well as enhanced transit services to attract non-eco travelers
  - The framework can be easily extended to any region to study the impacts of restricting/ incentivizing specific vehicle types for selected zones
- **Opportunities for Additional Research**
  - Evaluate the benefits of other incentives, such as free transit or time-of day travel demand strategies
  - Evaluate the benefits from “fees” to non-eco vehicle drivers

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Connected Vehicle Applications

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

The objective of the AERIS research program is to generate and acquire environmentally-relevant real-time transportation data, and use these data to create actionable information that support and facilitate "green" transportation choices by transportation system users and operators. 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.

Research Plan

AERIS Operational Scenarios and Applications

The AERIS program is investigating five Operational Scenarios or bundles of connected vehicle applications, including: Eco-Signal Operations, Eco-Lanes, Low Emissions Zones, Eco-Traveler Information, and Eco-Integrated Corridor Management. Each Operational Scenario encompasses a set of applications which individually achieve environmental benefits. By strategically bundling these applications, the AERIS Program expects that these Operational Scenarios can achieve additional environment benefits above those of the individual applications. Learn more about the AERIS Operational Scenarios and Aapplications.

AERIS Concepts of Operations

Concept of Operations (ConOps) documents were developed for three high-priority Operational Scenarios: Eco-Signal Operations, Eco-Lanes, and Low Emissions Zones. The documents serve to build consensus among AERIS user groups and stakeholders concerning the needs and expectations of the Operational Scenarios and their associated applications. Presentations adapted from the ConOps documents are

Latest News

2014 AERIS Summer Webinar Series

- **Wednesday, June 25th, 2014 at 1:00pm ET**: Combined Modeling of Eco-Signal Operations Applications
- **Wednesday, July 23rd, 2014 at 1:00pm ET**: Preliminary Eco-Lanes Modeling Results
- **Wednesday, September 24th, 2014 at 1:00pm ET**: Preliminary Low Emissions Zones Modeling Results

2013 – 2014 AERIS Fall/Winter Webinar Series:

- **Wednesday, November 20th, 2013 at 1:00pm ET**: Preliminary Eco-Approach and Departure at Signalized Intersections Modeling Results
- **Wednesday, December 4th, 2013 at 1:00pm ET**: Incorporation of Stakeholder Input into the AERIS Program
- **Wednesday, January 29th, 2014 at 1:00pm ET**: Preliminary Eco-Traffic Signal Timing Modeling Results
- **Wednesday, February 12th, 2014 at 1:00pm ET**: Preliminary Eco-Traffic Signal Priority (for Transit and Freight) and Connected Eco-Driving Modeling Results
- **Wednesday, March 12th, 2014 at 1:00pm ET**: Preliminary Eco-Traffic Signal Timing Modeling Results (Re-Issue)

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AERIS Team Partners

Questions?