APPLICATIONS FOR THE ENVIRONMENT: REAL-TIME INFORMATION SYNTHESIS

Who We Are

Cleaner Air through Smarter Transportation

USDOT connected vehicle research aims to tackle some of the biggest challenges in the surface transportation industry; in the areas of safety, mobility, and environment.

Employing a multimodal 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.

AERIS Research Objectives

- Identify connected vehicle applications that could **provide environmental impact reduction benefits via reduced fuel use, improved vehicle efficiency, and reduced 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 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.

The Environmental Problem

28% of GHG emissions associated with transport sector in the U.S.[1]

83% of transport sector GHG emissions are associated with surface vehicles[1]

2.9 billion gallons of wasted fuel resulting from congestion in urban areas[2]

Source: (1) *EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 to 2012. 2014.*
(2) TTI's 2012 Urban Mobility Report: http://mobility.tamu.edu/ums/report/

The AERIS Approach

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

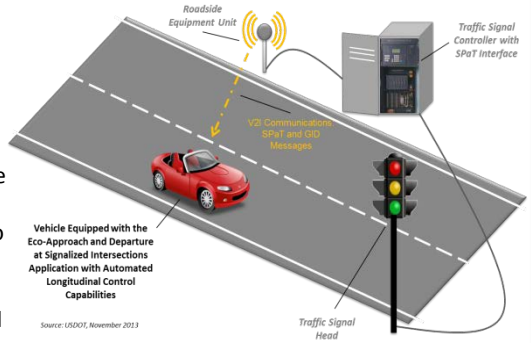
Concept Development – Identify high-level user needs and desired capabilities for each AERIS Operational Scenario

Preliminary Cost Benefit Analysis – Perform a preliminary cost benefit analysis to identify high priority applications

Modeling and Analysis – Model, analyze, and evaluate applications that make sense for development, and further research

AERIS Prototype Application

The AERIS Program will be developing a Proof of Concept Prototype for the Eco-Approach and Departure at Signalized Intersections application. The application will leverage automated longitudinal control capacities helping to reduce driver distraction and improve compliance with the application's speed recommendations.



AERIS Operational Scenarios

Eco-Signal Operations

Uses connected vehicle technologies to decrease fuel consumption emissions by reducing idling, the number of stops, unnecessary accelerations and decelerations, and improving traffic flow 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. The lanes may support variable speed limits, eco-cooperative adaptive cruise control (ECACC), and wireless inductive/resonance charging infrastructure embedded in the roadway.

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.

Eco-Traveler Information

Enables development of new, advanced traveler information applications through integrated, multisource, multimodal data. An open data/open source approach is intended to spur innovation and environmental traveler information applications.

Eco-ICM

Considers 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 and emissions.

AERIS Operational Scenarios

Applications for the Environment: Real-Time Information Synthesis

Overview of Operational Scenarios

The Applications for the Environment: Real-Time Information Synthesis (AERIS) Program identified five Operational Scenarios or bundles of applications: (1) Eco-Signal Operations, (2) Eco-Lanes, (3) Low Emissions Zones, (4) Eco-Traveler Information, and (5) 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 the Operational Scenarios can achieve additional environmental benefits above those of the individual applications.

Each Operational Scenario is comprised of applications, regulatory/policy tools, educational tools and performance measures. Applications are technological solutions (e.g., software, hardware, interfaces) designed to ingest, process, and disseminate data in order to address a specific strategy. For example, the Eco-Traffic Signal Priority application may collect data from vehicles, send these data to a local processor to determine if a vehicle should be granted priority at a signalized intersection, and then communicate this priority request to a traffic signal controller.

Applications are complemented with regulatory/policy and educational tools to further support the Operational Scenario.

Operational Scenarios and Applications

ECO-SIGNAL OPERATIONS

- **Eco-Approach and Departure at Signalized Intersections** *(similar to SPaT)*
- **Eco-Traffic Signal Timing** *(similar to adaptive traffic signal systems)*
- **Eco-Traffic Signal Priority** *(similar to traffic signal priority)*
- **Connected Eco-Driving** *(similar to eco-driving strategies)*
- **Wireless Inductive/Resonance Charging**

ECO-LANES

- **Eco-Lanes Management** ***(similar to HOV Lanes)***
- **Eco-Speed Harmonization** ***(similar to variable speed limits)***
- **Eco-Cooperative Adaptive Cruise Control** *(similar to adaptive cruise control)*
- **Eco-Ramp Metering** *(similar to ramp metering)*
- **Connected Eco-Driving** *(similar to eco-driving)*
- **Wireless Inductive/Resonance Charging**
- **Eco-Traveler Information Applications** *(similar to ATIS)*

LOW EMISSIONS ZONES

- **Low Emissions Zone Management** *(similar to Low Emissions Zones)*
- **Connected Eco-Driving** *(similar to eco-driving strategies)*
- **Eco-Traveler Information Applications** *(similar to ATIS)*

ECO-TRAVELER INFORMATION

- **AFV Charging/Fueling Information** *(similar to navigation systems providing information on gas station locations)*
- **Eco-Smart Parking** *(similar to parking applications)*
- **Dynamic Eco-Routing** *(similar to navigation systems)*
- **Dynamic Eco-Transit Routing** *(similar to AVL routing)*
- **Dynamic Eco-Freight Routing** *(similar to AVL routing)*
- **Multimodal Traveler Information** *(similar to ATIS)*
- **Connected Eco-Driving** *(similar to eco-driving strategies)*

ECO-INTEGRATED CORRIDOR MANAGEMENT

- **Eco-ICM Decision Support System** *(similar to ICM)*
- **Eco-Signal Operations Applications**
- **Eco-Lanes Applications**
- **Low Emissions Zones Applications**
- **Eco-Traveler Information Applications**
- **Incident Management Applications**

AERIS 2014 Workshop: Moving Toward Deployment

The AERIS Program is focused on near-term deployment of connected vehicle applications relevant to environmental outcomes or focused on environmental performance measures.

Environmentally-focused connected vehicle applications may include:

- Mobility and/or safety applications that also provide environmental benefits (e.g., Traffic Signal Priority or V2I Safety apps that reduce non-recurring congestion and thus emissions)
- Environmental-centric applications (e.g., Eco-Driving, Eco-Routing, Eco-Approach and Departure at Signalized Intersection)
- Applications that perform dual roles – apps that can be optimized for mobility or the environment (e.g., Speed Harmonization or Signal Timing)

AERIS is primarily focused on two performance measures: (1) fuel use and (2) emissions reductions

1

IDENTIFY LOCAL NEEDS- Identify local problems, challenges, and/or issues you are trying to address

2

SET PERFORMANCE GOALS- Set measurable goals and objectives that allow you to address local needs

3

SELECT CONNECTED VEHICLE APPLICATIONS THAT WORK TOGETHER TO MEET THOSE GOALS- Identify potential solutions – including connected vehicle applications – that help you meet your goals and objectives

Eco-Signal Operations

Applications for the Environment: Real-Time Information Synthesis

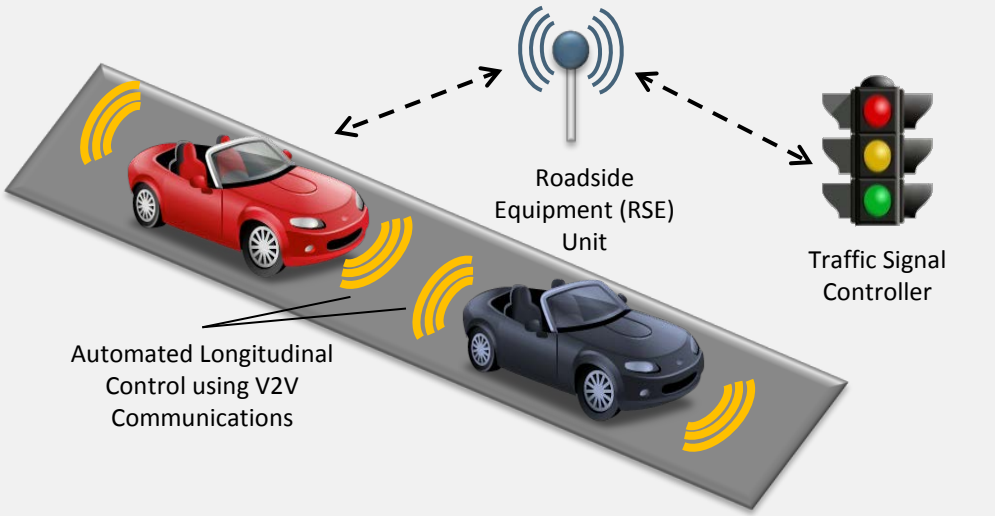
Operational Scenario Description

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

Potential Benefits

- The Eco-Approach and Departure at Signalized Intersections application provides up to 13% fuel reduction benefits for a coordinated corridor above the baseline:
  - 8% of the benefit is attributable to signal coordination
  - 5% attributable to the application
- Eco-Traffic Signal Timing provides up to 5% improvement in fuel consumption and environmental measures at full connected vehicle penetration.
- Eco-Signal Priority applications provide 2-4% fuel reduction benefits, resulting in approximately $650,000 savings per year for a transit or delivery truck fleet of 1,000 vehicles.
- Combined modeling of the Eco-Signal Operations applications resulted in a 9.6% reduction in fuel consumption and CO_2 over the baseline.

Operational Scenario Visualization



Source: USDOT, July 2013

Eco-Signal Operations

Applications for the Environment: Real-Time Information Synthesis

Application Description	Modeling Results
Eco-Traffic Signal Timing This application's objective is to optimize the performance of traffic signals for the environment. The application collects data from vehicles, such as vehicle location, speed, and emissions data using connected vehicle technologies. It then 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. The application evaluates traffic and environmental parameters at each intersection in real-time and adapts so the traffic network is optimized using available green time to serve the actual traffic demands while minimizing the environmental impact.	• The application provides up to 5% improvement in fuel consumption at full connected vehicle penetration. Benefits range from 1% to 4% under partial connected vehicle penetration in a fully coordinated signalized network. • Optimizing for the environment resulted in 5% benefits when optimizing for the environmental whereas optimizing for mobility resulted in 2% reductions in fuel consumption.

Eco-Approach and Departure at Signalized Intersections
This application uses wireless data communications sent from a roadside equipment unit to connected vehicles to encourage "green" approaches to signalized intersections. The application, located in a vehicle, collects signal phase and timing (SPaT) and Geographic Information Description messages using V2I communications and data from nearby vehicles using V2V communications. Upon receiving these messages, the application would perform 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. This information is then sent to longitudinal vehicle control capabilities in the vehicle to support partial automation.
	• The application provides 5% to 10% fuel reduction benefits for an uncoordinated corridor.
	• For a coordinated corridor, the application provides up to 13% fuel reduction benefits above the baseline:
	  • 8% of the benefit is attributable to signal coordination
	  • 5% attributable to the application
	• Driving a typical light vehicle 8,000 miles / year on arterials equates to $173 of saving/year/driver.
	• Savings for the driver of a SUV (lower MPG) are $280/year/driver.
	• A fleet operator with 150 vehicles would save $42,000/year.

Eco-Traffic Signal Priority This application allows either transit or freight vehicles approaching a signalized intersection to request signal priority. These applications consider 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-Transit Signal Priority provides up to 2% fuel reduction benefits for transit vehicles. This equates 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. This equates up to $649,000 annual savings for fleet of 1,000 city delivery vehicles driving 30,000 miles on arterials each year.

Eco-Signal Operations

Applications for the Environment: Real-Time Information Synthesis

Application Description	Modeling Results

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, optimal acceleration, and optimal deceleration profiles based on prevailing traffic conditions, interactions with nearby vehicles, and upcoming road grades. The application also provides feedback to drivers on their driving behavior to encourage drivers to drive in a more environmentally efficient manner. Finally, the application may also include vehicle-assisted strategies where the vehicle automatically implements the eco-driving strategy (e.g., changes gears, switches power sources, or reduces its speed in an eco-friendly manner).
	• The Connected Eco-Driving application provides up to 2% reduction in fuel consumption at full connected vehicle penetration.
	  • For a driver of a light duty vehicle driving 8,000 miles a year on arterials, this equates to $27/year/driver.
	  • For the driver of a SUV 8,000 miles a year on arterials, this equates to $37/year/driver.
	  • For a city delivery fleet with 150 vehicles traveling 30,000 miles per year on arterials, this equates to savings of $48,698/year.

Wireless Inductive/Resonance Charging Wireless inductive/resonance charging includes infrastructure deployed along the roadway that uses magnetic fields to wirelessly transmit large electric currents between metal coils placed several feet apart. This infrastructure enables charging of electric vehicles including cars, trucks, and buses. Roadside charging infrastructure supports static charging capable of transferring electric power to a vehicle parked in a garage or on the street and vehicles stopped at a traffic signal or a stop sign. It also supports charging vehicles moving at highway speeds.	Application not Modeled in Current Phase

Combined Modeling
After each application was modeled individually, the applications were modeled together on a six mile segment of the El Camino Real corridor near Palo Alto, CA. The corridor consisted mostly of three lanes in each direction with 40 mph speed limits. The six mile segment contained 27 signalized intersections spaced 650 to 1,600 feet apart. The Eco-Traffic Signal Timing application was applied to the corridor that was running the Eco-Approach and Departure at Signalized Intersections, Eco-Traffic Signal Priority, and Connected Eco-Driving applications.
	• The combined modeling resulted in a 9.6% reduction in fuel consumption and CO_2 over the baseline. The results can be broken down to 9.6%, 9.8% and 3.1% reductions in light vehicles, freight, and transit vehicles, respectively. This equates to:
	  • Light Vehicle at 23 mpg ~ $126 per year savings
	  • City Delivery Fleet (1,000 vehicles) at 7.3 mpg ~ $1.6M per year savings
	  • Transit Fleet (1,000 vehicles), 4 mpg ~ $918,000 per year savings

Eco-Lanes

Applications for the Environment: Real-Time Information Synthesis

Operational Scenario Description

The Eco-Lanes Operational Scenario includes dedicated freeway lanes – similar to managed lanes – optimized for the environment that encourage use from vehicles operating in eco-friendly ways. The lanes may support:

- Variable speed limits are optimized for the environment based on data collected from vehicles.
- Drivers may opt-in to eco-cooperative adaptive cruise control (ECACC) and vehicle platooning applications.
- Wireless Inductive/Resonance Charging infrastructure embedded in the roadway allows electric vehicles to charge their batteries while the vehicle is in motion.

Potential Benefits

Eco-Speed Harmonization

- In general, Eco-Speed Harmonization performs better at higher traffic volumes and high connected vehicle penetration rates.
- The application provides up to 4.5% fuel reduction benefits.
- Mobility dis-benefits may result from the decreased free-flow speed.

Eco-Cooperative Adaptive Cruise Control (ECACC)

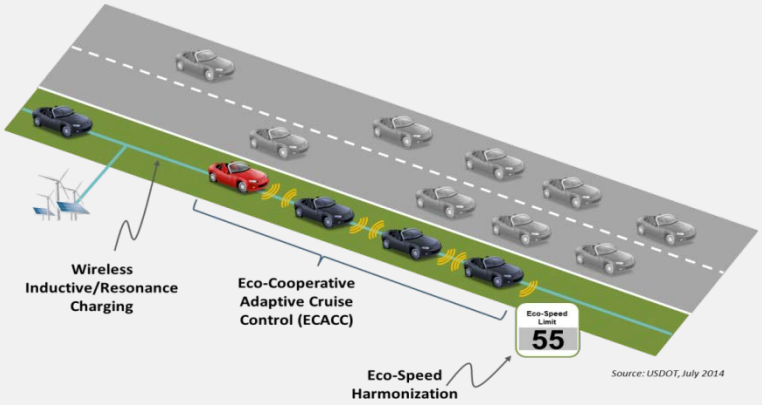
- The application provides up to 19% fuel savings on a real-world freeway corridor.
- The application results in up to 42% travel time savings on a real-world freeway corridor.

Eco-Speed Harmonization and ECACC Combined

- When combined, the applications provide up to 22% fuel savings on a real-world freeway corridor; and up to an additional 2% fuel savings when using a dedicated "eco-lane" on the freeway corridor.
- The applications provide up to 33% travel time savings on a freeway corridor.

Operational Scenario Visualization

Dedicated Eco-Lane



Eco-Lanes

Applications for the Environment: Real-Time Information Synthesis

Application Description

Eco-Lanes Management

This application establishes parameters and defines or geo-fences the eco-lanes boundaries. 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. The application also conveys pre-trip and en route traveler information about eco-lanes to travelers, including information about parameters for vehicles to enter the eco-lanes, current and predicted traffic conditions in the eco-lanes, and geographic boundaries of the eco-lanes.

Eco-Speed Harmonization

This application determines eco-speed limits based on traffic conditions, weather information, and GHG and criteria pollutant information. The purpose of speed harmonization is to change speed limits on links that approach areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that affect flow. Speed harmonization assists in maintaining flow, reducing unnecessary stops and starts, and maintaining consistent speeds, thus reducing fuel consumption, GHG emissions, and other emissions on the roadway. Eco-speed limits can be broadcast by roadside equipment units and received by on-board equipment units.

Eco-Cooperative Adaptive Cruise Control

Eco-Cooperative Adaptive Cruise Control includes longitudinal automated vehicle control while considering eco-driving strategies. Expanding on existing ACC systems, which use radar and LIDAR measurements to identify the location of the preceding vehicle, 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. This application allows following vehicles to use CACC aimed at relieving a driver from manually adjusting his or her speed to maintain a constant speed and a safe time gap from the lead vehicle. The Eco-Cooperative Adaptive Cruise Control application also incorporates other information, such as road grade, roadway geometry, and road weather information.

Modeling Results

Preliminary Modeling Results

Modeling of the Eco-Lanes Operational Scenario is in progress. Preliminary modeling results are summarized below:

Eco-Speed Harmonization

- The application provides up to 4.5% fuel reduction benefits.
- The application may provide mobility dis-benefits from the decreased speed free-flow speed.
- In general, Eco-Speed Harmonization performs better at higher traffic volumes and high connected vehicle penetration rates.

Eco-Cooperative Adaptive Cruise Control (ECACC)

- The application provides up to 19% fuel savings on a real-world freeway corridor.
- Up to 42% travel time savings can be achieved by this application based on modeling results on a real-world freeway corridor.
- The presence of a single dedicated "eco-lane" leads to significant increases in overall network capacity.

Eco-Speed Harmonization and Eco-Cooperative Adaptive Cruise Control (ECACC) Combined

- When the applications are combined, they provide up to 22% fuel savings on a real-world freeway corridor and up to 33% travel time savings on a real-world freeway corridor.
- The applications provide an additional 2% fuel savings when using a dedicated "eco-lane" on the freeway corridor.

Eco-Lanes

Applications for the Environment: Real-Time Information Synthesis

Application Description	Modeling Results
Eco-Ramp Metering The Eco-Ramp Metering application determines the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of entering vehicles. This application collects traffic and environmental data to allow on-ramp merge operations that minimize overall emissions, including traffic and environmental conditions on the ramp and on the freeway upstream and downstream of the ramp. Using this information, the application determines a timing plan for the ramp meter based on current and predicted traffic and environmental conditions. The objective for this application is to produce timing plans that reduce overall emissions.	Applications not Modeled in Current Phase
Connected Eco-Driving The Connected Eco-Driving application provides customized real-time driving advice to drivers, allowing them to adjust behaviors to save fuel and reduce emissions. This advice includes recommended driving speeds, optimal acceleration and deceleration profiles based on prevailing traffic conditions, and more local interactions with nearby vehicles. Finally, the application may also consider vehicle-assisted strategies, where the vehicle automatically implements the eco-driving strategy (i.e., change gears, switch power sources, or use start-stop capabilities.	Applications not Modeled in Current Phase
Wireless Inductive/Resonance Charging Wireless inductive/resonance charging includes infrastructure deployed along the roadway that uses magnetic fields to wirelessly transmit large electric currents between metal coils placed several feet apart. This infrastructure enables charging of electric vehicle batteries including cars, trucks, and buses.	Applications not Modeled in Current Phase
Eco-Traveler Information Applications Applications included in the Eco-Traveler Information Operational Scenario apply. Traveler Information specific to Eco-Lanes may include: parameters for the Eco-Lanes, travel time or fuel savings comparison between the Eco-Lanes and general purpose lanes, incident information, availability of wireless inductive/resonance charging in the Eco-Lanes, vehicle platooning rules and parameters, transit options, and parking information.	Applications not Modeled in Current Phase

Low Emissions Zones

Applications for the Environment: Real-Time Information Synthesis

Operational Scenario Description

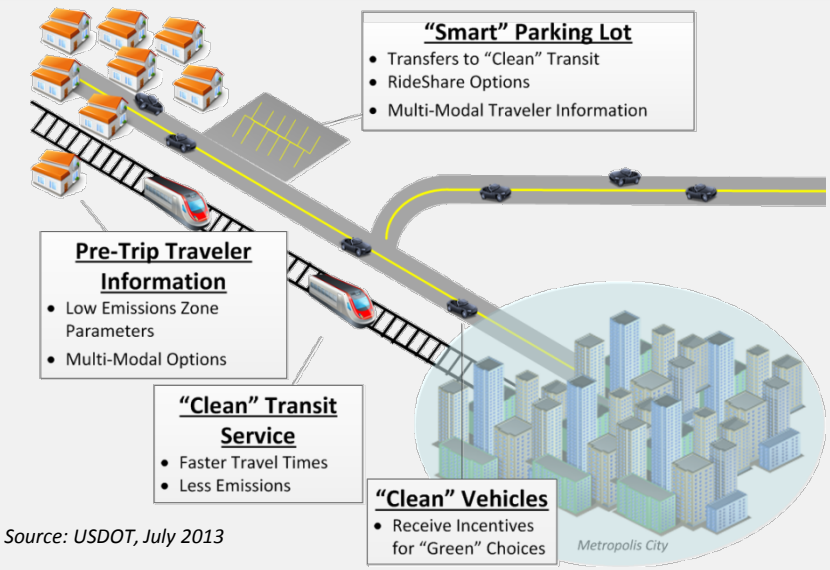
- Geographically defined areas that seek to incentivize "green transportation choices" or restrict specific categories of high-polluting vehicles from entering the zone to improve the air quality within the geographic area.
- Incentives may be based on the vehicle's engine emissions standard or emissions data collected directly from the vehicle using V2I communications.
- Geo-fencing the boundaries of Low Emissions Zones allows the possibility for these areas to be responsive to specific traffic and environmental conditions (e.g., pop-up for a Code Red Air Quality Day, special event, etc.).

Potential Benefits

Phoenix, AZ Metropolitan Area Sub-Region

- The Operational Scenario provides a 3% to 5% energy and emissions savings at modest levels of eco-vehicle penetration coupled with enhanced transit services.
- There is up to 2.5% reduction in fuel consumption with only eco-vehicle incentives offered.
- Low Emissions Zones may provide up to 4.5% reduction in fuel consumption when both eco-vehicle incentives and transit incentives to non-eco vehicle drivers.
- The Low Emissions Zones resulted in vehicle miles traveled (VMT) reductions of up to 2.5%, with a 20% increase in transit use to trips into the Low Emissions Zones.
- The Low Emissions Zones modeling framework can be easily extended to any region to study the impacts of restricting/ incentivizing specific vehicle types for selected zones.

Operational Scenario Visualization



Source: USDOT, July 2013

Low Emissions Zones

Applications for the Environment: Real-Time Information Synthesis

Application Description

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 uses data collected from vehicles using connected vehicle technologies and from roadside equipment as input to the system. The Low Emissions Zone Management application supports the geo-fencing of a cordon that may be scalable and moveable (e.g., created for a day, removable, flexible in its boundaries) and would be less dependent on conventional ITS infrastructure. 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 based on emissions data collected from the vehicle, and geographic boundaries for the low emissions zones. The application would also include electronic toll collection functions that support payments of fees or collection of incentives for registered vehicles.

Eco-Traveler Information Applications

Applications included in the Eco-Traveler Information Operational Scenario apply. Eco-Traveler Information Applications provide pre-trip and en-route traveler information about the Low Emissions Zones. This includes information about the geographic boundaries of the low emissions zones, criteria for vehicles to enter the Low Emissions Zones, expected fees and incentives for their trip, and current and predicted traffic and environmental conditions within and adjacent to the zones. Traveler information messages may be provided to various personal devices and in-vehicle systems and used by travelers to adjust their departure time or select an alternate route. Another key component of these applications is providing travelers with transit options to encourage mode shift as well as parking information in the Low Emissions Zones or at parking lots outside of the zones.

Modeling Results

Preliminary Modeling Results

Modeling of the Low Emissions Zones Operational Scenario is in progress. Preliminary modeling results are summarized below:

Phoenix, AZ Metropolitan Area Sub-Region Modeling

- There is a 3% to 5% energy and emissions savings at modest levels of eco-vehicle penetration coupled with enhanced transit services.
- Incremental scenario development allows for the flexibility to identify the benefits of a standalone policy vs a combination of policies.
- The Low Emissions Zones modeling framework can be easily extended to any region to study the impacts of restricting/ incentivizing specific vehicle types for selected zones.
- 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.