UNITED STATES
DEPARTMENT OF TRANSPORTATION

ITS for Energy Efficiency: Preliminary AERIS Eco-Signal Modeling Results

ITS Europe

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Intelligent Transportation Systems Joint Program Office

Connected Vehicle Research Program

Applications

- **Safety**
  - V2V
  - V2I
- **Mobility**
  - Real-Time Data Capture
  - Dynamic Mobility Apps
- **Environment**
  - AERIS
  - Road Weather Apps

Technology

- Harmonization of International Standards & Architecture
- Human Factors
- Systems Engineering
- Certification
- Test Environments

Policy

- Deployment Scenarios
- Financing & Investment Models
- Operations & Governance
- Institutional Issues

AERIS Research Objectives

- **Vision** – Cleaner Air through Smarter Transportation
  - Encourage the development and deployment of technologies and apps that support a more sustainable relationship between surface transportation and the environment through fuel use reductions and more efficient use of transportation services.
- **Objectives** – Investigate whether it is possible and feasible to:
  - 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 (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.

AERIS OPERATIONAL SCENARIOS & 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/HOT 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 strategies)*
- **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)*
- **Multi-Modal 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 Zone s Applications**
- **Eco-Traveler Information Applications**
- **Incident Management Applications**

Eco-Signal Operations

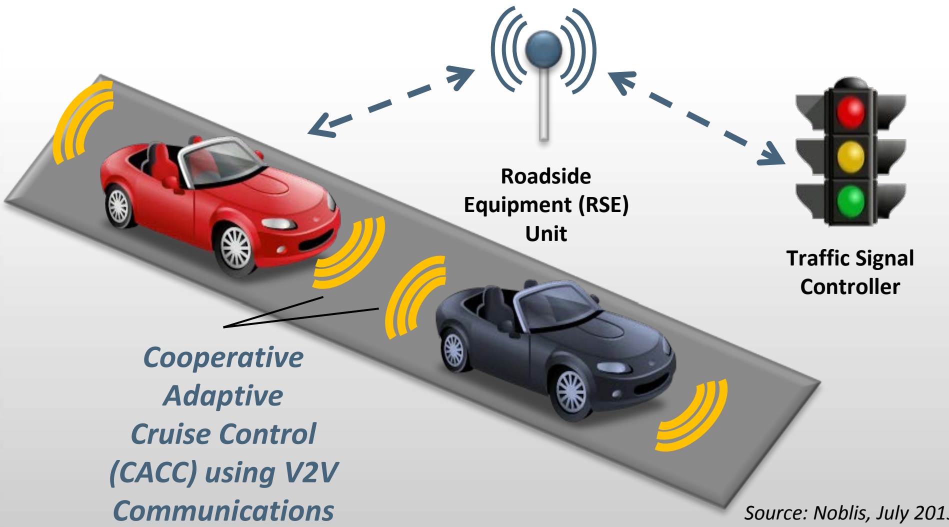
OPERATIONAL SCENARIO DESCRIPTION

- Uses connected vehicle technologies to **decrease fuel consumption** and decrease GHG and criteria air pollutant emissions by reducing idling, the number of stops, unnecessary accelerations and decelerations as well as 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 Charging, and (5) Vehicle Engine Start-Stop Technology.

POTENTIAL BENEFITS

- A number of traffic signal coordination projects have documented emissions savings.
  - Syracuse, New York | Emissions reductions ranging from 9 to 13%.
  - Los Angeles, California | Emissions reductions of 14% and a reduction of fuel by 13%.
- Eco-Approach and Departure at Signalized Intersections
  - Initial modeling results showed 5% to 10% fuel savings for individual vehicles with 100% penetration rate, without significantly increasing travel time. At lower penetration rates, there were still positive network benefits.

OPERATIONAL SCENARIO VISUALIZATION



Source: Noblis, July 2013

Eco-Lanes

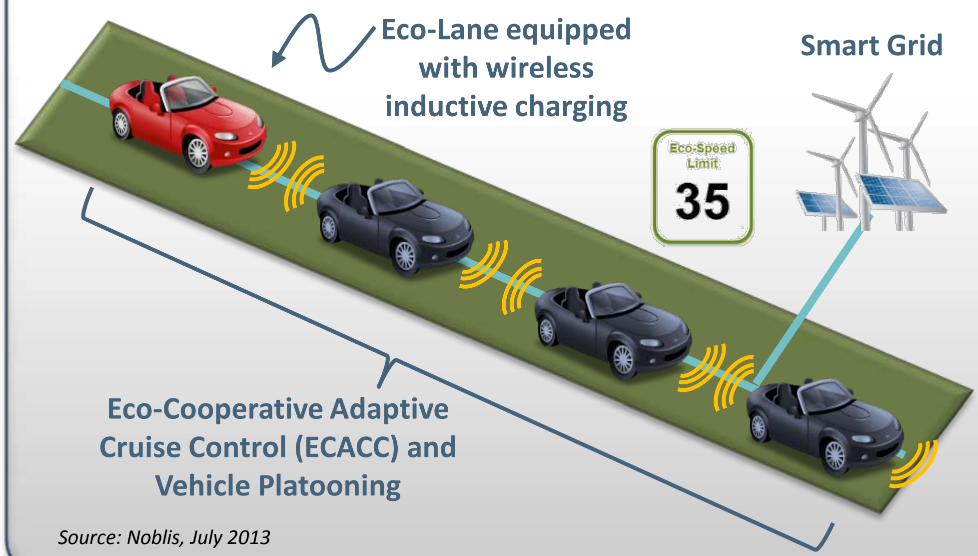
OPERATIONAL SCENARIO DESCRIPTION

- Dedicated freeway lanes – similar to HOV **lanes – optimized for the environment** that encourage use from vehicles operating in eco-friendly ways.
- 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) charging infrastructure embedded in the roadway allows electric vehicles to charge their batteries while the vehicle is moving.

POTENTIAL BENEFITS

- Variable Speed Limit (VSL) systems reduce congestion, provide more reliable journey times, reduce the frequency of accidents, reduce carbon emissions, and reduce driver stress.
- University of Texas at Austin research found that reducing speed limits on a freeway from 65 mph to 55 mph on a "Code Red Air Quality Day" resulted in a 17% reduction in NO_x over a 24 hour period.
- The Safe Road Trains for the Environment (SARTRE) Project in Europe estimates that vehicle platooning has the potential to reduce CO_2 emissions by 20%.

OPERATIONAL SCENARIO VISUALIZATION



Source: Noblis, July 2013

Low Emissions Zones

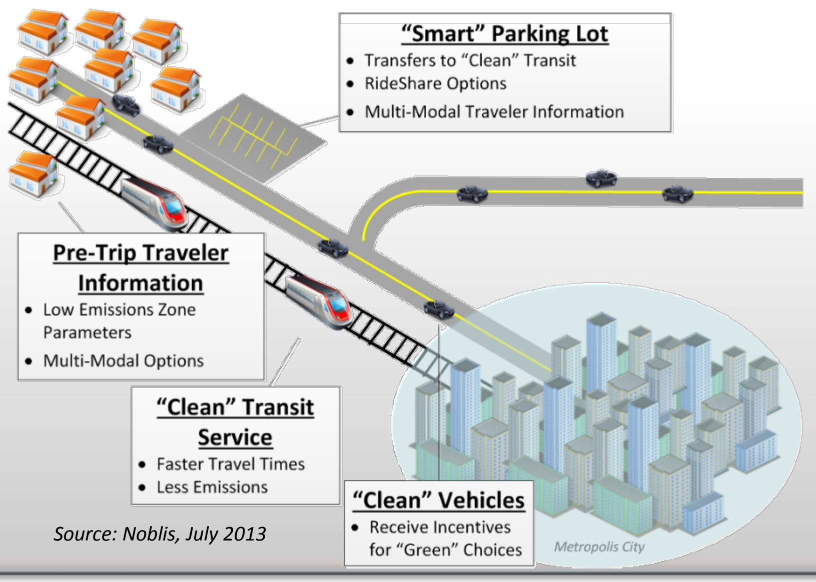
OPERATIONAL SCENARIO DESCRIPTION

- **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 the Low Emissions Zone 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

- The London Low Emissions Zone "aims to reduce traffic pollution by deterring the most polluting diesel-engine lorries, buses, coaches, minibuses, and large vans from driving within the city."
- According to a 2006 study, concentrations of small particles from traffic sources were expected to decrease across London by 4.3 percent in 2008 and 8.0 percent in 2010 due to the Low Emissions Zone, and NO_x was expected to decrease by 3.2 percent in 2008 and 4.1 percent in 2010.

OPERATIONAL SCENARIO VISUALIZATION



Source: Noblis, July 2013

Eco-Traveler Information

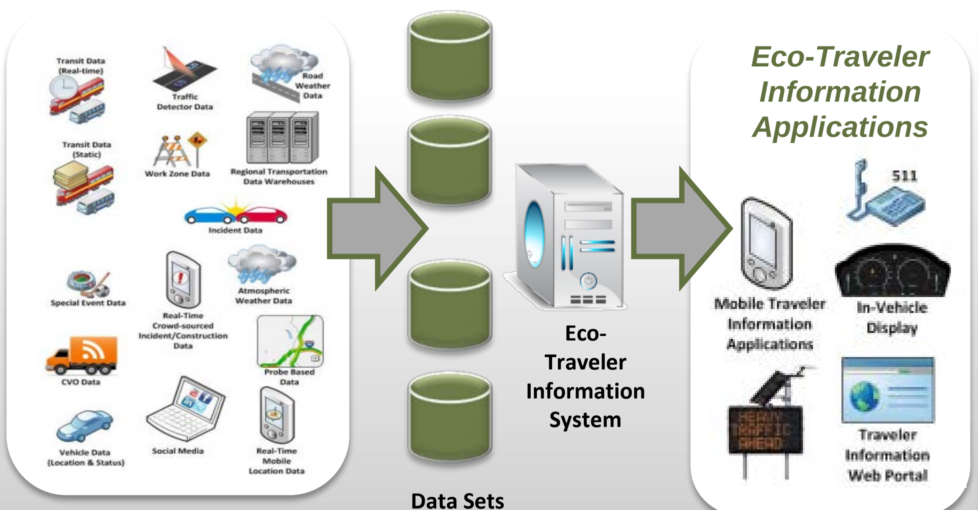
OPERATIONAL SCENARIO DESCRIPTION

- Enables development of new, advanced traveler information applications through integrated, multisource, multimodal data. An open data/open source approach is intended to engage researchers and the private sector to spur innovation and environmental applications, including:
  - Responsive Eco-Routing
  - Eco-Smart Parking
  - Alternative Fuel Vehicle Charging/Fueling Information
  - Multi-Modal Traveler Information (e.g., fuel use/$ saving/emissions reduction smartphone apps, car sharing information, mode choice, etc.)

POTENTIAL BENEFITS

- A study titled "Green Routing Buffalo Final Report" found that green routing could yield an average fuel consumption benefit of 16.7%.
- The benefits of multi-modal traveler information include reducing driving and VMTs due to increased carpooling, car sharing, public transportation, and planning ahead to combine trips.
- Estimates show that one person using mass transit for an entire year, instead of driving to work, can keep an average of 62.5 pounds of carbon monoxide (CO) from being emitted. This is equivalent to 28,350 grams of CO.

OPERATIONAL SCENARIO VISUALIZATION



Source: Graphic Adapted from Concept of Operations: DCM, August 2010

Eco-Integrated Corridor Management

OPERATIONAL SCENARIO DESCRIPTION

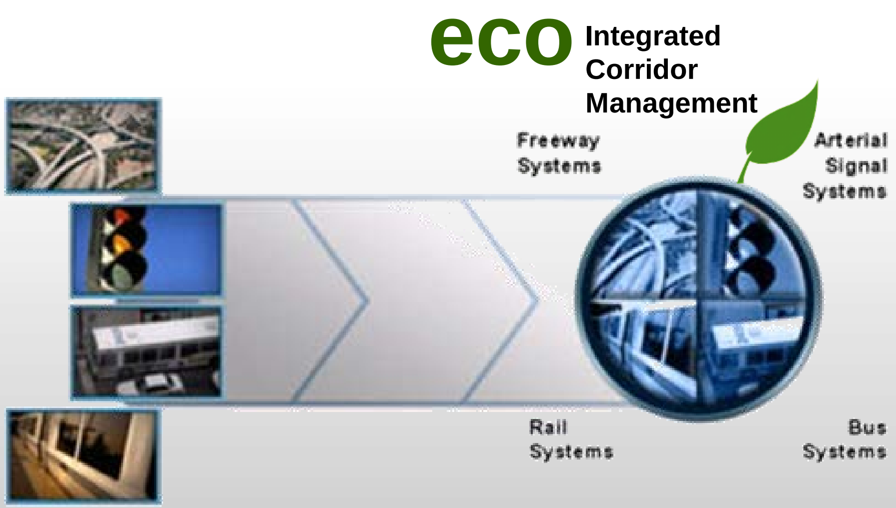
- Considers partnering among operators of various surface transportation agencies to treat travel corridors as an integrated asset, coordinating their operations simultaneously with a focus on decreasing fuel consumption, GHG emissions, and criteria air pollutant emissions.
- Includes a real-time data-fusion and decision support system that uses multisource, real-time data on arterials, freeways, and transit systems to determine which operational decisions have the greatest environmental benefit to the corridor.

POTENTIAL BENEFITS

ICM modeling for I-880 in Oakland, CA show:

- HOT lane and highway traveler information were the most effective strategies.
- Highway traveler information produced a large benefit, especially in the case of unexpected events such as a major incident.
- Transit traveler information produced less benefit than highway traveler information.
- In high demand conditions, arterial signal coordination produced a benefit-to-cost ratio that ranged from 12:1 to 20:1.
- Combining multiple ICM strategies produced a benefit-to-cost ratio that ranged from 7:1 to 25:1.

OPERATIONAL SCENARIO VISUALIZATION

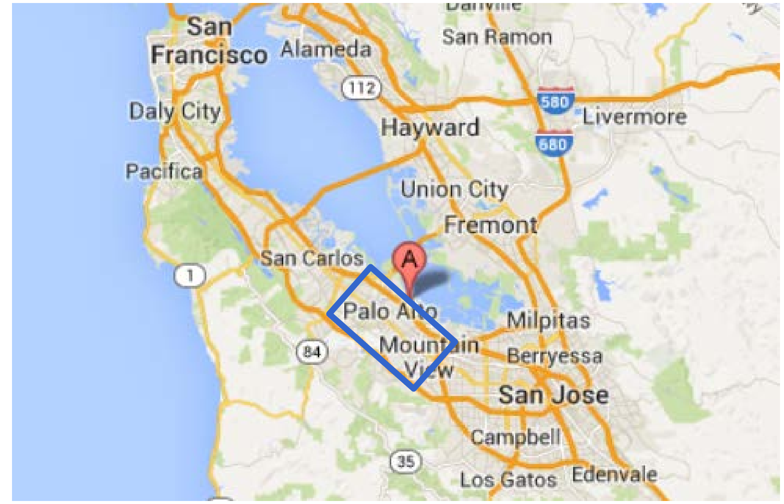


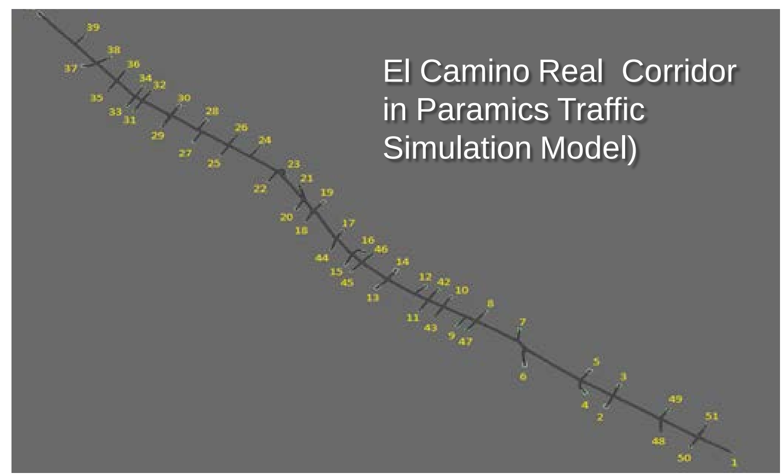
Source: USDOT

Eco-Signal Operations Modeling

Modeling Corridor: El Camino Real

- A real-world corridor was chosen for analysis and modeling
- El Camino Real is a major north-south arterial connecting San Francisco and San Jose, CA
- The modeling corridor consisted of:
  - A six-mile segment of El Camino Real
  - Three lanes in each direction for the majority of the corridor with a 40 mph speed limit
  - 27 signalized intersections that were well coordinated / optimized
  - Intersection spacing that varied from 650 to 1,600 feet

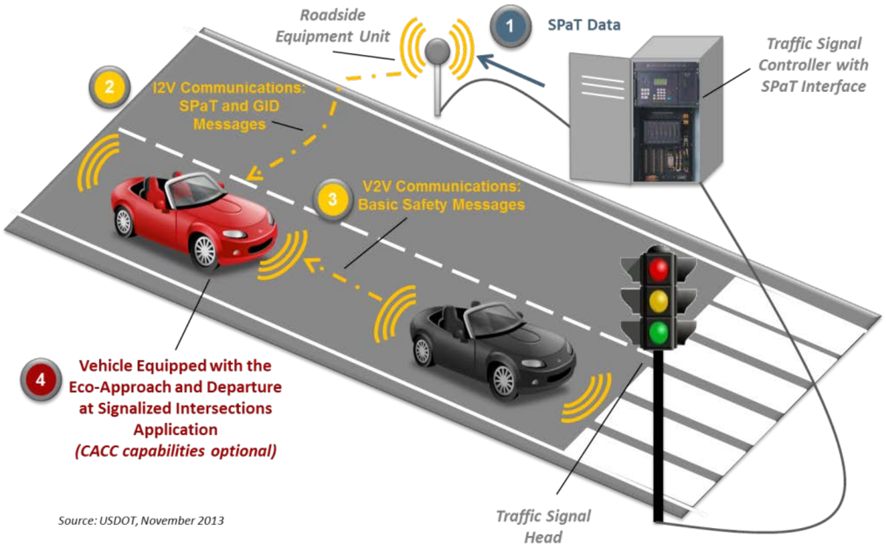




Eco-Approach and Departure at Signalized Intersections Application

Application Overview

- Collects signal phase and timing (SPaT) and Geographic Information Description (GID) messages using V2I communications
- Collects basic safety messages (BSMs) from nearby vehicles using V2V communications



Source: USDOT, November 2013

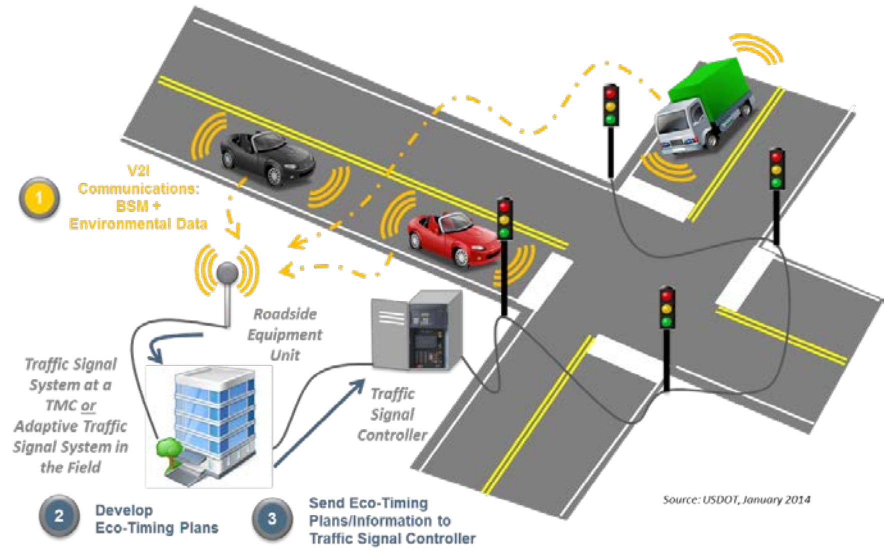
- Receives V2I and V2V messages, the application performs calculations to determine the vehicle's optimal speed to pass the next traffic signal on a green light or to decelerate to a stop in the most eco-friendly manner
- Provides speed recommendations to the driver using a human-machine interface or 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

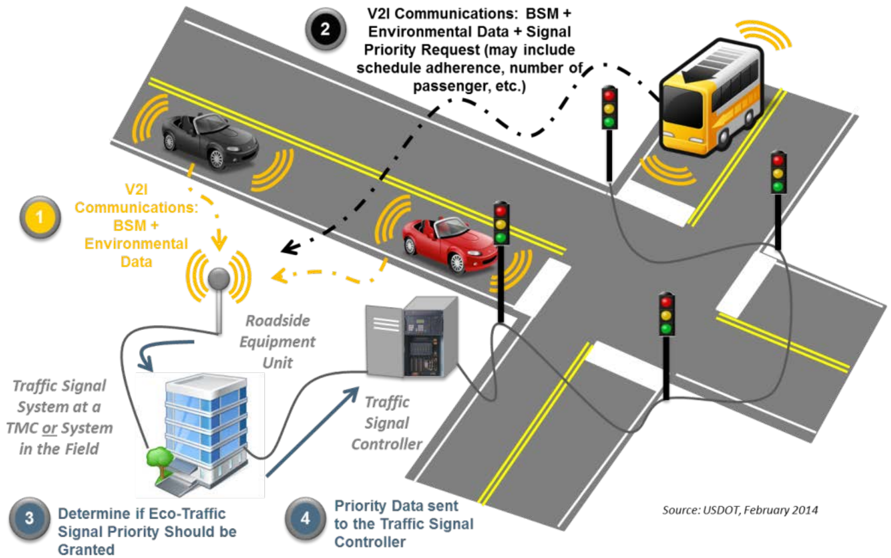
Eco-Traffic Signal Timing Application: Modeling Results

- **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



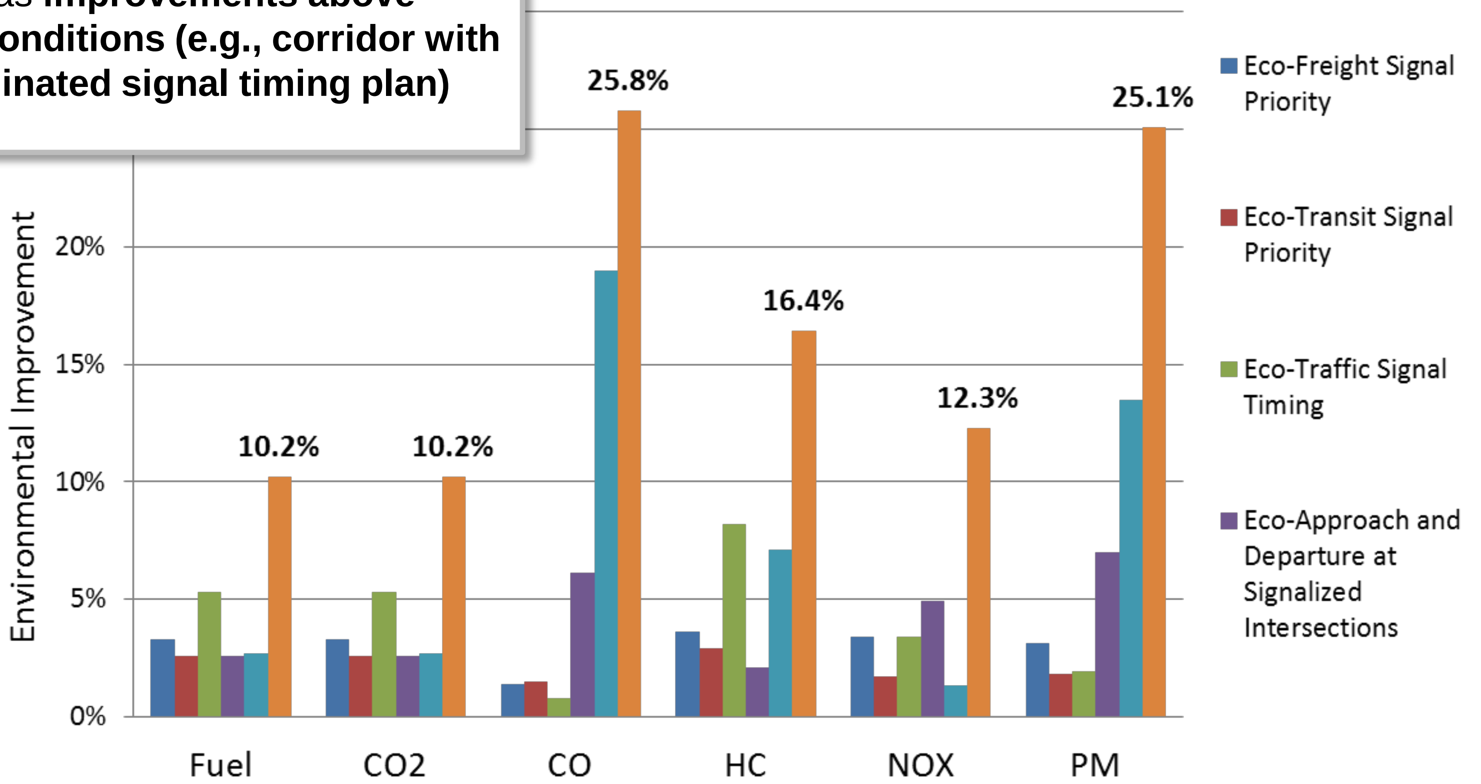
- Information collected from vehicles approaching the intersection, such as a transit vehicle's adherence to its schedule, the number of passengers on the transit vehicle, or weight of a truck may also be considered in granting priority
- If priority is granted, the traffic signal would hold the green 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 $140,000 annual savings for fleet of 1,300 transit vehicles driving 20,000 miles each on arterials a year (e.g., WMATA Fleet)
  - Eco-Freight Signal Priority provides up to 4% fuel reduction benefits for freight vehicles → Over $10.2M annual savings for a fleet of 96,000 trucks driving 10,000 miles each on arterials per year (e.g., UPS Fleet)
- **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

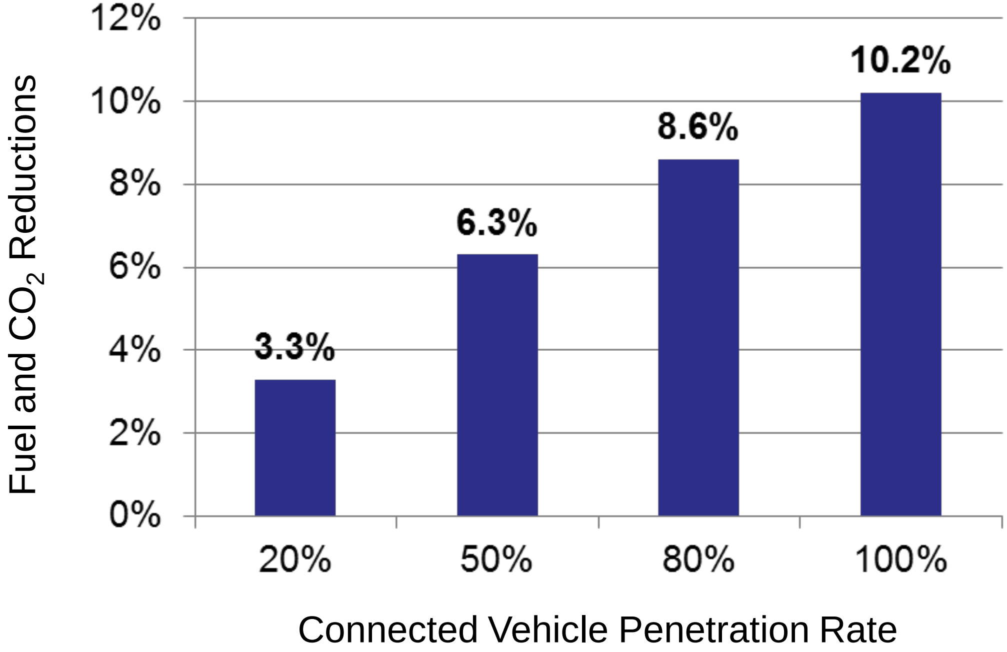
Eco-Signal Operations: Combined Modeling Results

- Results assume **100% connected vehicle penetration rate** for baseline traffic conditions (e.g., peak hour traffic) on El Camino Real
- Environmental improvements are presented as **improvements above baseline conditions (e.g., corridor with well coordinated signal timing plan)**



Key Takeaways from Combined Modeling

- Combined modeling of the Eco-Signal Operations application resulted in **10.2% reductions in fuel consumption and CO_2 over the baseline**
  - When the applications are combined, the total benefits are **NOT** simply the summation of benefits from each individual application
  - While the results were not additive, no application negated another application
- Combined modeling results indicate benefits at low penetration rates



Initial Takeaways

Free Flow Traffic Conditions → **Congested Traffic Conditions**

Arterials

- Eco-Approach & Departure
- Connected Eco-Driving

- Arterial Speed Harmonization *(partially modeled)*

- Eco-Traffic Signal Priority
- Eco-Traffic Signal Timing
- *Wireless Inductive / Resonance Charging (not modeled)*

Freeways

- Connected Eco-Driving

- Eco-Cooperative Adaptive Cruise Control
- Eco-Speed Harmonization
- *Eco-Ramp Metering (not modeled)*

- Eco-Lanes Management
- *Wireless Inductive / Resonance Charging (not modeled)*
- *Eco-Traveler Information Applications (not modeled)*

Cities

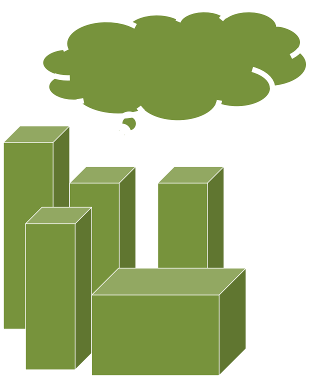
- Low Emissions Zones Management
- *Eco-Traveler Information Applications (not modeled)*
  - *Multi-modal Traveler Information (not modeled)*
  - *Eco-Smart Parking (not modeled)*
  - *Dynamic Eco-Routing (not modeled)*

When traffic conditions are severely congested, there are limited opportunities for Connected Vehicle Applications of all types to provide mobility or environmental benefits

Estimating 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.

Estimating User Benefits (Example)

- Assuming a corridor with average traffic congestion
  - Modeling results indicate for the combined modeling scenario provides roughly 10.2% reductions in CO_2 and fuel consumption
  - Light-duty vehicle, 24 mpg, gasoline costs $4.00/gallon
    - Unequipped vehicle spends $1 in fuel to traverse corridor
    - Equipped vehicle spends ~$0.90 in fuel to traverse the same corridor
  - Assuming a typical driver drives 8,000 miles/year on arterials *(Note: Average driver drives 16,000 miles per year on freeways and arterials)*
    - Light vehicle, 24 MPG, driver saves **~$136 per year**
    - Sport Utility Vehicle (SUV), 15 mpg, driver saves **~$217per year**
    - Fleet operator operating 1,000 mixed type vehicles, 15 mpg, driving 10,000 miles on arterials saves **~$272,000 per year**