AERIS
(Applications for the Environment: Real-Time Information Synthesis)
ConOps and Modeling Workshop: Day 1

Washington, D.C.
March 26th, 2013

“AERIS
“Cleaner Air Through Smarter Transportation”
WELCOME AND INTRODUCTIONS

MARCIA PINCUS, ITS-JPO
WORKSHOP OVERVIEW

MARcia PInCUS, ITS-JPO
Meeting Guidelines and Housekeeping

- **Webinar Participants**
  - Your input and questions are important to the AERIS Team.
  - Please type your questions/provide feedback using the webinar tool.
    - Questions will be addressed periodically throughout the workshop.

- **In-Person Attendees**
  - When asking questions or providing comments, please speak into a microphone so that our webinar participants can hear you.

- **Please Turn Your Cell Phones Off**

- **Lunch**

- **Restroom Locations**
91 Total Participants

40 attending in-person
51 participating on webinar

Who Is Here?
Why Are We Here?

- The objectives of the AERIS ConOps and Modeling Workshop are to:
  - Provide an update on the AERIS Program to the public.
  - Provide an overview of the content of three (3) Draft Concept of Operations (ConOps) documents:
    - Eco-Signal Operations
    - Dynamic Low Emissions Zones
    - Dynamic Eco-Lanes
  - Discuss the AERIS Transformative Concepts as they relate to emerging trends such as wireless charging, incentives for environmentally-friendly choices, and vehicle automation.
  - Begin detailed discussions on the plans for modeling and analysis of the AERIS Transformative Concepts.
Workshop Overview – Day 1

- Welcome, Introductions, and Workshop Overview
  Marcia Pincus, ITS-JPO 9:00 am to 9:10 am

- Connected Vehicle Research and AERIS Program Overview
  Bob Ferlis, FHWA 9:10 am to 9:30 am

- AERIS Transformative Concepts and Emerging Trends
  Marcia Pincus, ITS-JPO 9:30 am to 9:45 am

- Transit’s and Freight’s Roles in AERIS
  William Wiggins, FTA 9:45 am to 10:00 am
  Drennan Hicks, Noblis

- Break 10:00 am to 10:15 am

- AERIS Concept of Operations 101
  J.D. Schneeberger, Noblis 10:15 am to 10:30 am

- Eco-Signal Operations Concept of Operations
  J.D. Schneeberger, Noblis 10:30 am to 11:00 am
Workshop Overview – Day 1

- **Modeling and Analysis Plans 101**
  Balaji Yelchuru, Booz Allen Hamilton
  11:00 am to 11:15 am

- **Eco-Signal Operations Analysis Plan**
  Balaji Yelchuru, Booz Allen Hamilton
  11:15 am to 11:45 am

- **Lunch**
  11:45 am to 1:00 pm

- **Eco-Approach and Departure at Signalized Intersections Field Experiment and Initial Modeling Results**
  Matt Barth, UC-Riverside
  1:00 pm to 1:30 pm

- **Break-out Session #1**
  All – Facilitated Discussion
  1:30 pm to 3:00 pm

- **Break**
  3:00 pm to 3:15 pm

- **Break-out Session #1 Reports**
  All
  3:15 pm to 3:45 pm

- **Eco-Signal Operations Prototype Application Discussion**
  Marcia Pincus, ITS-JPO
  3:45 pm to 4:15 pm
Webinar Participants

- **Day 1 Webinar Times**
  - **9:00 am to 11:45 am**
    - AERIS Program Overview and Status Update
    - Transit’s and Freight’s Role in AERIS
    - AERIS ConOps 101
    - Eco-Signal Operations ConOps
    - Modeling and Analysis Plans 101
    - Eco-Signal Operations Analysis Plan
  - **1:00 pm to 1:30 pm**
    - Eco-Approach and Departure at Signalized Intersections Field Experiment and Initial Modeling Results
  - **3:00 pm to 4:30 pm**
    - Report back from breakout session and Eco-Approach and Departure Prototype Discussion

- **Day 2 Webinar Times**
  - **9:00 am to 10:15 am**
    - Dynamic Eco-Lanes ConOps
    - Dynamic Eco-Lanes Analysis Plan
  - **1:00 pm to 2:00 pm**
    - Dynamic Low Emissions Zones ConOps
    - Dynamic Low Emissions Zones Analysis Plan

**Questions**

- Please type in question in the Chat Box.
- Questions will be addressed periodically throughout the Workshop.
USDOT CONNECTED VEHICLE RESEARCH AND AERIS PROGRAM OVERVIEW

Bob Ferlis, FHWA
What is Connected Vehicle Research?

- Connected vehicle research addresses a suite of technologies and applications that use wireless communications to provide connectivity:
  - Among vehicles of all types
  - Among vehicles and a variety of roadway infrastructures
  - Among vehicles, infrastructure, and wireless consumer devices
Imagine: Connected Transportation
Connected Vehicle Technology – 5.9 GHz DSRC

- **What it is**
  - Wi-Fi radio adapted for vehicle environment
  - Inexpensive to produce in quantity
  - Original FCC spectrum allocation in 1999
  - FCC revised allocation in 2004 and 2006

- **How the technology works**
  - Messages transmitted 10 times/sec (300m range – line of sight)
    - Basic Safety Message: vehicle position, speed, heading, acceleration, size, brake system status, etc.
    - Privacy is protected (vehicle location is NOT recorded or tracked)

- **Benefits of DSRC technology compared to radar/laser technology**
  - Reduced price
  - Improved reliability → fewer false alarms
  - Increased performance → addresses more crash scenarios

- **Drawbacks of the technology**
  - Both vehicles need to be equipped to gain benefit
  - Requires security infrastructure

Source: USDOT
A Connected Vehicle (a networked computer on wheels)

Data Sent from the Vehicle

Real-time location, speed, acceleration, emissions, fuel consumption, and other vehicle diagnostics data

Improved Powertrain

More fuel efficient powertrain including: hybrids, electric vehicles, and other alternative power sources

Data Provided to the Vehicle

Real-time traffic information, safety messages, traffic signal messages, eco-speed limits, eco-routes, parking information, etc.
Today’s Transportation Challenges

Safety
- 32,367 highway deaths in 2011
- 5.3 million crashes in 2011
- Leading cause of death for ages 4, 11-27

Mobility
- 5.5 billion hours of travel delay
- $121 billion cost of urban congestion

Environment
- 2.9 billion gallons of wasted fuel
- 56 billion lbs of additional CO₂

Data Sources:
2011 Annual Urban Mobility Report, Texas Transportation Institute (Feb 2013)
Why Is the Environment Part of Connected Vehicle Research?

Surface transportation has a significant impact on the environment:

- Transport sector in the US accounts for 28% of GHG emissions and 70% of US petroleum consumption. Light duty vehicles and heavy trucks are the greatest fuel users in the transport sector.
- Surface vehicles represent almost 80% of the transport sector GHG in the US.

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

“Cleaner Air Through Smarter Transportation”
AERIS Research Objectives

- **Vision** | Cleaner Air through Smarter Transportation

- **Objectives** | Investigate whether it is possible and feasible to:
  - Generate/capture environmentally-relevant real-time transportation data (from vehicles and the system).
  - Use these environmental data to create actionable information that can be used by system users and operators to facilitate “green” transportation choices for all modes.
  - Identify connected vehicle applications that could provide environmental benefits.
  - Develop a prototype of an application to test its efficacy and usefulness.
  - Assess whether applications generate enough environmental benefits to justify further research investment by the USDOT.

TRANSFORMATIVE and INNOVATIVE
Basic Research Questions

Data

- What environmentally-relevant data is available, what is its quality, and how useful are these data with respect to the applications identified for analysis? (Data from all vehicle types, roadside sensors and handheld devices)

Information/Connectivity

- Is there a “Basic Environmental Message” similar to the safety message set? How can these data be transmitted effectively, how often, and among which actors, for an application to be effective?

Benefit

- What multimodal applications/strategies are available, or could be developed, (how) can they be modeled, and what are their expected benefits?
The AERIS Approach

**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

**Where we are today**

**5-year Program**
2 ½ Years into Research

“Cleaner Air Through Smarter Transportation”
Major AERIS Accomplishments

- **State-of-the-Practice Reports**
  - Application Assessment
    - Identified applications that have demonstrated environmental benefits through use of ITS technologies
  - Techniques for Evaluating the Environmental Impacts of ITS Deployment
    - Described methods of evaluating the benefits of AERIS applications
  - Behavioral and Activity-Based Modeling
    - Examined how behaviors may be influenced to reduce negative environmental impacts of surface transportation
  - Environmental Models
    - Identified types of Environmental Models to evaluate ITS strategies
  - Technology to Enable Environmental Data Acquisition
    - Assessed environmental models in representing various environmental measures for evaluating ITS strategies

All reports are available at: [http://www.its.dot.gov/aeris/index.htm](http://www.its.dot.gov/aeris/index.htm)
Major AERIS Accomplishments (cont’d)

- **Broad Agency Announcement (BAA) Projects**

  1. An Evaluation of Likely Environmental Benefits of Lowest Fuel Consumption Route Guidance in the Buffalo-Niagara Metropolitan Area | University at Buffalo
  2. Developing and Evaluating Intelligent Eco-Drive Applications | Virginia Tech
  3. Eco-Speed Control Using V2I Communication | Virginia Tech
  4. Preliminary System Development Plan for an AERIS Data Capture and Management System | Mixon Hill
  5. Eco-ITS | University of California at Riverside (UCR)
  6. Assessment, Fusion, and Modeling of Commercial Vehicle Engine Control Unit Data | Calmar Telematics and UCR
  7. Engaging the International Community | University of California Partners for Advanced Transit and Highways (PATH) Program
Major Accomplishments *(cont’d)*

- **Identification of AERIS Transformative Concepts and Applications**
  - Identified six (6) Transformative Concepts (or strategic groupings of applications) and eighteen (18) applications.

- **Initial Benefit Cost Analysis (BCA)**
  - **Purpose**
    - Documented the potential magnitude of benefits that can be expected from AERIS applications.
    - Results were used to prioritize applications for the modeling phase.
  - **Key Findings**
    - The magnitude of benefits realized is very sensitive to the compliance rate.
    - Applications that generate benefits on a vehicle miles traveled (VMT) basis (e.g., eco-driving) have highest overall benefits.
    - Applications may have significant local/regional benefits; however, they do not provide substantial nationwide benefits.
  - **Other Considerations Raised**
    - The role of dedicated short range communication (DSRC) vs. cellular communication and the implications for deployment.
    - Agencies may not turn on applications all the time; e.g., eco-speed harmonization may be activated during code red air quality days.
Next Steps

- **Concept of Operations (In Progress)**
  - Eco-Signal Operations
  - Dynamic Low Emissions Zones
  - Dynamic Eco-Lanes

- **Analysis Plans (In Progress)**
  - Eco-Signal Operations
  - Dynamic Low Emissions Zones
  - Dynamic Eco-Lanes

- **Modeling and Analysis (present through 2014)**
  - Initial Modeling of AERIS Applications
    - Eco-Approach and Departure at Signalized Intersections - Underway
    - Eco-Transit Signal Priority – starting shortly

- **Final Report and Recommendations**
How to Stay Involved?

- **AERIS Program Website:** [http://www.its.dot.gov/aeris/index.htm](http://www.its.dot.gov/aeris/index.htm)
  - Program Overview, Roadmap, News, Published Reports, and Contact Information

- **AERIS IdeaScale Site:** [https://aeris.ideascale.com](https://aeris.ideascale.com)
  - Crowdsourcing site allowing users to join an online dialogue on connected vehicle environmental research

- **AERIS Webinars**
  - Past webinars focused on:
    - State of the Practice Reports
    - Broad Agency Announcement (BAA) Projects
    - AERIS Benefit Cost Analysis (BCA)
    - AERIS Concepts of Operations
      - Eco-Signal Operations
      - Dynamic Eco-Lanes
      - Dynamic Low Emissions Zones

- **AERIS Workshops**
  - In-person meetings to provide an update on the AERIS Program and solicit stakeholder inputs/feedback on AERIS research
QUESTIONS?
AERIS TRANSFORMATIVE CONCEPTS

MARCIA PINCUS, ITS-JPO
AERIS TRANSFORMATIVE CONCEPTS

Cleaner Air Through Smarter Transportation

Arterial Data Environments
- Performance Measures
- Eco-Approach & Departure at Signalized Int.
- Connected Eco-Driving

Freeway Data Environments
- Performance Measures
- Dynamic Eco-Transit Routing
- Connected Eco-Driving

Corridor (Control) Data Environments
- Performance Measures
- Engine Performance Optimization
- Multi-Modal Traveler Information

Regional (Info) Data Environments
- Performance Measures
- AFV Charging / Fueling Information
- Engine Performance Optimization

Dynamic Low Emissions Zones
- Performance Measures
- Dynamic Emissions Pricing
- Multi-Modal Traveler Information

Eco-Integrated Corridor Management (E-ICM)
- Performance Measures
- Dynamic Eco-Lanes Apps
- Eco Signal Support System
- Eco-Traveler Information Apps

LEGEND
- AERIS Application
- Applications Supported with AERIS Data (R&D by Others)
- Performance Measures
- Regulatory / Policy Tool
- Educational Tool
Eco-Signal Operations

- **Similar to today’s ITS:** adaptive traffic signal systems and traffic signal priority applications

- **Imagine tomorrow’s connected vehicle applications:**
  - Broadcasting signal phase and timing (SPaT) data to vehicles where in-vehicle systems perform calculations to provide speed advice to the driver of the vehicle, to reduce queuing, starts, stops, idling, and to support speed management.
  - Traffic signal systems optimized for the environment using data collected from vehicles, such as vehicle location, speed, GHG and other emissions data using connected vehicle technologies.
  - Transit signal priority (TSP) based on vehicle emissions, transit vehicle occupancy, and schedule adherence.
  - Wireless (inductive) charging infrastructure embedded in the roadway at the stop bar enabling electric vehicles to charge while stopped at a traffic light.
Dynamic Eco-Lanes

- **Similar to today’s ITS:** managed lanes (e.g., HOV and HOT lanes)

- **Imagine tomorrow’s connected vehicle applications:**
  - Dedicated eco-lanes optimized for the environment that encourage use by low emission, high occupancy, freight, transit, and alternative fuel or regular vehicles operating in eco-friendly ways.
  - Dynamic parameters including the location and duration of the lanes, and types of vehicles permitted to use the lanes.
  - Speed optimized for the environment based on data collected from vehicles. Speed optimization would be implemented to help reduce unnecessary vehicle stops and starts by maintaining consistent speeds, thus reducing GHG and other emissions.
  - Eco-cooperative adaptive cruise control (eco-CACC) and vehicle platooning where individual drivers may elect to opt-into applications that provide cruise control capabilities designed to minimize vehicle accelerations and decelerations for the benefit of reducing fuel consumption and vehicle emissions.
  - Wireless (inductive) charging infrastructure embedded in the roadway that charges electric vehicles moving at highway speeds.
Dynamic Low Emissions Zones

- **Similar to today’s ITS:** cordons with fixed infrastructure (e.g., London’s Congestion Pricing)

- **Imagine tomorrow’s connected vehicle applications:**
  - Geo-fencing low emission zone boundaries with flexible parameters.
  - Connected vehicle technology allowing for Low Emissions Zones that can be:
    - Scalable and moveable (e.g., pop-up for a day or special event, removable, flexible)
    - Not dependent on conventional ITS infrastructure.
    - Dynamic based on real-time emissions data collected from vehicles and other sources.
  - Dynamic Low Emissions Zones that provide incentives to drivers who practice “eco-driving” within the Low Emissions Zone.
  - Dynamic Low Emissions Zones that encourage “green” transportation choices, including transit options and freight operations.
Support Alternative Fuel Vehicle Operations

- **Similar to today’s ITS:** hybrid vehicle engine optimization, electric vehicle charging

- **Imagine tomorrow’s connected vehicle applications:**
  - Applications that enhance engine performance in real-time based on vehicle, weather and external factors. This includes an AFV:
    - Switching power sources as it approaches an Eco-Lane or Low Emissions Zone
    - Turning off its engine as it waits at a red light at a traffic signal upon communication from a traffic signal
  - Applications that provide users with information about the locations of charging/fueling stations and allow users to make reservations from their vehicles based on traffic conditions and distance to the station.
  - Infrastructure embedded in the roadway that enables wireless (inductive) charging of electric vehicles including cars, trucks, and buses.
    - 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
    - Charging electric vehicles moving at highway speeds
  - Applications that dramatically reduce range anxiety for drivers of electric vehicles and technologies that allow electric vehicles to be less dependent on fixed infrastructure.
Eco-Traveler Information

- **Similar to today’s ITS:** 511 and traveler information websites, navigation systems, and traffic related phone applications

- **Imagine tomorrow’s connected vehicle applications:**
  - Applications that provide instantaneous feedback on driver behavior to encourage more environmentally efficient driving and incentivize their behavior.
  - Dynamic Eco-Routing that uses real-time data collected from vehicles to provide drivers with the eco-route that is updated in real-time during the driver’s trip. Special cases may also apply to transit and freight.
  - Multimodal Real-Time Traveler Information applications that convey real-time pre-trip and en-route information to encourage green choices.
  - Smart Parking applications targeted at providing real-time parking information to reduce unnecessary emissions and fuel consumption searching for a parking space.
  - New paradigms for car sharing and car ownership.
Eco-Integrated Corridor Management

- **Similar to today’s ITS**: Integrated Corridor Management for mobility

- **Imagine tomorrow’s connected vehicle applications**: Partners from various transportation modes working together to achieve the maximum environmental benefit for the entire transportation system.
  - A Code Red Air Quality Day where a “switch” is flipped that maximizes operations within an entire corridor or region to achieve a maximum environmental benefit **on that day**.
    - Traffic signals could be optimized to reduce emissions
    - Speed limits on the highways could be changed to eco-speed limits
    - Fare structures could be changed to encourage transit usage
    - Low Emissions Zones could pop up
    - More lane conversions to eco-lanes
    - Higher incentives for eco-behavior
Emerging Trends

Autonomous Vehicles

Smart Cities / Digital Society
The “Internet of Things”

Big Data

Sharing Economy / Collaborative Consumption
Crowdsourcing and “Gamification”

Incentivizing and Opting-In

Standards-based Subscriber Services

Transportation and Millennials

Wireless Charging

Transportation as a Service and New Models for Car Ownership
The US Department of Energy (DOE) instituted a challenge for improving safety and fuel efficiency through data innovation.

- Open data from OBD-II port provided to application developers (i.e., general public) by the DOE and challenge supporters.

Phase I of the challenge cast a wide net to gather compelling ideas, business plans, product development plans, and very-early-stage products.
Apps for Vehicles Challenge

1. **Dash Labs**
   - Turns any vehicle into a “smart car” by providing real diagnostics and alerts, enabling the driver to maximize engine performance, minimize carbon emissions, and save money.

2. **Moj.io (mo-jee-o)**
   - The cloud-connecting cars with a cellular device that lets apps on smart phones talk to virtually any car. Moj.io seeks to be the first open platform for car applications.

3. **VELOcar™**
   - By competitively comparing your improved driving habits to your peers, you can have a safer, cheaper and more environmentally friendly driving experience.

4. **Green Button Gamer**
   - This Driver Challenge is a merger of social apps and “gamification,” enabling a user with a platform that lets them save energy and become a safer driver.
Apps for Vehicles Challenge (cont’d)

5. Fuel Economy Coach
   Not only will this app show your actual fuel efficiency, as opposed to manufacturer’s advertisement, it will also provide custom recommendations to save money.

6. Drive5
   This app makes feedback available to any driver, anywhere, and is based on 5 key metrics: real-time MPG, social energy feedback, route comparisons, average MPG and overall performance score.

7. MyCarma
   A fuel economy sticker that’s completely based on you, allowing individuals purchasing a new car to predict fuel consumption based on their unique driving patterns.
TRANSIT’S ROLE IN AERIS

WILLIAM WIGGINS, FTA
Eco-Signal Operations | Transit Benefits

- **Eco-Approach and Departure at Signalized Intersections**
  - Transit vehicles receive signal phase and timing (SPaT) data and geographic information descriptions (GIDs) using vehicle-to-infrastructure (V2I) communications.
  - Drivers of transit vehicles are provided with eco-driving recommendations as the transit vehicle approaches or departs a signalized intersection.
  - Eco-driving recommendations allow transit vehicles to:
    - Ride the “green wave” or avoid stopping at red lights.
    - Decelerate to a stop in the most environmentally efficient manner.
    - Use engine stop-start technologies when a vehicle is stopped at a red light.
    - Charge their electric batteries using wireless charging while the transit vehicle is stopped at a red light.
Eco-Signal Operations | Transit Benefits (cont’d)

- In 2007, Research and Innovative Technology Administration (RITA) reported that TSP can reduce bus running time by 2% to 18%.
  - This reduction in running time can decrease fuel consumption between 208 and 1,872 gallons per year (per bus).
  - With this reduction in fuel consumption, a bus emits between 2 and 20 metric tons less of CO$_2$ (assuming diesel engine buses).

- On average, for every 1,000 miles traveled in a private automobile that has been displaced by bus travel, up to 0.18 metric tons of CO$_2$ are prevented from being emitted into the environment.

Imagine TSP using connected vehicle technologies:

- Signal priority decisions based on real-time traffic and environmental data collected from vehicles using V2I communications that minimize emissions at the intersection.
- TSP decisions that consider the number of passengers on the transit vehicle, the transit vehicle’s adherence to its schedule, and vehicle types and emissions.

Dynamic Low Emissions Zones | Transit Benefits

Transit is critical to the success of a Low Emissions Zone

- Dynamic Low Emissions Zones would support the following transit strategies:
  - Fees waived for transit vehicles entering the Low Emissions Zone.
  - Enhancements to transit service funded by fees from the Low Emissions Zone.
  - Real-time transit information based on connected vehicle technologies provided to travelers.
  - Flexible transit service based on traveler demands collected from handheld devices and conveyed to transit vehicles using connected vehicle technologies.
  - Incentives provided to transit travelers that would allow the traveler to receive fare reductions for future transit trips.

- Case Studies:
  - London’s Congestion Charging Zone went into effect February 2003 and bus ridership increased 37% between fall 2002 and fall 2003.
    - In 2009, there was an estimated 6% increase in bus ridership.
    - Mode split: 40% of weekday inner London trips via public transportation; 31% via walking; 29% via private vehicle.
  - Stockholm Sweden’s Congestion Charging Zone:
    - There was an estimated 6% to 9% increase in bus ridership during this period
    - Mode Split: Originally 75% transit on-peak; 34% car and 41% transit off-peak; transit split increased 4.5% due to congestion charge.
Dynamic Eco-Lanes | Transit Benefits

- The Dynamic Eco-Lanes Transformative Concept supports:
  - **Enhanced transit service for Code Red Air Quality Days and special events**
  - **Dynamic Wireless Charging**
  - **Transit Vehicle Platooning**
    - Allows transit vehicles to travel at small headways, improving operational efficiency, reducing drag and vehicle emissions
    - Allows for the creation of “articulated buses” at will.
  - **Eco-Cooperative Adaptive Cruise Control**
    - Allows transit vehicles to receive data from nearby vehicles using V2V communications and real-time traffic conditions from TMCs using V2I communications to support eco-driving strategies.

Source: Tappan Zee Bridge/I-287 Environmental Review
Source: California PATH
Support for AFV Operations | Transit Benefits

- Static wireless charging infrastructure embedded in the roadway may be deployed at:
  - Bus Stops
  - Signalized intersections
  - Bus Garages

- Dynamic wireless charging infrastructure allows electric transit vehicles to charge their batteries when the vehicle is in motion.

- Wireless charging allows transit vehicles to be less dependent on fixed charging infrastructure, and allows transit vehicles to travel greater distances.

How Wireless Charging Works

- Wireless charging uses an electromagnetic field to transfer energy between two objects.
- Energy is sent through an inductive coupling to an electrical device, which can use the energy to charge batteries or run the device.
- Energy may be transferred from the vehicle back to the Smart Grid.

Source: Federal Transit Administration (FTA)
Eco-Traveler Information | Transit Benefits

- **Multi-Modal Traveler Information Applications**
  - Provide travelers with real-time transit options comparing the environmental footprint of using transit to other travel modes (e.g., private vehicles) based on connected vehicle data.
  - Support flexible, demand responsive transit service leveraging connected vehicle technologies (e.g., passenger requests for transit from handheld devices).
  - Provide real-time transit information (e.g., bus arrival times) collected from transit vehicles equipped with connected vehicle technologies.

- **Connected Eco-Driving Applications**
  - Consider data collected from nearby vehicles using V2V communications, real-time traffic conditions, and road grade information to provide eco-driving recommendations.
    - Eco-driving recommendations have the potential to reduce vehicle emissions by 3% to 15%.
    - Eco-driving saves fuel, helping to reduce transit agency operating costs.

- **Eco-Routing Applications**
  - May be suitable for long-distance (e.g., commuter) transit service.
  - Provide drivers of transit vehicles with real-time eco-routing information based on data collected from vehicles equipped with connected vehicle technologies.
  - When eco-routing applications are combined with eco-driving applications, they have the potential to deliver up to a 20% reduction in fuel consumption and emissions.
FREIGHT’S ROLE IN AERIS

DRENNAN HICKS, NOBLIS
Freight GHG Emissions and Reduction Strategies

- Freight GHG emissions grew at a rate three times that of passenger GHG emissions between 1990 and 2008. This trend is expected to continue.¹

- Many technologies and operational strategies exist to reduce freight GHG emissions. Many relate to AERIS Applications including²:
  - Anti-idling programs
  - Truck stop electrification
  - Speed limit enforcement
  - Freight villages/consolidation centers
  - Traffic flow improvements
  - Pre-clearances at scale houses
  - Truck driver eco-training
  - Incentives to retire older trucks
  - Shifting freight from truck to rail
  - Hybrid power trucks

- With expected growth in freight VMT other strategies need to be investigated.

² NCHRP 20-24(59), Appendix C, on AASHTO “Real Solutions” website
Dynamic Eco-Lanes | Freight Benefits

- The Dynamic Eco-Lanes Transformative Concept supports:
  - **Dedicated e-corridors for freight vehicles**
    - Siemens’ eHighway concept proposed on I-710 near the Port of Los Angeles and the Port of Long Beach.
    - The Concept leverages a catenary system and diesel-hybrid electric vehicles.
  - **Dynamic Wireless Charging**
  - **Wireless Inspections**
    - Pre-clearance using V2I communications can reduce idling at truck inspections.
  - **Truck Platooning**
    - According to PATH research, truck platooning reduces aerodynamic drag, resulting in the fuel and carbon emissions savings between 10% and 20% for trucks cruising at highway speeds.

Source: Siemens [www.mobility.siemens.com](http://www.mobility.siemens.com)

The Dynamic Low Emissions Zone must support freight since the movement of goods is important to the economic vitality of a city/region.

Dynamic Low Emissions Zone may deter many high emitting freight vehicles from entering the zone (e.g., London’s Low Emissions Zone includes strict standards for lorries).

Dynamic Low Emissions Zone may support freight operations by providing incentives to trucking companies for:

- Off-peak delivery (or implementing a surcharge for peak-hour delivery)
- Retiring older, high emitting vehicles

Freight Villages/Consolidation Centers may be set-up outside of the Low Emissions Zone allowing goods to be transferred to more energy efficient vehicles (e.g., electric trucks, rail, etc.).

Ports may be excellent candidates for implementing Low Emissions Zones.
Eco-Traveler Information | Freight Benefits

- Dynamic Eco-Routing Applications
  - Allow truck drivers to receive dynamic eco-routing information that considers road grade and real-time traffic conditions.

- Eco-Driving Applications
  - Many trucking companies understand the benefits of eco-driving and are implementing training and incentives to drivers.
    - Scania Group, a truck retailer in Sweden, developed an in-vehicle eco-driving system called Scania Driver Support.
      - The system gives truck drivers real-time feedback and tips to help improve their driving with the goal of improving truck fuel economy.
      - Drivers were able to reduce their fuel consumption 5% to 20% – even experienced drivers significantly decreased consumption.
    - Eco-driving applications may include ‘anti-idling’ components that shut off the vehicles engine when idling for extended periods of time.

- Truck Parking Applications
  - Providing real-time parking information to truck drivers, using V2I communications, that help reduce unnecessary driving/emissions searching for a parking space.
Eco-Signal Operations | Freight Benefits

- Trucks will receive benefits from improved traffic signal timing applications and Eco-Approach and Departure at Signalized Intersections application.

- **Freight Signal Priority**
  - Provides priority to a traffic signal approach when trucks are detected.
  - Truck characteristics (e.g., truck size, weight, etc.) may be communicated to the traffic signal using V2I communications to support priority decisions.
  - May be used as a strategy to encourage trucks to use specific routes.
  - By implementing Freight Signal Priority, the following benefits may be achieved:
    - Reduction in truck travel times and consequently the cost of goods movement.
    - Improved safety resulting from reducing the number of stops by trucks approaching the intersection at the end of the green phase, which may reduce red light running.
    - Positive effect on emissions by reducing the number of stops by trucks, although freight signal priority may result in more stops for other vehicles.
Support for AFV Operations | Freight Benefits

- **Wireless (Inductive) Charging**
  - Static wireless charging infrastructure embedded in the roadway may be deployed at:
    - Unloading zones
    - Signalized intersections
    - Truck parking spaces
  - Dynamic wireless charging infrastructure allows electric freight vehicles to charge their batteries when the vehicle is in motion.
  - Wireless charging allows trucks to be less dependent on fixed charging infrastructure, and allows trucks to travel greater distances.

- **Truck Stop Electrification** *(for AFVs and non-AFVs)* **equipped with electric vehicle charging stations**
  - Electrical hook-ups can provide power for heating, cooling, and other needs.
  - Particularly beneficial at overnight rest stop locations.
  - According to the Climate Trust and Argonne National Laboratory, truck stop electrification could save nearly 90,000 metric tons of CO₂ each year.

Source: IdleAire
http://www.knoxnews.com
BREAK
Concept of Operations (ConOps)

- Provides an operational description of “how” the Transformative Concept may operate.
- Builds consensus among AERIS user groups and stakeholders concerning needs and expectations of:
  - USDOT
  - State and Local Departments of Transportation (DOTs)
  - Regional Planning Organizations
  - The Automotive Industry
  - ITS Developers, Integrators, and Researchers
- Serves as a guideline moving forward with research and development of AERIS applications.

AERIS Concepts of Operations are intended to be a blueprint describing the Transformative Concepts so all stakeholders can understand how they may work.
Conceptual Representation of a ConOps

Support Environment

What?
Where?
When?
Who?
Why?
How?

Operational
System

Facilitates Communication Among Interdisciplinary Team Members

Customer
Maintainers
Planners

View Point

View Point

View Point

View Point

View Point

View Point

View Point

Manager

System Engineers

View Point

View Point

View Point

Testers

View Point

View Point

View Point

Designers

Note: Graphic adapted from ANSI/AIAA’s “Guide for the Preparation of Operational Concept Documents” ANSI/AIAA G-043-1992)
The Systems Engineering Life-Cycle Process
AERIS Concept of Operations

- At this time, the AERIS Program is not planning to build a system.

- AERIS Concept of Operations documents are intended to convey “transformational ideas” that will be modeled to show the potential environmental benefits that can be achieved through connected vehicle applications.

- AERIS Concept of Operations are “generalized” and not specific to:
  - Geographic area
  - Operating entity (e.g., state or local DOT)
  - Existing systems that may be in place
AERIS Concept of Operations Approach

Step 1: Define Current Systems

Step 2: Identify Limitations of Existing Systems and Justification for Change

Step 3: Define the Systems and Relationships to External Actors

Step 4: Define User Needs / Desired Capabilities for the Systems

Step 5: Develop Operational Scenarios
Existing Systems and Limitations of Current Systems

▪ **Current Systems and their Environmental Benefits**
  ▪ Describes the system or situation as it currently exists.
  ▪ Provides an introduction to the problem, enabling readers to better understand the reasons for the desired changes and improvements.
  ▪ Identifies conventional ITS strategies and documents examples of the environmental benefits these strategies have been able to achieve.

▪ **Identify Limitations of Current Systems**
  ▪ Describes the shortcomings of the current system or situation that motivate development of a new system or modification of an existing system.
  ▪ Provides a transition from sections of the ConOps describing the current system or situation, to sections of the ConOps describing the proposed system.
  ▪ Focuses on justifying the need for connected vehicle applications (i.e., how connected vehicle applications overcome the limitations of current systems).
Defining the System and Actors

EXAMPLES OF ACTORS

Connected Vehicle Related Actors
- Connected Vehicle Roadway Equipment
- Connected Vehicle Core System
- Inductive Charging Roadway Equipment
- Vulnerable Road User

Vehicle Related Actors
- Driver
- Vehicle Diagnostic System
- Vehicle Actuators
- On-Board Sensors

ITS Related Actors
- Traffic Management Center
- Emissions Management Center
- Enforcement Agencies
- Information Service Providers (ISPs)
- ITS Roadway Equipment
- TMC Operator

Actors and their definitions were adapted from the National ITS Architecture
Defining the System

**Back-Office System**
- Most likely resides in a Traffic Management Center
- Developed by state and local DOTs and ITS developers
- Integrated with existing ITS systems (i.e., Advanced Traffic Management System (ATMS) operating platforms)
- Collect V2I messages (e.g., probe messages and environmental messages)
- Processes connected vehicle and ‘conventional’ data
- Disseminates traveler information messages
- Implements operational strategies (e.g., traffic signal timing plans, eco-speed limits, etc.)

**In-Vehicle System**
- Resides in the vehicle
- Developed by automobile OEMs or aftermarket device vendors.
- Collects vehicle diagnostics data, V2V, and I2V messages
- Provides V2V messages to other vehicles
- Provides V2I messages to Connected Vehicle Roadway Equipment
- Implement eco-driving strategies (e.g., eco-approach to a traffic signal, Cooperative-Adaptive Cruise Control (CACC), etc.)
Defining the System

ACTORS THAT PROVIDE INPUTS

Actor
Actor
Actor

SYSTEM

ACTORS THAT RECEIVE OUTPUTS

Actor
Actor
Actor
Defining Subsystems

ACTORS THAT PROVIDE INPUTS

SYSTEM

ACTORS THAT RECEIVE OUTPUTS

Data Collection Elements
- Subsystem
- Subsystem
- Subsystem

Data Processing Elements
- Subsystem
- Subsystem
- Subsystem

Data Dissemination Elements
- Subsystem
- Subsystem
- Subsystem

Data Storage Archive Elements

"Cleaner Air Through Smarter Transportation"
### Needs and Desired Capabilities

<table>
<thead>
<tr>
<th>Element</th>
<th>Subsystem</th>
<th>ID</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Collection</td>
<td>Traffic Data Collection Subsystem</td>
<td>DELS-DC-01</td>
<td>Collect Traffic Data</td>
<td>The Dynamic Eco-Lanes System needs to collect traffic data (e.g., volume, speed, occupancy, vehicle classification, incidents) for eco-lanes and regular lanes. Traffic data may be obtained from traffic sensors that detect the presence of vehicles at locations along the network (e.g. using traffic sensors) or directly from messages collected from vehicles that measure a vehicle’s speed, location, and other parameters. Finally, traffic data may be collected from other centers and Information Service Providers (ISPs). This information may also include lane closures due to construction or maintenance activities. Traffic data needs to be processed and then used as input to algorithms that determine whether traffic conditions support the imposition or cessation of an eco-lane. Traffic data also need to be processed and then used as input to algorithms that determine operational strategies for eco-speed limits, ramp metering, and dynamic merging. Traffic data may also be processed for dissemination of current or predicted traffic conditions to travelers.</td>
</tr>
</tbody>
</table>

---

“Cleaner Air Through Smarter Transportation”
Operational Scenarios

- **AERIS Operational Scenarios**
  - Provide a step-by-step description of how the proposed system should operate and interact with its actors in a fully deployed connected vehicle environment.
  - Use storyboards to walk through the AERIS Transformative Concepts and applications allowing readers to gain an understanding of how the proposed systems will function.
  - Tie together all parts of the system, the actors, and other entities by describing how they interact.
  - Support the development of simulation models that will be used to show the potential benefits of the AERIS Transformative Concepts.
### Eco-Approach and Departure at Signalized Intersections

**Step 1**
The traffic signal controller sends the traffic signal’s current SPaT data to the Connected Vehicle Roadway Equipment. Which converts the data to a SAE J2735 SPaT message.

**Step 2**
The Eco-Traffic Signal System sends traffic conditions data to the Connected Vehicle Roadway Equipment, including average speeds, queues at the stop bar, and incidents along the roadway. The Eco-Traffic Signal System also sends GIDs to the Connected Vehicle Roadway Equipment describing the static physical geometry of one or more intersections.

**Step 3**
The Connected Vehicle Roadway Equipment broadcasts SPaT, GID, and traffic condition messages. SPaT messages are broadcasted 10 times per second.

**Step 4**
Other Vehicles broadcast vehicle status messages including the vehicle’s location, motion (e.g., heading and acceleration), braking status, size, and vehicle type.

**Step 5**
The In-Vehicle System collects data and determines the vehicle’s optimal trajectory (e.g., speed, acceleration, and braking) as the vehicle approaches or departs from the signalized intersection.

- The application first attempts to identify a speed for the vehicle to traverse the intersection during a green light.
- If the application determines that the vehicle cannot traverse the intersection on a green light, it determines a strategy for the vehicle to decelerate to the intersection in the most environmentally efficient manner.
- If the vehicle is stopped or slows down, the application will recommend the most environmentally efficient acceleration as the vehicle departs from the intersection.
- Finally, if stopped, the application automatically shuts down and restarts the vehicle’s engine reducing the amount of time the engine spends idling, thereby reducing fuel consumption and emissions.
QUESTIONS?
ECO-SIGNAL OPERATIONS CONOPS
J.D. SCHNEEBERGER, NOBLIS
Eco-Signal Operations

- **Similar to today’s ITS**: adaptive traffic signal systems and traffic signal priority applications

- **Imagine tomorrow’s connected vehicle applications:**
  - Broadcasting signal phase and timing (SPaT) data to vehicles where in-vehicle systems perform calculations to provide speed advice to the driver of the vehicle, to reduce queuing, starts, stops, idling, and to support speed management.
  - Traffic signal systems optimized for the environment using data collected from vehicles, such as vehicle location, speed, GHG and other emissions data using connected vehicle technologies.
  - Transit signal priority based on vehicle emissions, transit vehicle occupancy, and schedule adherence.
  - Wireless (inductive) charging infrastructure embedded in the roadway at the stop bar enabling electric vehicles to charge while stopped at a traffic light.
Traffic Signal Operations

- **Fixed Timed Operation**
  - Does not require traffic detectors at the intersection
  - Includes a set programmed time to service all movements every cycle
  - Services all movements whether or not there is vehicle demand
  - Assumes that the traffic patterns can be predicted based on time of day

- **Actuated Operation (Semi-Actuated or Fully Actuated)**
  - Consists of actuated traffic signal controllers and traffic detectors placed in or on the roadways approaching the intersection
  - Primarily concerned with when green intervals terminate
    - Maximum Green Time
    - Traffic Flow Ceases on the Approach
    - Force-off by the Signal System
    - Traffic Signal Pre-emption

- **Adaptive Signal Operation**
  - Consists of adaptive traffic control system and traffic detectors placed in or on the roadways approaching the intersection
  - Coordinates control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions
Exiting Central Control Systems

Dynamic Message Signs

Traffic Signal Head

INCIDENT AHEAD
EXIT 56
EXPECT DELAYS

Video Surveillance

Traffic Controller and Cabinet

Traffic Detectors

Communications

Central Control System
Environmental Benefits from Current Systems

- The 2007 National Traffic Signal Report Card estimated that “updating signal timing costs less than $3,000 per intersection,” can reduce emissions up to 22%, and has a high return on investment.

- A number of traffic **signal coordination** projects in the United States have documented emissions savings. Some examples include:
  - **Syracuse, New York** | The implementation of traffic signal coordination reduced emissions by 9% to 13%, reduced delays by 14% to 19%, and increased the average speed by 7% to 17%.
  - **St. Augustine, Texas** | Traffic signal coordination resulted in a savings of 26,000 gallons of fuel, reduced delays by 36%, and saved $1.1 million.
  - **Los Angeles, California** | Emissions reductions of 14% and a reduction of fuel by 13% were achieved by implementing traffic signal coordination.
  - **Oakland County, Michigan** | The County’s traffic signal coordination project reduced CO by 1.7% to 2.5%, NOx by 1.9% to 3.5%, and reduced fuel consumption by 2.7% to 4.2%.
Environmental Benefits from Current Systems

- **Adaptive Signal Operations**
  - **Tucson, Arizona** | Models indicated adaptive signal control could decrease delay for travelers on the main street by 18.5% while decreasing delay for travelers on cross-streets by 28.4%.
  - **Los Angeles, California** | Adaptive signal control systems improved travel time by 13%, decreased stops by 31%, and reduced delay by 21%.
  - **The University of Virginia** | Simulation study found that adaptive signal control reduced delay by 18% to 20% when compared to fixed-time signal control.
  - **Lee’s Summit, Missouri** | An adaptive traffic signal system was implemented on a 2.5-mile arterial with 12 signals.
    - Emissions either increased or decreased depending on whether or not the signal favored the direction of travel.
      - When traveling in the direction favored by the signal, emissions decreased.
      - When traveling in the direction not favored by the signal, emissions ranged from an increase of 9% to a decrease of 50%.
Limitations of Current Systems

1. Limitations exists with the data collected from infrastructure-based sensors
2. Do not collect and use (or collect minimal) environmental data
3. Emissions data are not collected from vehicles
4. The majority of traffic signal systems are not optimized in “real-time”
5. Adaptive traffic signal systems require an extensive amount of detectors
6. Current traffic signal systems are optimized for mobility, not the environment
7. Current traffic signal priority applications do not consider environmental impacts
8. Current traffic signal systems do not provide information to drivers to support eco-driving
9. Electric vehicles are not capable of charging their batteries as they wait at signalized intersections
Defining the System

ECO-TRAFFIC SIGNAL SYSTEM

- Resides in the vehicle
- Developed by automobile OEMs or aftermarket device vendors
- Collects vehicle diagnostics data, V2V, and V2I messages
- Provides V2V messages to other vehicles
- Provides V2I messages to Connected Vehicle Roadway Equipment
- Implements eco-driving strategies (e.g., eco-approach to a traffic signal)

IN-VEHICLE SYSTEM

- Most likely resides in a Traffic Management Center
- Developed by state and local DOTs and ITS developers
- Integrated with existing ITS systems (i.e., Traffic Signal System operating platforms)
- Collect V2I messages (e.g., probe messages and environmental messages)
- Processes connected vehicle and ‘conventional’ data
- Implements operational strategies (e.g., traffic signal timing plans, eco-speed limits, etc.)
- Provides traffic conditions, environmental conditions, and GID messages to Roadside Equipment

Back-Office System

In-Vehicle System
Eco-Traffic Signal System

- Similar to current traffic signal systems, but uses connected vehicle technologies to help optimize traffic signals for the environment. The system:
  2. Processes these data to develop operational strategies at signalized intersections, focused on reducing fuel consumption and overall emissions at the intersection, along a corridor, or for a region.
  3. Evaluates traffic and environmental parameters at each intersection every cycle in real-time and adapts to fluctuating traffic and environmental conditions through its optimization algorithm.
  4. Readily adapts signal control to actual traffic volumes and environmental conditions so that the traffic network operation is optimized using available green time to serve the actual traffic demands while minimizing the environmental impact.
  5. Supports eco-traffic signal priority.
Eco-Signal Operations Needs

**ECO-TRAFFIC SIGNAL SYSTEM**

### Data Collection Element
1. ETSS-DC-01: Traffic Signal Priority Requests
2. ETSS-DC-02: Collect Traffic Data
3. ETSS-DC-03: Collect Environmental Data
4. ETSS-DC-04: Collect Traffic Signal Operational Status Data
5. ETSS-DC-05: Collect GIID Data
6. ETSS-DC-06: Collect Operator Input

### Data Processing Element
1. ETSS-DP-01: Process Traffic Data
2. ETSS-DP-02: Generate Predicted Traffic Conditions
3. ETSS-DP-03: Process Environmental Data
4. ETSS-DP-04: Generate Predicted Environmental Data
5. ETSS-DP-05: Provide Traffic Signal Priority Decision Support Capabilities
6. ETSS-DP-06: Generate Traffic Signal Timing Strategy

### Data Dissemination Element
1. ETSS-D-01: Disseminate Traffic Signal Priority Data
2. ETSS-D-02: Disseminate Traffic Information to Other Centers
3. ETSS-D-03: Disseminate Traffic Conditions to Vehicles
4. ETSS-D-04: Disseminate Environmental Conditions to Other Centers
5. ETSS-D-05: Disseminate Environmental Conditions to Vehicles
6. ETSS-D-06: Disseminate Traffic Signal Timing Plans
7. ETSS-D-07: Disseminate Geographic Information Descriptions

### Data Storage and Archive Element
1. ETSS-DA-01: Archive Data
2. ETSS-DA-02: Determine Performance Measures

### User Interface Element
1. ETSS-UI-01: User Interface
In-Vehicle System

- Allows drivers of vehicles to opt-in to applications that provide real-time information so that they can adjust driving behavior to save fuel and reduce emissions.
- Collects traffic data, environmental data, vehicle status data from other vehicles, terrain information, and SPaT information available through DSRC or other wireless communication.
- Processes data to determine optimal eco-driving strategies which in turn are disseminated to the driver through an operator interface.
- Considers start-stop capabilities that automatically shut down and restart the vehicle’s engine reducing the amount of time the engine spends idling, thereby reducing fuel consumption and emissions.
- Allows for wireless charging of electric vehicle batteries.
- Provides feedback / analysis of driving behavior including fuel consumption, emissions, and financial savings for a trip.
IN-VEHICLE SYSTEM

**ACTORS THAT PROVIDE INPUTS**

- Driver
- Connected Vehicle Roadway Equipment
- Vehicle Diagnostic Systems
- Other Vehicles
- Other Onboard Sensors
- Inductive Charging Roadway Equipment

**Data Collection Elements**

- Driver Input Data Collection
- Traffic Conditions Data Collection
- Environmental Conditions Data Collection
- SPaT and GID Data Collection
- Transit or Freight Specific Data Collection
- ‘Other Vehicle’ Vehicle Status Data Collection
- Vehicle Diagnostics Data Collection

**Data Processing Elements**

- Eco-Driving and Eco-Approach at Signalized Intersections Strategies
- Signal Priority Request
- Vehicle Status (e.g., BSM and BEM)

**ACTORS THAT RECEIVE OUTPUTS**

- Vehicle Actuators
- Driver
- Other Vehicles
- Connected Vehicle Roadway Equipment
- Inductive Charging Roadway Equipment

**Data Dissemination Elements**

- Eco-Driving Vehicle Assisted Control Strategy
- Eco-Driving Information Dissemination
- Signal Priority Request Dissemination
- Vehicle Status Dissemination
Eco-Signal Operations Needs

**IN-VEHICLE SYSTEM**

**Data Collection Element**
1. IVS-DC-01: Collect Driver Input
2. IVS-DC-02: Receive Traffic Conditions Data
3. IVS-DC-03: Receive Environmental Conditions Data
4. IVS-DC-04: Collect Signal Phase and Timing (SPaT) Data
5. IVS-DC-05: Collect Geographic Information Descriptions (GID) Data
6. IVS-DC-06: Collect Data for Signal Priority Requests
7. IVS-DC-07: Receive Vehicle Status Data from Other Vehicles (i.e., BSM)
8. IVS-DC-08: Collect Vehicle Diagnostics Data
9. IVS-DC-09: Receive Inductive Charge

**Data Processing Element**
1. IVS-DP-01: Determine Eco-Driving Recommendations
2. IVS-DP-02: Determine Eco-Approach & Departure at Intersections
3. IVS-DP-03: Determine Traffic Signal Priority Request Strategy
4. IVS-DP-04: Determine Vehicle Emissions Data

**Data Dissemination Element**
1. IVS-D-01: Provide Eco-Driving Information to the Driver
2. IVS-D-02: Send Traffic Signal Priority Request
3. IVS-D-03: Disseminate Vehicle Status Data (i.e., BSM)
4. IVS-D-04: Disseminate Vehicle Status Environmental Data (i.e., BEM)

**Vehicle Control Element**
1. IVS-VC-01: Provide Eco-Driving Vehicle Assisted Control
2. IVS-VC-02: Provide Start-Stop Capabilities

**Driver Interface Element**
1. IVS-DI-01: Driver Interface
<table>
<thead>
<tr>
<th>ID</th>
<th>ACTORS</th>
<th>DATA FLOW / ACTION</th>
<th>RELATED USER NEEDS</th>
</tr>
</thead>
</table>
| 1  | In-Vehicle System and Driver | In-Vehicle System sends to Driver  
- Eco-driving recommendations (e.g., recommended driving speeds, driver feedback, etc.)  
- SPA-T information (e.g., time to red, etc.)  
- Traffic conditions  
- Environmental conditions (e.g., code red air quality alerts)  
- Road weather conditions  
- Status of an electric vehicle’s electric charge and charge received from inductive charging field infrastructure |  
- IVS-DC-01: Collect Driver Input  
- IVS-D-01: Provide Eco-Driving Information to the Driver  
- IVS-DI-01: Provide Driver Interface  
Driver Sends to In-Vehicle System  
- Activation of Application (e.g., activate eco-driving application)  
- Updates to configurable parameters |
| 2  | In-Vehicle System and Other Vehicles | In-Vehicle System sends to Other Vehicles  
- Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.) |  
- IVS-DC-07: Receive Vehicle Status Data from Other Vehicles  
- IVS-D-03: Disseminate Vehicle Status Information  
Other Vehicles send to In-Vehicle System  
- Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.) |
- Traffic signal priority requests  
- Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.)  
- Vehicle status environmental data (e.g., BEM data including the vehicle’s fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel |  
- IVS-DC-02: Receive Traffic Conditions  
- IVS-DC-03: Receive Environmental Conditions  
- IVS-DC-04: Collect Signal Phase and Timing (SPA-T) Data  
- IVS-DC-05: Collect Geographic Information Description Data |
Eco-Approach and Departure at Signalized Intersections

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The traffic signal controller sends the traffic signal’s current SPaT data to the Connected Vehicle Roadway Equipment. Which converts the data to a SAE J2735 SPaT message.</td>
</tr>
<tr>
<td>2</td>
<td>The Eco-Traffic Signal System sends traffic conditions data to the Connected Vehicle Roadway Equipment, including average speeds, queues at the stop bar, and incidents along the roadway. The Eco-Traffic Signal System also sends GIDs to the Connected Vehicle Roadway Equipment describing the static physical geometry of one or more intersections.</td>
</tr>
<tr>
<td>3</td>
<td>The Connected Vehicle Roadway Equipment broadcasts SPaT, GID, and traffic condition messages. SPaT messages are broadcasted 10 times per second.</td>
</tr>
<tr>
<td>4</td>
<td>Other Vehicles broadcast vehicle status messages including the vehicle’s location, motion (e.g., heading and acceleration), braking status, size, and vehicle type.</td>
</tr>
</tbody>
</table>
| 5    | The In-Vehicle System collects data and determines the vehicle’s optimal trajectory (e.g., speed, acceleration, and braking) as the vehicle approaches or departs from the signalized intersection.  
  • The application first attempts to identify a speed for the vehicle to traverse the intersection during a green light.  
  • If the application determines that the vehicle cannot traverse the intersection on a green light, it determines a strategy for the vehicle to decelerate to the intersection in the most environmentally efficient manner.  
  • If the vehicle is stopped or slows down, the application will recommend the most environmentally efficient acceleration as the vehicle departs from the intersection.  
  • Finally if stopped, the application automatically shuts down and restarts the vehicle’s engine reducing the amount of time the engine spends idling, thereby reducing fuel consumption and emissions. |

“Cleaner Air Through Smarter Transportation”
### Eco-Approach and Departure at Signalized Intersections – Autonomous Control

**Step** | **Description**
--- | ---
1 | A vehicle is equipped with an eco-driving application which also includes a feature allowing for automated control of the vehicle (e.g., the feature controls the speed and acceleration of the vehicle, but still requires the driver to steer the vehicle). The driver turns on the application and the automated driving capability using a human machine interface (HMI) in the vehicle.

2 | The traffic signal controller sends the traffic signal’s current SPaT data to the Connected Vehicle Roadway Equipment. The data is converted into a SAE J2735 SPaT message.

3 | The Eco-Traffic Signal System sends traffic conditions and GIDs to the Connected Vehicle Roadway Equipment describing the static physical geometry of one or more intersections.

4 | The Connected Vehicle Roadway Equipment broadcasts SPaT, GID, and traffic condition messages. SPaT messages are broadcasted 10 times per second.

5 | Other Vehicles broadcast vehicle status messages including the vehicle’s location, motion (e.g., heading and acceleration), braking status, size, and vehicle type.

6 | The In-Vehicle System collects data and determines the vehicle’s optimal trajectory (e.g., speed, acceleration, and braking) as the vehicle approaches or departs from the signalized intersection.

7 | Once eco-driving recommendations are determined by the application, data is sent to vehicle actuators which adjust the speed, accelerations/decelerations, and braking of the vehicle. The driver maintains control of the steering of the vehicle. Data collected from other vehicles using vehicle-to-vehicle (V2V) communications are considered to ensure that the vehicle does not collide with other vehicles.
### Inductive Charging at Signalized Intersections

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The traffic signal controller sends the traffic signal's current SPaT data to the Connected Vehicle Roadway Equipment. The data is converted into a SAE J2735 SPaT message.</td>
</tr>
<tr>
<td>2</td>
<td>The Connected Vehicle Roadway Equipment broadcasts SPaT and GID messages. <strong>The GID message includes the locations of inductive charging infrastructure near signalized intersections.</strong></td>
</tr>
<tr>
<td>3</td>
<td>The In-Vehicle System receives SPaT and GID messages – including the location of inductive charging infrastructure. <strong>The driver of the electric vehicle opts into an inductive charging application. The application informs the driver of the location of inductive charging infrastructure.</strong></td>
</tr>
<tr>
<td>4</td>
<td>As the vehicle approaches the inductive charging pad at a red light, the vehicle establishes a wireless connection with the inductive charging infrastructure. A handshake process begins, payment information sent to inductive charging equipment, and electric charge is transferred from the pad to the vehicle.</td>
</tr>
<tr>
<td>5</td>
<td>The In-Vehicle System continues to receive SPaT messages as it sits at the red light. Five seconds before the traffic signal turns green, the charge terminates.</td>
</tr>
<tr>
<td>6</td>
<td>The traffic signal turns green and the vehicle accelerates away from the intersection. The In-Vehicle System notifies the driver about the vehicle’s charge level.</td>
</tr>
</tbody>
</table>
Eco-Traffic Signal Timing

**Step** | **Description**
--- | ---
1 | Vehicles send vehicle status data to the Connected Vehicle Roadway Equipment. Vehicle status data includes data about the vehicle’s location, motion (e.g., heading and acceleration), braking status, size, and vehicle type as well as environmental status data such as the vehicle’s fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption.

2 | The Connected Vehicle Roadway Equipment sends the vehicle status data to the Eco-Traffic Signal System.

3 | The Eco-Traffic Signal System processes the vehicle status data to develop real-time and predicted traffic and environmental conditions for the roadway segment. Together the traffic and environmental data are used to generate eco-traffic signal timing plans (e.g., cycle lengths, phases, offsets and other parameters). This may include fixed timing plans based on the time of day or capabilities similar to current adaptive traffic control systems; however, the objective should be to generate signal timing plans to minimize the environmental impact of traffic at a single intersection, along a corridor, or a region, and to select the appropriate traffic signal timing strategy to be implemented.

4 | The Eco-Traffic Signal System sends the traffic signal timing plans to the ITS Roadway Equipment (i.e., traffic signal controller) which implements the signal timing plan.
The Transit Vehicle sends a request for signal priority to the Connected Vehicle Roadway Equipment. In addition to the signal priority request, the transit vehicle also collects and transmits data from on-board systems including the number of passengers on the transit vehicle and the transit vehicle’s adherence to its schedule.

Vehicles in the vicinity of the signalized intersection send vehicle status data to the Connected Vehicle Roadway Equipment. Vehicle status data includes the vehicle’s location, motion (e.g., heading and acceleration), braking status, size, and vehicle type as well as the vehicle’s fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption.

The Connected Vehicle Roadway Equipment sends the vehicle status data to the Eco-Traffic Signal System. The Connected Vehicle Roadway Equipment also sends the Transit Vehicle’s signal priority request.

Upon receiving the signal priority request from the Transit Vehicle, the Eco-Traffic Signal System uses the traffic and environmental conditions data to determine if signal priority should be granted. The Eco-Traffic Signal Priority application considers the current state of the traffic signal, traffic volumes for all approaches to the traffic signal, vehicle emissions from vehicles at all approaches to the traffic signal, traffic conditions downstream of the intersection, the number of passengers on the transit vehicle, and the transit vehicle’s adherence to its schedule.

If it is determined that signal priority should be granted, the Eco-Traffic Signal System sends the request for signal priority to the ITS Roadway Equipment which implements the traffic signal control strategy (i.e., signal priority).
Goals, Objectives, and Performance Measures

<table>
<thead>
<tr>
<th>Goal #1: Reduce Environmental Impacts</th>
<th>Goal #2: Support “Green Transportation Decisions” by Travelers and Operating Entities</th>
<th>Goal #3: Enhance Mobility of the Transportation System (secondary goal)</th>
<th>Goal #4: Improve the Safety of the Transportation System (secondary goal)</th>
</tr>
</thead>
</table>
| • Reduce Emissions from Surface Transportation Vehicles  
  • Reduce CO₂, CO, NOₓ, SO₂, PM₁₀, PM₂.₅, VOCs  
• Reduce Energy Consumption Associated with Surface Transportation Vehicles  
  • Reduce excess fuel  
  • Reduce energy consumption | • Increase Eco-Driving Awareness and Practice  
  • Increase the numbers of drivers practicing eco-driving strategies  
  • Increase the number of eco-driving marketing/outreach activities  
• Reduce Range Anxiety for Drivers Driving Electric Vehicles  
  • Reduce Drivers fear of Range Anxiety  
• Increase the Range of Electric Vehicles  
  • Increase the distance that electric vehicles can travel without stopping at a charging station | • Improve the Efficiency of the Transportation System  
  • Reduce delay per person  
  • Decrease control delay per vehicle on arterials  
  • Increase miles of arterials operating at LOS ‘X’  
• Improve Transit Operating Efficiency  
  • Reduce transit travel times  
  • Decrease signal delay on transit routes  
  • Increase the implementation of transit signal priority  
• Improve Freight Operating Efficiency  
  • Reduce delay on freight-significant routes  
  • Increase customer satisfaction | • Reduce Crashes, Injuries, and Fatalities on Arterials  
  • Reduce crashes, injuries, and fatalities at signalized intersections  
  • Reduce secondary crashes, injuries, and fatalities at signalized intersections  
  • Reduce crashes, injuries, and fatalities due to red-light running  
  • Reduce crashes, injuries, and fatalities due to adverse road weather conditions  
  • Reduce crashes, injuries, and fatalities at railroad crossings |
Eco-Signal Operations | Policy Considerations

- Would certain vehicle types be allowed to move through a signalized intersection at a higher priority than other vehicle types?

- Are there mobility tradeoffs? If so, how do operating entities make a decision to optimize for the environment instead of optimizing for mobility?

- How can this Transformative Concept facilitate “green” choices by:
  - Drivers,
  - State and local DOT’s operating the transportation system, and
  - Decision Makers?

- How can this Transformative Concept incentivize “green” choices by:
  - Drivers,
  - State and local DOT’s operating the transportation system, and
  - Decision Makers?

- How does open data sharing and standardization be used to support public and private sector deployment?

- Under what situation(s) would an operating entity choose to optimize traffic signals for the environment?

- How do Decision Makers value Eco-Signal Operations applications as an option for investing scarce resources?
Eco-Signal Operations | Education

- What are the social benefits of “green” transportation decisions?
  - Drivers
  - State and local DOT’s operating the transportation system

- What types of educational campaigns could be used to educate the traveling public to make green transportation choices?

- What types of educational campaigns could be used to educate entities operating traffic signal systems to optimize for the environment?

- How do you incentivize a choice versus another choice? And how do you get people to act on that choice?

Provide travelers and entities operating the transportation network the information they need to make “green” transportation choices.
QUESTIONS?
MODELING AND ANALYSIS PLANS 101

Balaji Yelchuru, Booz Allen Hamilton
Need for Modeling AERIS Applications

- AERIS applications have the potential to provide significant environmental benefits by reducing emissions (e.g., GHG, criteria pollutants) and fuel consumption.

- Environmental impacts of surface transportation can be reduced by encouraging positive changes in traveler and driving behaviors by:
  - Providing speed or route recommendations to drivers
  - Providing incentives to drivers using fuel-efficient vehicles or other eco-friendly modes

- To quantify the potential environmental benefits of AERIS applications, behavior changes and the resulting environmental impacts need to be modeled.
Potential Behavior Changes from AERIS Applications

**Directly Result in VMT Reduction**
- Route changes that reduce distance
- Mode shift to alternative transportation (e.g. transit)
- Reduction in the number of trips
- Trip chaining

**No Direct VMT Reduction, but Positive Environmental Impact**
- Improved driving behavior (eco-driving)
- Improvement in smoothness of traffic flow
- Better transit and freight planning and operations
- Eco-routing (can reduce VMT)
- Cleaner fuel and vehicle choices
Modeling Overview | Why Use a Model?

Models allow us to:

• Explore research questions that cannot be tested in the real world because real-world tests or experiments would be too costly or impossible.

• Diagnose problems to determine what could happen within different systems.

• Forecast outcomes and impacts for different scenarios.

• Determine the range of benefits.
AERIS Modeling Challenges

- Is the model based on best-practices and sound science?
- What is the quality of the data? Does it meet the models needs/requirements? Does it represent the phenomena under investigation?
- How closely does the model approximate the system under investigation?
- Have the research questions been clearly identified?
- What are the major areas of risk and uncertainty?
AERIS Modeling Challenges (cont’d)

There is no one optimal model or one-single tool for modeling AERIS Transformative Concepts – there are pros and cons to each tool.

Most of the modeling work is uncharted territory due to the innovative nature and long-range timeframe of AERIS Transformative Concepts.

Modeling obstacles are surmountable with integration of models, reliable data, and clear assumptions associated with key variables.

There are needs to develop new algorithms that represent the transformative AERIS Applications.
Transportation Demand Model: Uses land-use, socio-demographic, and transportation network data to estimate network performance.

Dynamic Traffic Assignment (DTA) Model: Uses finer transportation network details to estimate network performance at a finer temporal fidelity.

Microsimulation Model: Simulates the movement of every vehicle on a second-by-second (or sub-second) basis to generate very detailed estimates of vehicle and network performance.

Emissions Model: Uses vehicle or network performance outputs from traffic assignment or microsimulation models to generate emissions and fuel consumption estimates.
Transportation Modeling Terminology (cont’d)

- **Hypothesis**
  - A proposed idea or assumption that can be tested, and falsified or confirmed through study or analysis. Typically written as *If* <idea/action>, *then* <expected outcome>.

- **Algorithm**
  - A step-by-step problem-solving computational procedure (normally expressed as a formula) for solving a problem. Used for computation and data processing.

- **Application Programming Interface (API)**
  - Interface that allows user the capability to access and modify the underlying software/tool.

- **Plug-in**
  - Software components that adds specific or additional abilities to an existing software/tool. Plug-ins are developed using API.

- **Scenario**
  - An imagined or proposed vision of the future expressed as events that could occur.
AERIS Modeling Steps

1. Predict Behavior Changes
   Predict behavior changes (e.g., change in time of travel, route choice, mode choice) due to implementation of AERIS applications

2. Predict Changes in Network Performance
   Use traffic assignment and simulation models to predict changes in network performance (speeds, volumes, driving profiles, etc.) due to implementation of AERIS applications

3. Estimate Emissions
   Feed detailed vehicle speed and traffic volume data to advanced emissions models to estimate emission impacts (i.e., GHG and pollutant emissions)

4. Compare Emissions with and without AERIS
   Compare emissions with and without AERIS applications to quantify environmental benefits
High-Level Modeling Overview

Note: Modeling structure is changed to suit the modeling needs of individual applications

1. INPUT
   Travel Demand Model Data (e.g., highway and transit network, activities)

2. Travel Demand and Activity Based Models
   (Predict Traveler Behavior)

3. OUTPUT
   Modeled Behavior Changes (e.g., mode choice, departure time)

4. Dynamic Traffic Assignment and Microsimulation Tools
   (Used to Obtain High Resolution Vehicle Trajectories)

5. AERIS Application Plug-in

6. OUTPUT
   1. Link Volume and Speeds (by Time of Day) and Instantaneous Vehicle Speed
   2. Fleet Mix and Vehicle Types

7. Emissions Models
   (Used to Estimate Emissions)

8. OUTPUT
   Modeled Fuel Consumption and Emissions Quantities (e.g., NOx, CO, CO₂, Particulate Matter)
Travel Demand Models

INPUTS

Roadways
Capacity, Posted Speeds, etc.

Transit
Routes, Service Levels, Fares, etc.

Zone
Land-use Data, Access to Transit, etc.

OUTPUTS

Person and Vehicle Travel Demands, Origin-Destination (OD) Patterns

Types:
• Traditional Four-Step Model
• Advanced Activity-Based Tour-Oriented
Dynamic Traffic Assignment (DTA)

**INPUTS**

- **Roadways**
  - Lanes, Turning Lanes, Merge Lanes, etc.

- **Intersections**
  - Signals, Signs, etc.

- **Person and Vehicle Travel Demands, OD patterns**

**OUTPUTS**

- **Queue Lengths at Intersections**
- **Number of Vehicles on each Roadway by Time Period**
- **Average Speeds on each Roadway**

Assigns traffic on the roadway network to achieve higher accuracy in speed estimates than traditional Four-Step Models.
Microsimulation Tools

**INPUTS**
- **Roadways**
  Lanes, Turning Lanes, Merge Lanes, etc.
- **Intersections**
  Signals, Signs, etc.
- **Travel Demand**
  Person and Vehicle Travel Demands, OD Patterns
- **Driver Behavior**
  Acceleration, Breaking, Gap Acceptance
- **Transit**
  Transit Routes, Service Levels, Fares

**Outputs**
- Number of Vehicles on each Roadway by Time Period
- Intersection Delays, Queue Lengths, etc.
- Average Speeds on each Roadway
- Individual Vehicle Trajectories, Vehicle Operating Modes

*Microscopic simulation* models are necessary to quantify environmental impacts of strategies that *do not affect trip choices* and/or vehicle miles traveled (VMT)
Microsimulation Models

- Traffic Simulation Models
  - Microscopic simulation models are necessary to capture driving behavior changes and quantify environmental impacts of strategies that do not affect trip choices and/or vehicle miles traveled (VMT).

- Off-the-Shelf Microsimulation Models
  - Have limited capabilities in modeling connected vehicle applications
    - V2V and V2I interactions
    - Application algorithms
  - Use driving behavior logics that do not reflect V2V and V2I communications
  - Include only basic environmental tools

- Plug-in’s using APIs need to be developed using APIs to represent AERIS applications
Microsimulation Plug-ins (Example)

**SIMULATION PARAMETERS**

**TRAFFIC SIMULATION MODEL INPUTS**

- Intersection characteristics (e.g., signals types, Signal Phasing and Timing Plan)
- Roadway characteristics (e.g., number of lanes, grade, speed limit)
- Vehicle demands and their OD patterns
- Transit schedules/routes

**Application Programming Interface (API)**

**Process Step**

- Vehicle Type
- Traffic Data (e.g., vehicle speeds, delay, travel times, signal timing plans, etc.)

**Note:** Steps 3 and 4 occur every second in the simulation model
The AERIS Program needs to develop microsimulation software plug-ins to:

- Generate Speed advice for vehicles approaching or departing signalized intersections
- Generate eco-signal timing plans
- Model transit/freight signal priority requests, grants, and denials
- Generate time-of-day eco-ramp meter timing plans
- Generate eco-speed limits
- Generate parameters for vehicle platooning
- Model vehicle-vehicle and vehicle-infrastructure communications
- Interface emissions models with traffic simulation models for real-time emissions estimation and change operations
Emissions Tools

**INPUTS**

Average Speeds, Drive Cycles, Vehicle Operating Mode Distributions

**OUTPUTS**

Fuel Consumption

Emissions (e.g., GHG and Criteria Pollutants)

Use detailed outputs from the traffic simulation models to generate emissions estimates and fuel consumption.
Emissions Models

- **MOVES**, a model developed by the U.S. Environmental Protection Agency (EPA), is well suited to assess environmental impacts.

- Emissions models need both transportation and non-transportation data.
  - *Transportation Data*: Vehicle trajectories (i.e., speed profiles), link characteristics (such as grade) and vehicle fleet characteristics.
  - *Non-Transportation Data*: Meteorological data (such as air temperature, relative humidity, etc.), fuel supply data.

- Emissions estimates are sensitive to vehicle speed profiles.
  - Traffic simulation models are necessary to produce data required for detailed emissions analysis using MOVES.

- Default data used in emissions models affect emissions results and needs to be adjusted to based on the analysis scenarios.
  - Fleet assumptions, vehicle age distribution, fuel assumptions, meteorological data, other data, etc.
# Models/Software To Evaluate AERIS Applications

<table>
<thead>
<tr>
<th>MODEL CATEGORY</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Modeling</td>
<td></td>
</tr>
<tr>
<td>Travel Demand Models or Activity-Based</td>
<td>• Travel Demand Models: TransCAD, CUBE</td>
</tr>
<tr>
<td>Based Models</td>
<td>• Activity-Based Models: Custom Software – DaySim, SimTravel</td>
</tr>
<tr>
<td>Traffic Assignment and Microsimulation</td>
<td></td>
</tr>
<tr>
<td>Dynamic Traffic Assignment Models</td>
<td>• DYNASMART, VISTA, DYNAMIT</td>
</tr>
<tr>
<td>Microsimulation Models</td>
<td>• CORSIM, Paramics, VISSIM, SimTraffic, Aimsun, TransModeler, Cube Dynamism</td>
</tr>
<tr>
<td>Emissions</td>
<td></td>
</tr>
<tr>
<td>Microscopic Emissions Models</td>
<td>• Motor Vehicle Emission Simulator (MOVES), CMEM, and VT-Micro</td>
</tr>
</tbody>
</table>
AERIS Analysis Plans

- Describe Analysis Hypothesis
- Describe environmental (performance) measures to be considered
- Identify region/network to be used for modeling and data needs
- Identify analysis settings/scenarios
- Identify the modeling/software needs
- Describe the modeling approach including Algorithm development approach Overview
- Developed for the following AERIS Transformative Concepts
  - Eco-Signal Operations
  - Dynamic Eco-Lanes
  - Dynamic Low Emissions Zones
QUESTIONS?
Eco-Signal Operations Analysis Plan

Balaji Yelchuru, Booz Allen Hamilton
Eco-Signal Operations Applications

- **The Eco-Signal Operations Transformative Concept:**
  - Includes applications that use connected vehicle technologies to decrease fuel consumption and GHG and criteria air pollutant emissions at signalized intersections.
  - Seeks to reduce idling, the number of stops, unnecessary accelerations and decelerations at signalized intersections.
  - Seeks to improve traffic flow at signalized intersections.

- **Applications**
  - Eco-Approach and Departure at Signalized Intersections
  - Eco-Traffic Signal Timing
  - Eco-Transit Signal Priority
  - Eco-Freight Signal Priority
  - Connected Eco-Driving
# Traveler/Driving Behavior Affected

<table>
<thead>
<tr>
<th>Application</th>
<th>Part of Trip Chain Affected</th>
<th>Driving Behavior</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eco-Approach and Departure at Signalized Intersections</td>
<td>Destination Choice</td>
<td></td>
<td>Route changes may or may not be seen.</td>
</tr>
<tr>
<td></td>
<td>Mode Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time-of-Day Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Route Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eco-Traffic Signal Timing</td>
<td>Destination Choice</td>
<td></td>
<td>Primary changes are in driving behavior.</td>
</tr>
<tr>
<td></td>
<td>Mode Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time-of-Day Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Route Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eco-Transit Priority</td>
<td>Destination Choice</td>
<td></td>
<td>Mode choice may be affected if transit becomes reliable and efficient.</td>
</tr>
<tr>
<td></td>
<td>Mode Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time-of-Day Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Route Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eco-Freight Priority</td>
<td>Destination Choice</td>
<td></td>
<td>Lane Choice and Driving behavior are likely to be most affected.</td>
</tr>
<tr>
<td></td>
<td>Mode Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time-of-Day Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Route Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected Eco-Driver</td>
<td>Destination Choice</td>
<td></td>
<td>Route changes may or may not be seen.</td>
</tr>
<tr>
<td></td>
<td>Mode Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time-of-Day Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Route Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lane Choice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Full Circle**: Application has a definite influence on the particular trip chain element.
- **Three-Quarter Circle**: Application has a probable influence on the particular trip chain element.
- **One-Quarter Circle**: Application has only a possible influence on the particular trip chain element.
Performance Measures Used for Modeling

**Environmental Measures**
- Fuel Consumption (gallons)
- Emissions
  - CO₂ (Carbon Dioxide)
  - PM-10 (Particulate Matter)
  - PM-2.5 (Particulate Matter)
  - NOₓ (Oxides of Nitrogen)
  - Non-methane Hydro Carbon
  - CO (Carbon Monoxide)

**Mobility Measures**
- Total Delays
- Intersection Delay
- Travel Times
- Number of Stops

*Mobility Performance Measures not used for AERIS benefit assessment*
AERIS Baseline

- For the purpose of defining AERIS modeling, baseline conditions assume a region that includes both arterial and freeway facilities under “high” levels of traffic.

**Arterial Network**
- Signalized corridor with 2-3 lanes per direction
- **Speed Limit**: 35 to 45 mph
- **Traffic Signal Operations**: Uncoordinated, non-optimized, and fixed signal controls
- **Intersection Spacing**: Approximately 3-4 intersections/mile
- **Traffic Congestion (high)**: 500-600 vehicles/hour/lane

**Freeway Network**
- Basic freeway segment with 3-5 lanes/direction
- **Speed Limit**: 55 to 65 mph
- **Traffic Congestion (high)**: 2,000 vehicles/hours/lane
- **Ramp Spacing**: 1 mile
- **Road Grade**: 0%
Model Region Description | El Camino Real, CA

- 6-mile segment between
  - Churchill Ave in Palo Alto and Grant Rd in Mountain View
- 27 signalized intersections
- Actuated and coordinated signals
- Mostly three lanes in each direction
- Parallel to the US-101 freeway

Applications Modeled:
- Eco-Approach and Departure at Signalized Intersections
- Eco-Signal Timing
- Eco-Transit Priority
- Connected Eco-Driving
Model Region Description | South Alameda St, CA

- Ports of Los Angeles and Long Beach
  - container trade
  - 40% of US imports
  - 25% of US exports
- Major Highways
  - I-710 and I-110
  - Approximately 15% of traffic is freight
- South Alameda St.
  - Arterial with high truck traffic
  - Connects to port
  - 3.5 mile segment between North Avalon Boulevard and East Sepulveda Boulevard
  - Two or three lanes per direction
  - Five signalized intersections
- Applications Modeled
  - Eco-Freight Signal Priority

Port of Long Beach
AERIS Hypothesis Overview

- Primary Hypothesis
  - Using connected vehicle data, signal and vehicle operations can be altered to achieve significant environmental benefits.

- Hypothesized environmental benefits are based on % fuel and emissions savings of the same or similar applications reported in literature, or estimated by the research team if no existing information is available.

- For the purposes of developing hypothesis, AERIS environmental benefits are expressed in terms of % savings from AERIS application relative to the baseline.

\[
\begin{align*}
\text{% Fuel Savings} &= 100\% \times \frac{(\text{fuel}_{\text{baseline}} - \text{fuel}_{\text{AERIS}})}{\text{fuel}_{\text{baseline}}} \\
\text{% CO}_2\text{Savings} &= 100\% \times \frac{(\text{CO}_2\text{baseline} - \text{CO}_2\text{AERIS})}{\text{CO}_2\text{baseline}}
\end{align*}
\]
Hypothesis | Eco-Signal Operations Transformative Concept

- Hypothesis
  - If all five applications in the Eco-Signal Operations Transformative Concept are implemented together, then there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
    - 15%–20% under partial connected vehicle penetration.
    - 20%–25% under full connected vehicle penetration.

% saving estimates consider operational improvements only; potential mode shift and route changes are assumed to have a minimal impact.

Fuel savings from the Connected Eco-Driving application, which works outside the intersection vicinity would be augmented by fuel savings from the applications that work inside the intersection.
Modeling Approach | Overview

- Applications will be initially modeled and tested individually using a corridor network/region.
- After the initial development and testing of individual applications, the applications will be modeled together on a combined network/region to estimate benefits of all applications implemented together.
  - Estimate the total benefits of the Transformative Concept.
  - Inspect the interactions of the applications with each other.
- All Eco-Signal Operations applications will be modeled using microsimulation software (e.g., Paramics, VISSIM).
  - AERIS application Algorithms will be developed using an API and implemented through plug-ins.
For the initial analysis, mode choice and route choice impacts resulting from Eco-Signal Operations applications will not be considered as the impact is expected to be minimal.

All applications will be implemented on El Camino Real, CA corridor.

- Datasets readily available to project team (Paramics Model exists)
- Tested/used before in prior research efforts
Eco-Signal Operations Modeling Version 1.0

1. **Traffic Simulation Model Inputs**
   - Intersection characteristics (e.g., signals types, Signal Phasing and Timing Plan)
   - Roadway characteristics (e.g., number of lanes, grade, speed limit)
   - Vehicle demands and Origin-Destination patterns
   - Transit schedules/routes
   - Freight demand

2. **Data sent from Simulation tool to Emissions tool**
   - Input data fed to Emissions tool
   - Vehicle types
   - Fuel types
   - Weather Data (e.g., temperature, relative humidity)
   - Vehicle age distribution

3. **Emissions Model Inputs**
   - Emissions (e.g., CO₂, NOₓ, CO, Particulate Matter)
   - Travel delay
   - Intersection delay

4. **Data sent from ApplicationsPlugins to Simulation tool**
   - Final outputs generated

5. **Microsimulation Tool**
   - Roadway characteristics (e.g., speed limits)
   - Signal Phase and Timing (SPaT)
   - Vehicle type and location
   - Second-by-second speed profiles
   - Priority requests

6. **Data sent from Simulation tool to Environmental Plugin**
   - Signal timing plans optimized for environment

7. **Data sent from Emissions tool to Environmental Plugin**
   - Emissions Rates

8. **Applications Plugins**
   - Eco-Approach Algorithm
   - Eco-Signal Timing Algorithm
   - Eco-Signal Priority Algorithm

9. **Outputs**
   - Fuel consumption
   - Travel delay
   - Intersection delay
Hypothesis | Eco-Approach and Departure at Signalized Intersections

- If speed advice is provided to drivers who are within a communication range with signals (~300 m) as their vehicle is approaching and departing at signalized intersections, then there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 3%–4% under partial connected vehicle penetration.
  - 6%–8% under full connected vehicle penetration.

% fuel savings during off-peak hours are expected to be higher as the drivers have more ability to adjust their vehicle’s speed.

Vehicles that are not enabled with connected vehicle technologies are also likely to benefit from improvements in overall traffic flow.
Modeling Approach | Eco-Approach/Departure

- Build on fixed-time signal control algorithm researched by UCR.
- Develop Algorithm to provide speed recommendations to vehicles based on signal phasing and timing (SPaT) information and encourage “green” approaches to intersection.
- Change vehicle speed trajectory to pass the next signal on green or to decelerate to a stop in an eco-friendly manner and reduce idling time.
- Take into account traffic conditions at the intersection (whether a queue exists), so vehicle simply follow car-following logic when it gets close to the queue or in the queue.
- Include variation in the algorithm to handle both fixed time and actuated signals.
Hypothesis | Eco-Traffic Signal Timing

- *If* Eco-Traffic Signal Timing Application is used to dynamically adjust signal phase and timing plans based on the speed of vehicles approaching an intersection, and vehicle emissions characteristics, *then* there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 2%–3% under partial connected vehicle penetration.
  - 4%–6% under full connected vehicle penetration.

% fuel savings during off-peak hours are expected to be higher as the intersection would have more capacity left for optimization.

Vehicles that are not enabled with connected vehicle technologies are also likely to benefit from improvements in overall traffic flow and signal timing optimization.
Modeling Approach | Eco-Traffic Signal Timing

- Existing Adaptive Signal Timing algorithms are a starting point, but would need to be enhanced to optimize signal timings for the environment.

- Estimate the traffic volumes and the composition of the traffic arriving at each approach and obtain an estimate of the vehicle emissions at each approach. Perform vehicle energy/emissions data aggregation and signal optimization.

- Revise the signal timings with changing demand at the intersection. Achieve coordination of signal timings with upstream and downstream signalized intersections by re-estimating offsets.

- Periodic Optimization approach to be based on the assumption that traffic states in the region of interest are stationary over each time interval (e.g., 15 minutes or 20 minutes).

- Real-Time Optimization approach is similar to adaptive signal control systems (e.g., SCOOT, SCATS, RHODES).
  - Use information pertaining to approaching vehicles as inputs and performs short-term prediction on vehicles’ dynamics as well as energy consumption and emissions.
Hypothesis | Eco-Transit Signal Priority

- *If* Eco-Transit Signal Priority application is used to grant signal priority to selected transit vehicles based on their adherence to schedule, number of passengers on the transit vehicles and environmental characteristics of all vehicles at the signalized intersection, *then* there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 1%–2% under partial connected vehicle penetration.
  - 2%–4% under full connected vehicle penetration.

% emissions reductions does not consider mode choice impacts.

% fuel savings during off-peak hours are expected to be higher as the intersection would have more capacity left for granting signal priority.

% fuel savings for transit vehicles alone would be higher as they would stop and idle less – improve transit reliability.
Modeling Approach | Eco-Transit Signal Priority

- Build on existing transit signal priority algorithms, but enhance to grant transit signal priority with an environmental objective.
- Simulate signal priority requests made by transit vehicles with information about the transit vehicle type, occupancy, next stop and schedule. Grant signal priority to a transit vehicle to minimize total emissions.
- Algorithm to determine if priority should be granted based on environmental benefits.
  - Maintain signal coordination with upstream and downstream-signalized intersections once the priority is granted.
- Algorithm to support both a decentralized system to provide priority (single intersection) and centralized system (co-ordination at a corridor level).
- Develop a process to capture mode-shift impacts by iterating the route-choice model with mode share.
Hypothesis | Eco-Freight Signal Priority

- **If** Eco-Freight Signal Priority application is used to grant signal priority to selected freight vehicles based on their location, speed, size, vehicle class and traffic and environmental characteristics of all vehicles at the signalized intersection, **then** there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 1%–2% under partial connected vehicle penetration.
  - 2%–4% under full connected vehicle penetration.

**% fuel savings during off-peak hours are expected to be higher as the intersection would have more capacity left for granting signal priority.**

**% fuel savings for freight vehicles alone would be higher as they would stop and idle less.**
Modeling Approach | Eco-Freight Signal Priority

- Build on existing truck signal priority algorithms, but grant priority based on environmental objectives.

- Use travel time prediction and trucking tracking to determine whether or not to grant freight signal priority.

- Provide green extension/red truncation upon approach.

- Algorithm to grant priority based on truck type and emissions data generated from trucks and other vehicles in the traffic stream. Data items include:
  - Vehicle’s location, speed, size, vehicle class (e.g., alternative fuel vehicles), load and fuel consumption/emissions.

- Maintain signal coordination with upstream and downstream signalized intersections once the priority is granted.
Hypothesis | Connected Eco-Driving

- *If* real-time driving advice (e.g. recommended driving speeds, optimal acceleration, optimal deceleration) is provided to drivers based on prevailing traffic conditions and interactions with nearby vehicles and feedback is provided to encourage drivers to drive in a more environmentally efficient manner, *then* there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 10%–15% under partial connected vehicle penetration.
  - 15%–20% under full connected vehicle penetration.

% savings assume both freeway and arterial travel

% savings during off-peak hours are expected to be the same or lower as the drivers may already be driving at optimal speeds

Vehicles that are not enabled with connected vehicle technologies are also likely to benefit from improvements in overall traffic flow
Modeling Approach | Connected Eco-Driving

- Provide real-time speed recommendations based on real-time traffic conditions and interactions with nearby vehicles.

- The application would not be limited to signalized intersections, but instead applicable to all sections of the arterial and freeway travel.

- Algorithm to use real-time link by link traffic performance and interaction between vehicles as feedback/input to vehicles’ speed and acceleration selection process as they traverse the network.

- Use downstream traffic conditions to determine speed recommendations and eco-friendly acceleration rates for vehicles.

- Update recommended speeds when the vehicle enters a new roadway link or when the real-time traffic speed information on the current roadway link is updated.

- Algorithm to update vehicle trajectories to avoid stop-and-go driving and instead facilitate smooth driving at a constant speed.

- Model the benefit of vehicle-assisted strategies by changing default driving behavior parameters in simulation model (e.g. switch power sources, change gears).
Analysis Scenarios

- Modeling will be performed under various settings to test the hypotheses.

- The existing conditions at the El Camino Real network will be used for initial modeling, but necessary changes will be made to the network as needed to create a “Testbed” network that includes all the features of interest (such as higher cross-traffic) to estimate the benefits of the applications under different scenarios.

- A baseline, “do nothing”, model will be developed to represent the conditions of the analyzed area without the AERIS applications.

- Another set of models will be developed where the applications are implemented and their benefits in terms of emissions (e.g. GHG, $\text{CO}_2$) and fuel savings are assessed.
Analysis Scenarios (cont’d)

- Variables or Parameters of Interest
  - **Signal Type**: Fixed-timed, actuated, etc.
  - **Signal Settings**: Cycle length, max green time, lead/lag, etc.
  - **Geometry**: Number of lanes of main & cross streets, speed limit, etc.
  - **Congestion**: In terms of volume-to-capacity (V/C) ratio
  - **Vehicle Mix**: % trucks, % alternative fuel vehicles, etc.
  - **Connected Vehicle Deployment**: % of signals enabled with roadside equipment (RSE) units and number of vehicles equipped with on-board equipment (OBE)
  - **Compliance Rate**: Compliance rate of drivers using applications
Application Analysis Scenarios | Examples

Eco-Approach and Departure
- Communication distance from intersection (upper limit based on cellular communication case)
- Baseline signal operations along the corridor (coordinated vs. uncoordinated)

Eco Signal Timing
- Frequency at which the signal timing plans get updated
- Baseline signal operations along the corridor (coordinated vs. uncoordinated)
- Different levels of traffic along the major and minor approaches

Eco-Transit Priority
- Different levels of transit vehicle volume
- Percentage of transit vehicles that are behind the schedule
- Passenger Occupancy
- Minimum dwell times for the buses to reflect increased ridership
- Varying location of bus stops (near-side stop vs. far-side stop)
- Bus fuel type and age (to reflect the emissions generated by different bus types)
Application Analysis Scenarios | Examples

Eco-Freight Priority
- Different levels of freight volume
- Fuel type and age of the truck
- Grade of the road
- Number of signals through which the truck passes through in the signalized corridor

Connected Eco-Driving
- Changing the spacing between the signalized intersections
- Baseline speed limits set at different levels
- Include both freeway and arterial travel under different levels of congestion
QUESTIONS?
Lunch
Eco-Approach and Departure at Signalized Intersections Field Experiment and Initial Modeling Results

Matt Barth, UC-Riverside
BREAK-OUT SESSION GUIDANCE
Break-out Session #1

- **Work in groups (led by group facilitators)**
  - Validate Concept of Operations and Modeling Approach Diagrams – 30 minutes
  - Facilitated discussion around ConOps and Modeling questions – 50 minutes
  - Combine comments for debrief to the larger group – 10 minutes
  - Debrief feedback to whole group – 15 minutes per group
Break-out Session Ground Rules

- The AERIS Team wants to promote an open, honest exchange of ideas among workshop participants.

- Break-out Session Ground Rules:
  - Speak openly and honestly
  - Listen carefully to what others have to say
  - Treat everyone, and their ideas, with respect
  - All input provided by stakeholders will be treated as anonymous
  - Input will be aggregated and synthesized
  - Where appropriate, input will be selectively excerpted without attribution
  - ‘Imagine’

Be Nice, Listen, Think
Break-out Session #1

- Workshop participants will be divided among 2 rooms to ensure that everyone has the opportunity to think creatively and constructively.

- The first round of Break-out Groups will facilitate discussion around the Eco-Signal Operations Transformative Concept.

- Break-out Session Rooms
  - Room #1: Concord
  - Room #2: Lexington
BREAK-OUT SESSION #1
ECO-SIGNAL OPERATIONS
ECO-SIGNAL OPERATIONS PROTOTYPE APPLICATION DISCUSSION
Eco-Signal Operations Prototype Application

- The AERIS Program is investigating the potential for developing a Proof-of-Concept (PoC) prototype application for the Eco-Signal Operations Transformative Concept.
  - Are there components of this Transformative Concept that could be developed for a PoC prototype application?
    - Eco-Approach and Departure at Signalized Intersections
    - Eco-Traffic Signal Timing
    - Eco-Traffic Signal Priority
  - What would a PoC prototype application look like?
  - How could the PoC prototype application be implemented in a real-world environment considering that all vehicles will be equipped with connected vehicle technologies?
  - What do you foresee as the challenges to developing a PoC prototype application?
Eco-Signal Operations PoC Application | Phase 1

- Develop and Test an Application to Implement an Eco-Approach and Departure Application at Signalized Intersections
  - The PoC application is expected to build on the field experiment conducted at Turner Fairbank Highway Research Center (TFHRC) on August 23rd, 2012.
  - Additional capabilities may include:
    - Collecting Basic Safety Messages (BSMs) from nearby vehicles for use in the algorithm.
    - Determining optimal vehicle trajectory for traffic signals operating fixed timed and actuated signal timing plans.
    - Conduct the test along a corridor.
    - Estimating Fuel Consumption and vehicle emissions on the vehicle and formatting the data in a message for broadcasting to RSE units in Phase 2.
    - Displaying Fuel Savings and Emissions Reductions to the Driver through a graphical user interface (GUI).
Eco-Signal Operations PoC Application | Phase 2

- Develop and Test an Eco-Traffic Signal Timing Application
  - Capabilities of the PoC application may include:
    - Collecting Basic Safety Messages (BSMs) from nearby vehicles for use in the algorithm.
    - Collecting environmental data from vehicles for use in the algorithm.
    - Collecting traffic data from roadway sensors (e.g., traffic detectors).
    - Generating eco-traffic signal timing plans along a corridor.
Eco-Signal Operations PoC Application | Phase 3

- Conduct a Demonstration of the PoC Application for the 2014 ITS World Congress
  - Allow meeting participants to drive a vehicle equipped with the application to implement *Eco-Approach and Departure at Signalized Intersections*.
  - Provide data in real-time (or near real-time) to other meeting participants via an onsite display (e.g., large television monitor). The display would show the vehicle’s actual speed against the recommended eco-speed. A score for the driver would be determined based on how well he or she followed the application’s recommendations.
  - Conduct a contest showing the top 10 scores on a display.
CLOSING REMARKS
The Charge for Tomorrow

- The purpose for tomorrow’s workshop is to:
  - Discuss the content of the Dynamic Eco-Lanes and Dynamic Low Emissions Zones Transformative Concepts.
  - Continue detailed discussions on the plans for modeling and analysis of the aforementioned AERIS Transformative Concepts.

Review the Read-Ahead Materials and come prepared to discuss of the AERIS Transformative Concepts

http://www.its.dot.gov/aeris/index.htm
AERIS
(Applications for the Environment: Real-Time Information Synthesis)
ConOps and Modeling Workshop: Day 2

Washington, D.C.
March 27th, 2013

“Cleaner Air Through Smarter Transportation”
DAY 1 Recap and Day 2 Overview

Marcia Pincus, ITS-JPO
Workshop Overview – Day 2

- Day 1 Recap and Day 2 Overview
  *Marcia Pincus, ITS-JPO*  
  9:00 am to 9:15 am

- Dynamic Eco-Lanes Concept of Operations
  *J.D. Schneeberger, Noblis*  
  9:15 am to 9:45 am

- Dynamic Eco-Lanes Analysis Plan
  *Balaji Yelchuru, Booz Allen Hamilton*  
  9:45 am to 10:15 am

- Break
  *TBD*  
  10:15 am to 10:30 am

- Break-out Session #2
  *All – Facilitated Discussion*  
  10:30 am to 11:30 am

- Break-out Session #2 Reports
  *All*  
  11:30 am to 11:45 am

- Lunch  
  11:45 am to 1:00 pm
Workshop Overview – Day 2

- Dynamic Low Emissions Zones Concept of Operations
  
  J.D. Schneeberger, Noblis  
  1:00 pm to 1:30 pm

- Dynamic Low Emissions Zones Analysis Plan
  
  Balaji Yelchuru, Booz Allen Hamilton  
  1:30 pm to 2:00 pm

- Break-out Session #3
  
  All – Facilitated Discussion  
  2:00 pm to 3:00 pm

- Break
  
  TBD  
  3:00 pm to 3:15 pm

- Break-out Session #3 Reports
  
  All  
  3:15 pm to 3:30 pm

- Next Steps and Closing Remarks
  
  3:30 pm to 3:45 pm
Webinar Participants

- **Day 2 Webinar Times**
  - 9:00 am to 10:15 am
    - Dynamic Eco-Lanes ConOps
    - Dynamic Eco-Lanes Analysis Plan
  - 1:00 pm to 2:00 pm
    - Dynamic Low Emissions Zones ConOps
    - Dynamic Low Emissions Zones Analysis Plan

**Questions**

- Please type in question in the Chat Box.
- Questions will be addressed periodically throughout the Workshop.
DYNAMIC ECO-LANES CONOPS

J.D. SCHNEEBERGER, NOBLIS
Dynamic Eco-Lanes

- **Similar to today’s ITS:** managed lanes (e.g., HOV and HOT lanes)

- **Imagine tomorrow’s connected vehicle applications:**
  - Dedicated eco-lanes optimized for the environment that encourage use by low emission, high occupancy, freight, transit, and alternative fuel or regular vehicles operating in eco-friendly ways.
  - Dynamic parameters including the location and duration of the lanes, and types of vehicles permitted to use the lanes.
  - Speed optimized for the environment based on data collected from vehicles. Speed optimization would be implemented to help to reduce unnecessary vehicle stops and starts by maintaining consistent speeds, thus reducing GHG and other emissions.
  - Eco-cooperative adaptive cruise control (eco-CACC) and vehicle platooning where individual drivers may elect to opt-into applications that provide cruise control capabilities designed to minimize vehicle accelerations and decelerations for the benefit of reducing fuel consumption and vehicle emissions.
  - Wireless (inductive) charging infrastructure embedded in the roadway that charges electric vehicles moving at highway speeds.
Managed Lanes

- **HOV Lanes**
  - Restricted traffic lanes, reserved at peak travel times (or longer) for exclusive use of vehicles with a driver and one or more passengers.
  - Increase average vehicle occupancy and person throughput.
  - Improve traffic flow, reducing car trips, and thus reduce vehicular emissions.
  - Some jurisdictions exempt low emission and green vehicles (e.g., hybrid vehicles).

- **HOT Lanes or Express Lanes**
  - Capitalize on unused capacity in HOV lanes by providing motorists in single-occupant vehicles access to HOV lanes.
  - Pricing schemes are established to minimize traffic congestion on the HOT lanes.
  - Collect fee using open roll tolling (ORT) technologies.

Source: The Washington Post

Source: My FOXdc
http://www.myfoxdc.com/story/20133760/caution-urged-for-rush-hour-with-new-express-lanes#axzz2IFr7Hu8
Variable Speed Limit (VSL) Systems and Speed Reductions

- **Variable Speed Limit (VSL) Systems**
  - Collect traffic data using traffic sensors and post speed limits that harmonize traffic flow using dynamic speed signs.
  - Account for traffic conditions, weather conditions, time of day, traffic incidents and lane closures.
  - Reduce congestion, provide more reliable journey times, reduce the frequency of accidents, reduce carbon emissions, and reduce driver stress.

- **Speed Reductions**
  - Research from the University of Texas at Austin 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\textsubscript{x} over a 24 hour period.
  - Graz, the second largest city in Austria, reduced speed limits from 50 kph (31 mph) to 30 kph (19 mph) for the entire city area. During the two-year trial, NO\textsubscript{x} emissions were reduced by 25%.

Source: The A14 Alternative
http://a14alternative.com

Source: FHWA Office of International Program
http://international.fhwa.dot.gov/pubs/pl07012/atm_eu07_02.cfm
Adaptive Cruise Control and Vehicle Platooning

Environmental Benefits of ACC:

- The Netherlands: ACC reduced CO\textsubscript{2} and NO\textsubscript{x} by 3\%.\textsuperscript{1}
- Southeast Michigan: ACC tests with 108 non-professional drivers reduced fuel consumption by 10% compared to manual driving.\textsuperscript{2}
- California: An ACC simulation between Palo Alto and San Jose reduced fuel consumption by 5% to 7\%.\textsuperscript{2}

Environmental Benefits of Vehicle Platooning:

- Volvo demonstrated vehicle platooning- a new technology that lets driverless cars sync up with a leading vehicle.
- A demonstration was conducted in Gothenburg, Sweden as part of the European Union’s research project, known as SARTRE (Safe Road Trains for the Environment).
- Vehicle platooning is expected to slash motorway CO\textsubscript{2} emissions by up to 20\%.\textsuperscript{3}

Limitations of Current System

1. Current HOV and HOT lanes are not fully optimized for the environment and do not incentivize “green” driving behavior (e.g., eco-driving) while vehicles are in the lanes

2. Current HOV and HOT lane systems are limited geographically by roadside infrastructure

3. Current systems do not always consider real-time traffic and environment data when establishing parameters for the HOV and HOT lanes

4. Current VSL and ramp metering systems are limited by the data collected from infrastructure-based sensors

5. Current VSL and ramp metering systems are optimized for mobility, not the environment

6. Current VSL and ramp metering systems do not collect and use (or collect and use minimal) environmental data

7. Emissions data are not collected from vehicles
Limitations of Current System (cont’d)

8. Current VSL Systems, especially in the United States, have low levels of speed compliance

9. ACC systems have a delay in sensing changes in the lead vehicle’s motion, requiring a longer minimum gaps between vehicles than CACC systems

10. In-Vehicle Systems do not provide travelers with parameters about HOV, HOT, and/or eco-lanes or alternative travel choices for entering the eco-lanes

11. Electric vehicles are not capable of charging their batteries as they drive along the roadway
Defining the System

**Dynamic Eco-Lanes System**
- Most likely resides in a Traffic Management Center
- Developed by state and local DOTs and ITS developers
- Integrated with existing ITS systems (i.e., ATMS operating platforms)
- Collect V2I messages (e.g., probe messages and environmental messages)
- Processes connected vehicle and ‘conventional’ data
- Disseminates traveler information messages
- Implements operational strategies (e.g., ramp meter timing plans, eco-speed limits, etc.)

**In-Vehicle System**
- Resides in the vehicle
- Developed by automobile OEMs or aftermarket device vendors.
- Collects vehicle diagnostics data, V2V, and V2I messages
- Provides V2V messages to other vehicles
- Provides V2I messages to Connected Vehicle Roadway Equipment
- Implements eco-driving strategies (e.g. CACC, vehicle platooning, etc.)
Dynamic Eco-Lanes System

- The Dynamic Eco-Lanes System is a computerized transportation operations system that:
  - Gathers traffic and environmental information from multiple sources.
  - Processes data and determines whether an eco-lane should be created or decommissioned along a roadway.
  - Readily adapts to actual and predicted traffic volumes and environmental conditions so that the traffic network operation is optimized to reduce emissions.
  - Establishes parameters for eco-lanes including the locations of the eco-lanes. Parameters may include:
    - Number of lanes of the roadway that will be dedicated as eco-lanes
    - Start and end time for the eco-lanes
    - Criteria for vehicles entering the eco-lanes
    - Parameters for vehicle platooning
  - Manages operational strategies (e.g., eco-speed limits, ramp metering, and vehicle platooning) in the eco-lanes with the objective of reducing fuel consumption and overall emissions along the roadway segment.
  - Provides traveler information and shares information about the eco-lane with regional jurisdictions to support coordinated operations.
Potential Variations of Eco-Lanes

Parameters for Electric Vehicle or AFV Lanes

Parameters for Dedicated Truck-Only Lanes

Parameters for Bus-Only Lanes

Parameters for Vehicle Platoon Lanes

Source: Nissan
http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/eco_town.html

Source: The Atlantic Cities
http://www.theatlanticcities.com/technology/2012/05/coming-soon-l-dedicated-electric-lanes-trucking/2016/

Source: Energy, Climate, Transportation Blogspot
http://energyclimatetransportation.blogspot.com

Source: PATH
http://www.path.berkeley.edu(PATH)/Research/Demos/
DYNAMIC ECO-LANES SYSTEM

**ACTORS THAT PROVIDE INPUTS**

- Traffic Management Centers
- Connected Vehicle Roadway Equipment
- ITS Roadway Equipment
- Emissions Management Centers
- Operator

**ACTORS THAT RECEIVE OUTPUTS**

- Traffic Management Centers
- Connected Vehicle Roadway Equipment
- ITS Roadway Equipment
- Emissions Management Centers
- Enforcement Agencies
- Operator

**Data Collection Elements**

- Traffic Data Collection
- Environmental Data Collection
- Field Device Status Data Collection
- Vehicle Specific Data Collection
- Operator Input

**Data Processing Elements**

- Real-Time and Predicted Traffic Conditions
- Real-Time and Predicted Environmental Conditions
- Eco-Ramp Meter Timing
- Eco-Speed Limits
- Vehicle Platooning Parameters
- Eco-Lanes Parameters
- Eco-Lane Violations

**Data Dissemination Elements**

- Traffic and Environmental Conditions Dissemination
- Eco-Ramp Meter Timing Dissemination
- Eco-Speed Limit Dissemination
- Vehicle Platooning Parameters Dissemination
- Eco-Lane Parameters Dissemination
- Eco-Lane Violation Dissemination

**Data Storage Archive Elements**

“Cleaner Air Through Smarter Transportation”
In-Vehicle System

- The In-Vehicle System:
  - Collects information about the dynamic eco-lanes, as well as traffic and environmental conditions, and presents this information to the driver to assist him or her in making informed pre-trip and en-route travel choices.
  - Provides real-time advice to drivers so that they can adjust driving behavior to save fuel and reduce emissions. The advice includes recommended driving speeds, optimal acceleration, and optimal deceleration profiles on freeways.
  - Supports eco-driving, eco-cooperative adaptive cruise control (eco-CACC), and vehicle platooning applications.
  - Collects emissions data from vehicle diagnostic systems or other on-board sensors to disseminate these data to Connected Vehicle Roadway Equipment. These data would be used by the Dynamic Eco-Lanes System – located at a center – to determine:
    - Dynamic eco-lane parameters
    - Vehicle platooning parameters
    - Eco-speed limits, ramp metering plans, and other traffic control strategies.
IN-VEHICLE SYSTEM

**Data Collection Elements**
- Driver Input
- Traffic Conditions
- Environmental Conditions
- Vehicle Platooning Parameters
- Eco-Lanes Parameters
- Eco-Speed Limits
- ‘Other Vehicle’ Vehicle Status
- Diagnostics Data

**Data Processing Elements**
- Traveler Information Processing
- Dynamic Eco-Lanes Criteria Determination
- Eco-Driving, Eco-Cooperative Cruise Control, and Vehicle Platooning
- Vehicle Status

**Data Dissemination Elements**
- Driver Information Dissemination
- Vehicle Status Dissemination

**Vehicle Assisted Control Element**
- Vehicle Control Strategy

**Data Storage Archive Elements**

**ACTORS THAT PROVIDE INPUTS**
- Driver
- Connected Vehicle Roadway Equipment
- Vehicle Diagnostic Systems
- Other Vehicles
- Other Onboard Sensors
- Inductive Charging Roadway Equipment

**ACTORS THAT RECEIVE OUTPUTS**
- Vehicle Actuators
- Driver
- Other Vehicles
- Connected Vehicle Roadway Equipment
- Inductive Charging Roadway Equipment
Dynamic Eco-Lanes Needs Version 1.0

IN-VEHICLE SYSTEM

Data Collection Element
1. IVS-DC-01: Collect Driver Input
2. IVS-DC-02: Receive Traffic Conditions Data
3. IVS-DC-03: Collect Geographic Information Descriptions (GID) Data
4. IVS-DC-04: Receive Environmental Conditions Data
5. IVS-DC-05: Receive Vehicle Platooning Parameters
6. IVS-DC-06: Receive Eco-Lanes Parameter Information
7. IVS-DC-07: Receive Eco-Speed Limits
8. IVS-DC-08: Receive Vehicle Status Data from Other Vehicles (i.e., BSM)
9. IVS-DC-09: Collect Vehicle Diagnostics Data
10. IVS-DC-10: Receive Inductive Charge

Data Processing Element
1. IVS-DP-01: Generate Eco-Driving Strategies
2. IVS-DP-02: Determine if Vehicle Meets Criteria for Vehicle Platooning
3. IVS-DP-03: Generate Eco-Cooperative Adaptive Cruise Control and Vehicle Platooning Strategies
4. IVS-DP-04: Determine if the Vehicle Meets Criteria to Enter the Dynamic Eco-Lanes
5. IVS-DP-05: Process Traffic and Environmental Data for Traveler Information Messages
6. IVS-DP-06: Determine Vehicle Emissions Data

Data Dissemination Element
1. IVS-D-01: Disseminate Vehicle Status Data
2. IVS-D-02: Disseminate Vehicle Status Environmental Data
3. IVS-D-03: Provide Traffic Conditions to the Driver
4. IVS-D-04: Provide Environmental Conditions to the Driver
5. IVS-D-05: Provide Eco-Lanes Parameters to the Driver
6. IVS-D-06: Provide Vehicle Platooning Parameters to the Driver
7. IVS-D-07: Provide Eco-Driving Information to the Driver

Vehicle Control Element
1. IVS-VC-01: Provide Eco-Driving Vehicle Assisted Control Strategy

Driver Interface Element
1. IVS-DI-01: Provide Operator Interface
<table>
<thead>
<tr>
<th>ID</th>
<th>Actors</th>
<th>Data Flow / Action</th>
<th>Related User Needs</th>
</tr>
</thead>
</table>
| 1  | In-Vehicle System and Driver | In-Vehicle System sends to Driver  
- Eco-Lanes Parameter Information (e.g., Location, entrance criteria, Eco-Speed Limits, etc.)  
- Vehicle Platooning Parameters (e.g., locations, number of vehicles, speeds, etc.)  
- Eco-Dimming Information  
- Traffic conditions  
- Environmental conditions (e.g., code red air quality alerts)  
- Road weather conditions  
- Status of an electric vehicle’s electric charge and charge received from inductive charging field infrastructure  
Driver Sends to In-Vehicle System  
- Activation of Application (e.g., activate eco-Cooperative adaptive cruise control)  
- Updates to configurable parameters | IVS-DC-01: Collected Driver Input  
IVS-D-03: Provide Traffic Conditions to the Driver  
IVS-D-04: Provide Environmental Conditions to the Driver  
IVS-D-05: Provide Eco-Lanes Parameters to the Driver  
IVS-D-06: Provide Vehicle Platooning Parameters to the Driver  
IVS-D-07: Provide Eco-Dimming Information to the Driver  
IVS-DI-01: Provide Driver Interface |
| 2  | In-Vehicle System and Other Vehicles | In-Vehicle System sends to Other Vehicles  
- Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.)  
Other Vehicles send to In-Vehicle System  
- Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.) | IVS-DC-08: Receive Vehicle Status Data from Other Vehicles  
IVS-D-01: Disseminate Vehicle Status Information |
- Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.)  
- Vehicle status environmental data (e.g., BEM data including the vehicle’s fuel type, engine type, current emissions, average | IVS-DC-02: Receive Traffic Conditions  
IVS-DC-03: Collected Geographic Information Description Data  
IVS-DC-04: Receive Environmental Conditions |
### Dynamic Eco-Lanes: Establishing an Eco-Lane

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>In-Vehicle Systems</strong> collect data from vehicle diagnostic systems and other onboard systems about the vehicle’s emissions and vehicle’s status (e.g., current speed, acceleration, location, etc.). These data are sent to Connected Vehicle Roadway Equipment using DSRC, cellular, or other wireless communications.</td>
</tr>
<tr>
<td>2</td>
<td><strong>Other Centers</strong> provide traffic, environmental, and transit data to the <strong>Dynamic Eco-Lanes System</strong>. Traffic data includes volumes, speeds, occupancy, travel times, incidents, or other traffic data collected by a Traffic Management Center. These data may be collected using ITS Roadway Equipment such as traffic sensors, probe vehicles, or other ITS technologies. Environmental data includes air quality data or weather data collected by Emissions Management Centers.</td>
</tr>
<tr>
<td>3</td>
<td>The <strong>Dynamic Eco-Lanes System</strong> uses the data collected from Connected Vehicle Roadway Equipment, ITS Roadway Equipment, and Other Centers to determine whether an eco-lane should be established, and if so, the parameters of the eco-lane. <strong>These parameters include the geographic limits of the eco-lane, the duration of the eco-lane, and types of vehicle permitted to use the eco-lane (i.e., the eco-lanes may restrict high emitting vehicles from using the lanes).</strong></td>
</tr>
<tr>
<td>4</td>
<td>The eco-lane is established by the <strong>Dynamic Eco-Lanes System</strong> and is approved by the operator. <strong>The Dynamic Eco-Lanes System</strong> geo-fences the geographic limits of the eco-lane and assigns parameters including the types of vehicles permitted to use the eco-lanes.</td>
</tr>
</tbody>
</table>
### Dynamic Eco-Lanes: Traveler Information

**Step 1 |** The Dynamic Eco-Lanes System determines the parameters for the eco-lanes.
- **Step 1 A |** The Dynamic Eco-Lanes System determines the parameters for the eco-lanes.
- **Step 1 B |** The Dynamic Eco-Lanes System sends parameters about the eco-lanes to Other Centers such as Traffic Management Centers and Transit Management Centers. These centers use information about the eco-lanes to support their traffic and transit operations in the vicinity of the eco-lanes.
- **Step 1 C |** Connected Vehicle Roadside Equipment broadcast messages about the parameters of the eco-lanes. Messages may be broadcast using DSRC communications or other wireless communications (e.g., 4G).
- **Step 1 D |** ITS Roadway Equipment including Dynamic Message Signs and 511 Systems provide information about the parameters of the eco-lanes.

**In-Vehicle Systems receive information about the parameters of the eco-lanes.** This information is presented to drivers to assist them in making informed en-route travel choices as they approach the eco-lane. **Prior to entering the eco-lane,** drivers would be presented with comparisons about using the eco-lanes versus the regular lanes. The traveler information would also inform the driver if his or her vehicle is permitted to use the eco-lane.

**Step 2 |** Other Centers These centers use information about the eco-lanes to support their traffic and transit operations in the vicinity of the eco-lanes.

**Step 3 |** Travelers receive pre-trip traveler information about the parameters of the eco-lanes and other traveler information on their personal computers, cell phones, tablets, television, radio, or 511 traveler information systems.

**Step 4 |** Travelers receive pre-trip traveler information about the eco-lanes and other traveler information on their personal computers, cell phones, tablets, television, radio, or 511 traveler information systems. Travelers use this information to plan their trips accordingly. For example, upon receiving information about the eco-lanes, travelers may use their alternative fuel vehicle to drive into Metropolis City.
In-Vehicle Systems collect data from vehicle diagnostic systems and other onboard systems about the vehicle’s emissions and vehicle’s status (e.g., current speed, acceleration, location, etc.). These data are sent to Connected Vehicle Roadway Equipment using DSRC, cellular, or other wireless communications.

The Dynamic Eco-Lanes System collects vehicle status data from vehicles traveling in an eco-lane. This information along with historical traffic conditions, and data collected from roadway sensors are used to calculate environmentally optimized speed limits for the eco-lane(s). The speed limits also consider congestion and incidents to slow the speed of vehicles approaching the back of a queue. Eco-speed limits are determined for each roadway segment and are specific to a travel lane. Lane specific eco-speed limits need to be determined to differentiate speeds for eco-lanes versus regular lanes running adjacent to the eco-lanes. The system updates the eco-speed limit every 5 minutes based on real-time and predicted traffic conditions.

The Dynamic Eco-Lanes System sends eco-speed limit information to VSL signs and to Connected Vehicle Roadway Equipment.

In-Vehicle Systems receive eco-speed limits disseminated by Connected Vehicle Roadway Equipment and present this information to the driver. The driver adjusts his/her vehicle’s speed according to the speed limit.
### Dynamic Eco-Lanes: Eco-CACC (Non-Platooning)

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Dynamic Eco-Lanes System determines traffic and weather conditions and for the eco-lanes and regular lanes. This information includes average speeds for roadway segments, incidents, lane closures, construction and maintenance activities, and road weather conditions. Traffic and weather messages are disseminated to vehicles using Connected Vehicle Roadway Equipment that uses DSRC and other wireless communications (e.g., 4G).</td>
</tr>
<tr>
<td>2</td>
<td>The lead vehicle’s In-Vehicle System collects data from its diagnostic systems about the vehicle’s status (e.g., current speed, acceleration, location, etc.). These data are broadcasted by the In-Vehicle Systems using DSRC.</td>
</tr>
<tr>
<td>3</td>
<td>The following vehicle is equipped with an Eco-Cooperative Adaptive Cruise Control Application. Its In-Vehicle System receives traffic conditions from Connected Vehicle Roadway Equipment and vehicle status messages from surrounding vehicles using V2V communications. V2V messages from the lead vehicle are received at a rate of ten times per second. The Driver activates the Eco-Cooperative Adaptive Cruise Control application setting a desired or acceptable gap between his/her vehicle and the lead vehicle. The Eco-Cooperative Adaptive Cruise Control application controls the speed of a vehicle adjusting the vehicle’s speed to maintain a constant speed and a safe time gap from the lead vehicle. The Eco-Cooperative Adaptive Cruise Control application incorporates information, such as road grade, roadway geometry, and road weather information, to determine the most environmentally efficient trajectory for the vehicle. Note: Road grade and road geometry data are collected from the In-Vehicle System’s map.</td>
</tr>
</tbody>
</table>

“Cleaner Air Through Smarter Transportation”
The Dynamic Eco-Lanes System disseminates vehicle platooning parameters including the geographic limits (start and end locations) for vehicle platooning capabilities, as well as, speed, and gap strategies for the platoon.

Vehicles in a vehicle platoon disseminate parameters about the platoon including the speed of the platoon, number of vehicles in the platoon, location of the platoon, and type of vehicles in the platoon (e.g., platoons may be limited to trucks or transit vehicles). This information is broadcast using V2V DSRC.

Note: The lead vehicle in the platoon is an autonomous vehicle.

A vehicle approaching the back of the platoon meets the security requirements to enter the platoon and has been approved by the operating entity to join the platoon. The vehicle's In-Vehicle System receives information about the nearby platoon and its parameters. As the vehicle approaches the end of the vehicle platoon, the vehicle "attaches" itself to the platoon. Vehicles travel with small gaps, reducing aerodynamic drag. V2V communication allows vehicles to accelerate or brake with minimal lag to maintain the platoon with the lead vehicle.

The In-Vehicle System sends a message to the last vehicle in the platoon requesting the vehicle to join the platoon. The last vehicle in the platoon accepts the request. The vehicle “attaches” itself to the platoon. The driver is notified that he has joined the platoon and has been released from lateral and longitudinal movement of the vehicle while his vehicle is in the platoon. Vehicles travel with small gaps, reducing aerodynamic drag. V2V communication allows vehicles to accelerate or brake with minimal lag to maintain the platoon with the lead vehicle. The reduction in drag results in reduced fuel consumption, greater fuel efficiency, and less pollution for vehicles.
**Dynamic Eco-Lanes: Leaving a Vehicle Platoon**

1. **Description**: The Dynamic Eco-Lanes System disseminates a message containing location for the end of the vehicle platooning lane. The message also includes information to assist the vehicles in merging with the regular lane including recommended gaps and speeds for the vehicles as they leave the platoon. These recommended speeds and gaps are based on real-time traffic conditions in the eco-lanes and regular lanes. The message is broadcasted by Connected Vehicle Roadway Equipment using DSRC or other wireless communications (e.g., 4G).

2. **Description**: Vehicles in the platoon receive the message about the end of the platooning lane and information about recommended speeds and gaps as the vehicles merge with the regular lanes. Prior to the end of the vehicle platooning lanes, the gaps between vehicles increases and the vehicle speeds decrease. The larger gaps between vehicles continue to increase until a threshold is met and the driver is alerted that control of the vehicle will be given back to the driver.

3. **Description**: Vehicles in the regular lanes receive messages that the vehicle platooning lanes are ending. The vehicles also receive messages with recommended speeds specific to the regular lanes to assist with upcoming merge and possibly messages directing them to move to the right lane. This information is provided to drivers who manually adjust their vehicle’s speed.
### Dynamic Eco-Lanes: Dynamic Inductive Charging

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Connected Vehicle Roadway Equipment broadcasts parameters about the eco-lanes. <strong>These parameters include information about the location of inductive charging infrastructure in the eco-lanes.</strong></td>
</tr>
<tr>
<td>2</td>
<td>The In-Vehicle System receives messages about the parameters for the eco-lanes – including the location of inductive charging infrastructure. The driver of the electric vehicle opts into an inductive charging application. The application informs the driver of the location of inductive charging infrastructure.</td>
</tr>
<tr>
<td>3</td>
<td>As the vehicle approaches the first inductive charging pad, the vehicle establishes a wireless connection with the inductive charging infrastructure. A handshake process begins, payment information is sent to inductive charging equipment, and an electric charge is transferred from the pad to the vehicle.</td>
</tr>
<tr>
<td>4</td>
<td>The vehicle passes over wireless inductive charging pads. Each time the vehicle is positioned over the pad and the vehicle’s application is activated, the vehicle receives energy from the pads.</td>
</tr>
<tr>
<td>5</td>
<td>The vehicle stops receiving energy from the inductive charging pads when one of the following criteria is met: (1) the vehicle’s battery is fully charged, (2) the driver opts out of the inductive charging application, or (3) the vehicle passes over the last charging pad. Upon termination, transfer of payment is made for the energy transferred.</td>
</tr>
</tbody>
</table>

**DRAWING NOT TO SCALE**
## Goals, Objectives, and Performance Measures

<table>
<thead>
<tr>
<th>Goal #1: Reduce Environmental Impacts</th>
<th>Goal #2: Support “Green Transportation Decisions” by Travelers and Operating Entities</th>
<th>Goal #3: Enhance Mobility of the Transportation System (secondary goal)</th>
<th>Goal #4: Improve the Safety of the Transportation System (secondary goal)</th>
</tr>
</thead>
</table>
| • Reduce Emissions from Surface Transportation Vehicles  
  • Reduce CO₂, CO₂, NOₓ, SO₂, PM₁₀, PM₂.₅, VOCs  
• Reduce Energy Consumption Associated with Surface Transportation Vehicles  
  • Reduce excess fuel  
  • Reduce energy consumption | • Increase Modal Shifts to Transit, Carpooling, and Vanpooling  
• Increase Purchases of Alternative Fuel Vehicles (AFVs)  
• Increase Vehicle Miles Traveled (VMT) of Alternative Fuel Vehicles  
• Increase Eco-Driving Awareness and Practice  
• Reduce Range Anxiety for Drivers of Electric Vehicles  
• Increase the Range of Electric Vehicles | • Improve the Efficiency of the Transportation System  
  • Reduce delay  
  • Improve the efficiency of the freeway (e.g., LOS)  
• Improve Transit Operating Efficiency  
• Improve Freight Operating Efficiency | • Reduce Crashes, Injuries, and Fatalities  
  • Reduce total number of crashes on the freeway  
  • Reduce the number of injuries on the freeway  
  • Reduce the number of fatalities on the freeway |

“Cleaner Air Through Smarter Transportation”

U.S. Department of Transportation
Dynamic Eco-Lanes | Policy Considerations

- Would certain vehicle types be allowed to use eco-lanes at a higher priority than other vehicle types?

- Are there mobility tradeoffs? If so, how do operating entities make a decision to optimize for the environment instead of optimizing for mobility?

- How can this Transformative Concept facilitate “green” choices by:
  - Drivers,
  - State and local DOT’s operating the transportation system, and
  - Decision Makers?

- How can this Transformative Concept incentivize “green” choices by:
  - Drivers,
  - State and local DOT’s operating the transportation system, and
  - Decision Makers?

- How does open data sharing and standardization be used to support public and private sector deployment?

- Under what situation(s) would an operating entity choose to implement eco-lanes?

- How do Decision Makers value eco-lanes as an option for investing scarce resources?
Dynamic Eco-Lanes | Education

- What are the social benefits of “green” transportation decisions?
  - Drivers
  - State and local DOT’s operating the transportation system
- What types of educational campaigns could be used to educate the traveling public to make green transportation choices?
- What types of educational campaigns could be used to educate entities operating the transportation network to optimize for the environment?
- How do you incentivize a choice versus another choice? And how do you get people to act on that choice?

Provide travelers and entities operating the transportation network the information they need to make “green” transportation choices.
DYNAMIC ECO-LANES ANALYSIS PLAN

BALAJI YELCHURU, BOOZ ALLEN HAMILTON
Dynamic Eco-Lanes Applications

- **The Dynamic Eco-Lanes Transformative Concept:**
  - Uses connected vehicle technologies to decrease fuel consumption and GHG and criteria air pollutant emissions.
  - Uses dedicated lanes optimized for the environment and supports operational strategies such as variable speed limits, cooperative adaptive cruise control, traveler information and driving recommendations to reduce environmental impacts.

- **Applications**
  - Dynamic Eco-Lanes
  - Eco-Speed Harmonization
  - Eco-Cooperative Adaptive Cruise Control
  - Eco-Ramp Metering
  - Multi-Modal Traveler Information
  - Connected Eco-Driving
## Traveler/Driving Behavior Affected

<table>
<thead>
<tr>
<th>Application</th>
<th>Part of Trip Chain Affected</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Eco-Lanes</td>
<td></td>
<td>If the travel times are affected severely, route choices may be affected.</td>
</tr>
<tr>
<td>Eco-Speed Harmonization</td>
<td></td>
<td>Lane Choice and Driving behavior are likely to be most affected.</td>
</tr>
<tr>
<td>Eco-Cooperative Adaptive Cruise Control</td>
<td></td>
<td>Lane Choice and Driving behavior are likely to be most affected.</td>
</tr>
<tr>
<td>Eco-Ramp Metering</td>
<td></td>
<td>May influence route choice if the travel times are affected.</td>
</tr>
<tr>
<td>Multi-Modal Traveler Information</td>
<td></td>
<td>Most parts of trip chain are likely to be impacted to some degree.</td>
</tr>
<tr>
<td>Connected Eco-Driving</td>
<td></td>
<td>Route changes may or may not be seen.</td>
</tr>
</tbody>
</table>

- Full circle: Application has a definite influence on the particular trip chain element.
- Half circle: Application has a probable influence on the particular trip chain element.
- Quarter circle: Application has only a possible influence on the particular trip chain element.
Performance Measures Used for Modeling

Environmental Measures

- Fuel Consumption (gallons)
- Emissions
  - CO₂ (Carbon Dioxide)
  - PM-10 (Particulate Matter)
  - PM-2.5 (Particulate Matter)
  - NOₓ (Oxides of Nitrogen)
  - Non-methane Hydro Carbon
  - CO (Carbon Monoxide)

Mobility Measures

- Total Delays
- Intersection Delay
- Travel Times
- Number of Stops

*Mobility Performance Measures not used for AERIS benefit assessment*
AERIS Baseline

- For the purpose of defining AERIS modeling, baseline conditions assume a region that includes both arterial and freeway facilities under “high” levels of traffic.

**Arterial Network**

- Signalized corridor with 2-3 lanes per direction
- **Speed Limit**: 35 to 45 mph
- **Traffic Signal Operations**: uncoordinated, non-optimized, and fixed signal controls
- **Intersection Spacing**: Approximately 3-4 intersections/mile
- **Traffic Congestion (high)**: 500-600 vehicles/hour/lane

**Freeway Network**

- Basic freeway segment with 3-5 lanes/direction
- **Speed Limit**: 55-65 mph
- **Traffic Congestion (high)**: 2,000 vehicles/hours/lane
- **Ramp spacing**: 1 mile
- **Roadway grade**: 0%
Model Region Description | SR-91 E, CA

- 12-mile stretch of State Route 91 eastbound (SR-91 E) in Riverside County, California
- Freeway connects Riverside County to Orange and LA Counties
- Most congested freeway in Riverside County
- 3-5 mixed-flow (MF) lanes plus one HOV lane
- 11 off-ramps and 9 on-ramps of which two have HOV bypass
- The HOV lane is buffer separated with limited access (24hr operation)

Applications modeled
- Dynamic Eco-Lanes
- Eco-Speed Harmonization
- Eco-Cooperative Adaptive Cruise Control
- Eco-Ramp Metering

“Cleaner Air Through Smarter Transportation”
Model Region Description | Phoenix, AZ

- Entire Greater Phoenix metropolitan region modeled by Maricopa Association of Governments (MAG), AZ
  - 3000 zones
  - 3.5+ million people, and
  - 15 million trips and transit
- Includes 500 sq. miles of Phoenix region and surroundings
- Applications modeled
  - Multi-Modal Traveler Information
AERIS Hypothesis Overview

- **Primary Hypothesis**
  - Using connected vehicle data, signal and vehicle operations can be altered to achieve significant environmental benefits.

- Hypothesized environmental benefits are based on % fuel and emissions savings of the same or similar applications reported in literature, or estimated by the research team if no existing information is available.

- For the purposes of developing hypothesis, AERIS environmental benefits are expressed in terms of % savings from AERIS application relative to the baseline.

\[
\text{% Fuel Savings} = 100\% \times \frac{\text{fuel}_{\text{baseline}} - \text{fuel}_{\text{AERIS}}}{\text{fuel}_{\text{baseline}}}
\]

\[
\text{% CO}_2\text{Savings} = 100\% \times \frac{\text{CO}_2_{\text{baseline}} - \text{CO}_2_{\text{AERIS}}}{\text{CO}_2_{\text{baseline}}}
\]
Hypothesis | Dynamic Eco-Lanes Transformative Concept

- Hypothesis
  - If all six applications in the Dynamic Eco-Lanes Transformative Concept are implemented together, then there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
    - 10%–15% under partial connected vehicle penetration.
    - 15%–20% under full connected vehicle penetration.

Fuel and emissions savings may result from operational improvements, potential mode shift and route changes.
Modeling Approach | Overview

- Applications except Multi-Modal Traveler Information will be initially modeled and tested individually using a corridor network.
  - Algorithms will be developed and implemented through an API to represent AERIS applications using microsimulation software (e.g., Paramics, VISSIM).
- Multi-Modal Traveler Information modeled using a regional network on a region using a demand and DTA tool with an emissions tool.
- With the exception of Multi-Modal Traveler Information Application, for the initial analysis, mode choice and route choice impacts resulting from Dynamic Eco-Lanes application will not be considered as the impact is expected to be minimal.
Bundling of Applications

- After the initial development and testing of individual applications, applications will be modeled together on a combined network/region (Phoenix) to estimate benefits of all applications implemented together.
  - Estimate total benefits of the Transformative Concept
  - Inspect interactions of applications with each other
  - Route choice and mode choice impacts will be captured
  - Regional impacts of Eco-lanes applications will be captured
  - Small area microsimulation simulation will be carried out and integrated with demand and DTA tool
Hypothesis | Dynamic Eco-Lanes

- **If** Eco-Lanes criteria and boundaries are established to encourage use by low emission, high occupancy, freight, transit, and alternative fuel or regular vehicles operating in eco-friendly ways (e.g. eco-speed limits or vehicle platooning), **then** there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 0%–1% under partial connected vehicle penetration.
  - 0%–2% under full connected vehicle penetration.

% fuel and emissions savings during off-peak hours are expected to be higher as the freeway would have more capacity left for establishing Eco-Lanes.

% fuel and emissions savings are due only to operational improvements and not any from potential route shift.
Modeling Approach | Dynamic Eco-Lanes

- Application modeling builds on existing HOV/HOT lanes modeling.
- Dynamically establish:
  - Criteria for entering the eco-lanes
  - Number of lanes
  - Start and end of the eco-lanes (both spatially and temporally)
- Develop algorithm to use information about criteria for vehicles to enter the eco-lanes, current and predicted traffic conditions in the eco-lanes, and geographic boundaries of the eco-lanes to determine lane choice.
- Develop process to restrict entry into eco-lanes using information pertaining to vehicle such as vehicle type, fuel type, and emissions generated.
- Use pre-trip and en-route information in the lane choice module to determine paths.
Hypothesis | Eco-Speed Harmonization

- If eco-speed limits determined based on traffic condition, weather, and vehicle characteristics (e.g., vehicle type, age, fuel type) are broadcasted via in-vehicle driver interfaces and variable speed limit (VSL) signs, then there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 3%–6% under partial connected vehicle penetration.
  - 5%–10% under full connected vehicle penetration.

% fuel and emissions savings during off-peak hours are expected to be lower as traffic would already travel close to the original speed.
Modeling Approach | Eco-Speed Harmonization

- The application builds on existing algorithms for modeling Variable Speed Limits applications, but the speed recommendations seek to minimize emissions and fuel consumption.

- Develop algorithms that dynamically generate and change speed limits while approaching areas of traffic congestion, bottlenecks and other conditions that impact flow.
  - Based on grade, vehicle type, and other considerations

- Objective function is to minimize emissions by improving flow, reducing unnecessary stops and starts and maintaining consistent speeds.

- Model the dissemination of eco-speed limit information using VSL signs on specific links or sent directly to vehicle.
Hypothesis | Eco-Cooperative Adoptive Cruise Control

- *If* two or more vehicles are platooned to reduce queuing effects and aerodynamic drag, *then* there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 4%–8% under partial connected vehicle penetration.
  - 8%–16% under full connected vehicle penetration.

% fuel and emissions savings during off-peak hours are expected to be lower as the platooning strategy in this application would have less effects on the traffic flow.

% fuel and emissions savings for heavy duty vehicles would be higher due to the aerodynamic drag effects.
Modeling Approach | Eco-Cooperative Adoptive Cruise Control

- Modeling builds on the existing Cooperative Adaptive Cruise Control algorithms, but parameters are set with environmental objective.
- Algorithm determines the most fuel-efficient speed profiles for lead vehicle based on vehicle characteristics and other information, such as road grade, roadway geometry, and road weather information.
- Develop a logic to establish platoons and model V2V communication to simulate vehicle receiving vehicle platooning parameters such as instantaneous speed and safe time gap from the lead vehicle. Over-ride the default car-following model.
- Collect vehicle specific information regarding its current speed and acceleration/deceleration rates at each time step and use information to determine environmentally optimum acceleration and speed profiles for the following vehicles.
- Model environmental impact of vehicle platoons that considers aerodynamic drag.
Hypothesis | Eco-Ramp Metering

- If signal timing plan of freeway on-ramps are adjusted based on mainline traffic and emissions estimates from vehicles, then there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 5%–8% under partial connected vehicle penetration.
  - 10%–15% under full connected vehicle penetration.

% fuel and emissions savings during off-peak hours are expected to be smaller as the application would have less effect on the network.

% fuel and emissions savings for heavy duty vehicles would be higher as they would stop and idle less.
Modeling Approach | Eco-Ramp Metering

- The application builds on existing ramp metering algorithms, but the freeway on-ramp signal timing plan is updated to achieve overall emissions reductions instead of mobility objective.

- Develop algorithm to determine environmentally efficient operation of traffic signals at freeway on-ramps.
  - Change the rate of vehicles entering the freeway.
  - Develop timing plan for ramp-meter that reduces overall emissions
    - Reducing emissions from bottlenecks forming on the freeways as well as emissions from vehicles on the ramp.

- Use real-time and predicted traffic and environmental conditions on the ramp, on the freeway upstream and downstream of the ramp.

- Determine a timing plan for the ramp meter based on current and predictive traffic and environmental conditions.
Hypothesis | Multi-Modal Traveler Information

- *If* pre-trip and en-route multi-modal traveler information is provided to encourage environmentally friendly transportation choices such as taking transit and potentially changing travel patterns and mode, *then* there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 3%–5% under partial connected vehicle penetration.
  - 6%–8% under full connected vehicle penetration.

% fuel and emissions savings during off-peak hours are expected to be the same or lower as the mode shift and changes in travel patterns may have less effect.
Modeling Approach | Multi-Modal Traveler Information

- Builds on existing Advanced Traveler Information Systems algorithms.

- Model behavior changes (mode choice, time of day choice and route choice) in response to providing pre-trip and en-route traveler information such as real-time and predicted roadway speeds, transit arrival and departure times and transit schedule.

- Estimate the regional emissions impact of predicted behavior changes.

- Establish a dynamic relationship between demand generation (mode and route choice) and prevailing network performance.
  - Support multi-modal analysis
Modeling Approach | Multi-Modal Traveler Information (cont’d)

- Use SimTRAVEL Integrated Modeling Framework developed by Arizona State University.
  - An Integrated Land Use – Transport Model System with Dynamic Time-dependent Activity-travel Microsimulation

- The multimodal activity-based travel demand model and the DTA model are integrated in a tightly coupled manner.

- Constant communication between the activity-based travel model and the DTA model and captures the dynamic nature of Multi-Modal Traveler Information application.

- Possible to reflect the impact of even slight changes in network conditions on activity schedules and patterns.
Hypothesis | Connected Eco-Driving

- If real-time driving advice (e.g. recommended driving speeds, optimal acceleration, optimal deceleration) is provided to drivers based on prevailing traffic conditions and interactions with nearby vehicles and feedback is provided to encourage drivers to drive in a more environmentally efficient manner, then there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 10%–15% under partial connected vehicle penetration.
  - 15%–20% under full connected vehicle penetration.

% savings assume both freeway and arterial travel.

% savings during off-peak hours are expected to be the same or lower as the drivers may already be driving at optimal speeds.

Vehicles that are not enabled with connected vehicle technologies are also likely to benefit from improvements in overall traffic flow.
Modeling Approach | Connected Eco-Driving

- Provide real-time speed recommendations based on real-time traffic conditions and interactions with nearby vehicles.

- The application would not be limited to signalized intersections, but instead applicable to all sections of the arterial and freeway travel.

- Algorithm to use real-time link by link traffic performance and interaction between vehicles as feedback/input to vehicles’ speed and acceleration selection process as they traverse the network.

- Use downstream traffic conditions to determine speed recommendations and eco-friendly acceleration rates for vehicles.

- Update recommended speeds when the vehicle enters a new roadway link or when real-time traffic speed information on the current roadway link is updated.

- Algorithm to update vehicle trajectories to avoid stop-and-go driving and instead facilitate smooth driving at a constant speed.

- Model the benefit of vehicle-assisted strategies by changing default driving behavior parameters in simulation model (e.g. switch power sources, change gears).
Analysis Scenarios

- Modeling will be performed under various settings to test the hypotheses.

- SR-91E, Phoenix region and El Camino Real networks will be used for initial modeling.
  - All applications will be modeled together using the Phoenix network/region at a later stage.

- A baseline, “do nothing”, model will be developed to represent the conditions of the analyzed area without the AERIS applications.

- Another set of models will be developed where the applications are implemented and their benefits in terms of emissions and fuel savings are assessed.
Analysis Scenarios (cont’d)

- Variables or Parameters of Interest
  - Facility type, such as freeway, arterial, etc.
  - Network Characteristics (e.g. speed limit)
  - Congestion in terms of volume-to-capacity ratio
  - Vehicle mix, % trucks, % alternative fuel vehicles
  - Connected vehicle deployment, such as % of signals enabled with roadside equipment (RSE) and number of vehicles equipped with on-board equipment (OBE).
  - Compliance rate of drivers
Application Analysis Scenarios | Examples

**Dynamic Eco-Lanes**
- Changing the frequency at which the Eco-Lanes boundaries are redefined
- Changing the length of Eco-Lanes
- Exclusive bus-lane
- Dynamically changing the speed limits of eco-lanes based on the vehicle fleet mix and congestion levels
- Changing the criteria for vehicles to enter eco-lanes (e.g. vehicle type)
- Implementation of eco-lanes in an arterial facility

**Eco-Speed Harmonization**
- Changing the frequency at which the variable eco-speed limits get updated
- Changing the stretch of roadway for which the variable speed limits are applicable
- Using anticipated traffic conditions to set the eco-speed limits
Application Analysis Scenarios | Examples

**Eco-Cooperative Adaptive Cruise Control**
- Changing grade of the roadway
- Number of vehicles in the platoon
- Types of vehicles in the platoon (e.g. cars, SUVs)

**Eco-Ramp Metering**
- Changing the frequency at which the signal timing plans get updated
- Different levels of traffic entering and exiting freeway
- Changing the fleet mix of vehicles entering the freeway section

**Multi-Modal Traveler Information**
- Providing predictive travel-time information to travelers
- Providing information on transit operations including schedule, reduced fares
- Providing information on parking availability
Application Analysis Scenarios | Examples

Connected Eco-Driving

- Baseline speed limits set at different levels
- Include both freeway and arterial travel under different levels of congestion
QUESTIONS?
BREAK-OUT SESSION #2
DYNAMIC ECO-LANES
Break-out Session #2

- **Work in groups (led by group facilitators)**
  - Validate Concept of Operations and Modeling Approach Diagrams – 20 minutes
  - Facilitated discussion around ConOps and Modeling questions – 35 minutes
  - Combine comments for debrief to the larger group – 5 minutes
  - Debrief feedback to whole group – 15 minutes per group
Break-out Session #2

- Workshop participants will be divided among 2 rooms to ensure that everyone has the opportunity to think creatively and constructively.

- The first round of Break-out Groups will facilitate discussion around the Dynamic Eco-Lanes Transformative Concept.

- Break-out Session Rooms
  - Room #1: Concord
  - Room #2: Lexington
BREAK-OUT SESSION #2
DYNAMIC ECO-LANES
DYNAMIC LOW EMISSIONS ZONES CONOPS

J.D. SCHNEEBERGER, NOBLIS
Dynamic Low Emissions Zones

- **Similar to today’s ITS**: cordons with fixed infrastructure (e.g., London’s Congestion Pricing)

- **Imagine tomorrow’s connected vehicle applications:**
  - Geo-fencing low emission zone boundaries with flexible parameters.
  - Connected vehicle technology allowing for Low Emissions Zones that can be:
    - Scalable and moveable (e.g., pop-up for a day or special event, removable, flexible)
    - Not dependent on conventional ITS infrastructure.
    - Dynamic based on real-time emissions data collected from vehicles and other sources.
  - Dynamic Low Emissions Zones that provide incentives to drivers who practice “eco-driving” within the Low Emissions Zone.
  - Dynamic Low Emissions Zones that encourage “green” transportation choices, including transit options and freight operations.
Most Polluted Cities | American Lung Association

Over 127 million people live in counties that receive an F for pollution.

Nearly 6.4 million people (2.1%) in the United States live in an area with unhealthful year-round levels of particle pollution. These people live in areas where chronic levels are regularly a threat to their health.

Nearly 4 in 10 people in the United States (38.5%) live in areas with unhealthful levels of ozone. Counties that were graded F for ozone levels have a combined population of almost 116.7 million.

Nearly one in six (16.1%) people in the United States live in an area with unhealthful short-term levels of particle pollution. Nearly 50 million Americans live in 66 counties that experienced too many days with unhealthy spikes in particle pollution. Short-term spikes in particle pollution can last from hours to several days and can increase the risk of heart attacks, strokes and emergency-room visits for asthma and cardiovascular disease, and most importantly, can increase the risk of early death.

Mapping of Most Polluted U.S. Cities

http://www.stateoftheair.org/2012/city-rankings/most-polluted-cities.html

“Cleaner Air Through Smarter Transportation”
Case Study: London’s Low Emissions Zone

- The 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.”
- Covers roadways 24 hours a day, seven days a week.
- Vehicles must meet the Euro III standard for particulate matter (PM), or else pay a daily fee of £200 to drive in the Low Emissions Zone.
- Euro III standards limit emissions of Carbon Monoxide (CO) to 2.1 grams per kilowatt hour (g/kWh), Hydrocarbons (HC) to 0.66 g/kWh, NO$_x$ to 5.0 g/kWh, and PM to 0.10 g/kWh.
Case Study: London’s Low Emissions Zone

How It Works

- Static road signs alert drivers when they are entering or leaving the low emissions zone.
- Closed circuit television (CCTV) cameras capture license plate numbers, and automatic license plate recognition (ALPR) technology uses optical character recognition software to identify vehicles by their license plates.
- System software compares them to a database of vehicles that meet the emissions standards to analyze whether payment is required.
- The system informs officials if a vehicle meets the emissions standards, is exempt, is registered for a discount or if the owner has already paid the daily charge.

Benefits

- According to a 2006 study, concentrations of small particles from traffic sources were expected to decrease across London by 4.3% in 2008 and 8.0% in 2010 due to the Low Emissions Zone, and nitrogen oxides (NO\text{\textsubscript{x}}) were expected to decrease by 3.2% in 2008 and 4.1% in 2010.
Limitations of Current Systems

1. Limited geographically by tolling and other roadside infrastructure
2. Not easily flexible in size, location, nor the time they are operational
3. Do not always consider real-time traffic and environment data when establishing parameters for the Low Emissions Zone
4. Emissions data are not collected from vehicles
5. Do not determine fees for entering the Low Emissions Zone based on vehicle specific data
6. Do not consider incentives to drivers practicing eco-driving strategies
7. Limited real-time travel choices provided en-route to travelers about alternative travel choices for entering the Low Emissions Zone
8. Do not always consider restrictions for passenger vehicles or encourage “green” transportation choices like carpooling, vanpooling, and transit.
Defining the System

Dynamic Low Emissions Zone System
- Most likely resides in a Traffic Management Center
- Developed by state and local DOTs and ITS developers
- Integrated with existing ITS systems (i.e., ATMS operating platforms)
- Collect V2I messages (e.g., probe messages and environmental messages)
- Processes connected vehicle and ‘conventional’ data
- Disseminates traveler information messages (e.g., parameters for the low emissions zone)
- Collects fees or provides incentives

In-Vehicle System
- Resides in the vehicle
- Developed by automobile OEMs or aftermarket device vendors.
- Collects vehicle diagnostics data, V2V, and V2I messages
- Provides V2I messages to Connected Vehicle Roadway Equipment
- Implements eco-driving strategies (e.g. CACC, vehicle platooning, etc.)
- Facilitates fee payments and collection of incentives
Dynamic Low Emissions Zone System

- The Dynamic Low Emissions Zone System is a computerized transportation system that:
  - Gathers traffic and environmental information from multiple sources.
  - Processes these data and determines whether a low emissions zone should be created or decommissioned for an area, along a corridor, or for a region.
  - Determines parameters for the zone including the location and duration of the zone, criteria for vehicles entering the zone, and fee / incentive structures.
  - Supports the collection of fees and/or incentives. Travelers may:
    - Pay a fee for entering the low emissions zone, preferably using connected vehicle electronic toll collection technology. Fees may be based on criteria such as the type of vehicle, engine type, and emissions profile of the vehicle.
    - Receive an incentive (e.g., partial or full fee rebate, credit that can be applied to future low emission zone fees or transit fares) when entering or leaving the zone for green transportation choices. Incentives may be determined based on:
      - Transit usage
      - Amount of time the vehicle spent in the low emissions zone
      - Mileage driven within the zone
      - Amount of emissions emitted while in the zone
  - Provides traveler information and shares information about the low emissions zone with regional jurisdictions to support coordinated operations.
DYNAMIC LOW EMISSIONS ZONE SYSTEM

Data Collection Elements
- Special Event Data Collection
- Transit Operational Data Collection
- Traffic Data Collection
- Environmental Data Collection
- Vehicle Specific Data Collection
- Operator Input
- Electronic Payment / Incentive Data Collection

Data Processing Elements
- Real-Time and Predicted Traffic Conditions
- Real-Time and Predicted Environmental Conditions
- Dynamic Low Emissions Zone Parameters
- Vehicle Fees and Incentives
- Vehicle Violations

Data Dissemination Elements
- Dynamic Low Emissions Zone Parameters Dissemination
- Traffic Conditions Dissemination
- Environmental Conditions Dissemination
- Payment and Incentives Disseminations
- Violations Dissemination

Data Storage Archive Elements

ACTORS THAT PROVIDE INPUTS
- Event Promoters
- Other Centers
- Operator
- ITS Roadway and Payment Equipment
- Connected Vehicle Roadway Equipment

ACTORS THAT RECEIVE OUTPUTS
- Other Centers & ISPs
- ITS Roadway and Payment Equipment
- Connected Vehicle Roadway Equipment
- Operator
- Enforcement Agencies
- Financial Institutions

“Cleaner Air Through Smarter Transportation”
Dynamic Low Emissions Zones Version 1.0

**DYNAMIC LOW EMISSIONS ZONE SYSTEM**

**Data Collection Element**
1. DLEZS-DC-01: Collect Special Event Data
2. DLEZS-DC-02: Collect Transit Operations Data
3. DLEZS-DC-03: Collect Traffic Data
4. DLEZS-DC-04: Collect Environmental Data
5. DLEZS-DC-05: Collect Operator Input
6. DLEZS-DC-06: Collect Vehicle Specific Data
7. DLEZS-DC-07: Collect Electronic Payments

**Data Processing Element**
1. DLEZS-DP-01: Process Traffic Data
2. DLEZS-DP-02: Generate Predicted Traffic Conditions & Forecast Demand
3. DLEZS-DP-03: Process Environmental Data
4. DLEZS-DP-04: Generate Predicted Emissions Profile
5. DLEZS-DP-05: Create and Decommission Low Emissions Zones
6. DLEZS-DP-06: Determine Fees for Vehicles
7. DLEZS-DP-07: Determine Incentives for Individual Vehicles
8. DLEZS-DP-08: Detect Violations for Individual Vehicles
9. DLEZS-DP-09: Manage Electronic Payment Processing

**Data Storage and Archive Element**
1. DLEZ-DA-01: Archive Low Emissions Zone Data
2. DLEZ-DA-02: Archive Financial Data
3. DLEZ-DA-02: Determine Performance Measures

**Data Dissemination Element**
1. DLEZS-D-01: Disseminate Low Emissions Zone Parameters to Vehicles
2. DLEZS-D-02: Disseminate Low Emissions Zone Parameters to Centers & Travelers
3. DLEZS-D-03: Disseminate Traffic Conditions to Other Centers and Travelers
4. DLEZS-D-04: Disseminate Traffic Conditions to Vehicles
5. DLEZS-D-05: Disseminate Multi-Modal Travel Options
6. DLEZS-D-06: Disseminate Environmental Conditions to Other Centers & Travelers
7. DLEZS-D-07: Disseminate Environmental Conditions to Vehicles
8. DLEZS-D-08: Request for Electronic Payment to Individual Vehicles
9. DLEZS-D-09: Request for Payment from Financial Institutions
10. DLEZS-D-10: Provide Incentives
11. DLEZS-D-11: Provide Confirmation of Payment or Incentive to Vehicles
12. DLEZS-D-12: Provide Notice of Violation to Vehicles
13. DLEZS-D-13: Notify Enforcement Agencies of Violations

**User Interface Element**
1. DLEZ-UI-01: User Interface
In-Vehicle System

- **The In-Vehicle System:**
  - Collects information about the Dynamic Low Emissions Zone, as well as traffic and environmental conditions, and presents this information to the driver to assist him or her in making informed pre-trip and en-route travel choices.
  - Collects emissions data from vehicle diagnostic systems or other on-board sensor to disseminate these data to Connected Vehicle Roadway Equipment. These data would be used by the Dynamic Low Emissions Zone System – located at a center – to determine when a Low Emissions Zone should be established or decommissioned based on real-time environmental conditions data. These data would also be used to help determine the fee / incentive structure for the low emissions zone.
  - Collects data to help determine fees / incentives, including:
    - Vehicle type
    - Time or mileage driven within the low emissions zone
    - Emissions emitted while the vehicle is in the low emissions zone
  - Supports payment of fees or collection of incentives using connected vehicle (and other) technologies.
  - Supports eco-driving applications.
### IN-VEHICLE SYSTEM

#### Data Collection Element
1. IVS-DC-01: Collect Driver Input
2. IVS-DC-02: Receive Traffic Conditions Data
3. IVS-DC-03: Receive Environmental Conditions Data
4. IVS-DC-04: Receive Dynamic Low Emissions Zone Parameter Data
5. IVS-DC-05: Receive Payment of Incentive Request Information
6. IVS-DC-06: Receive Confirmation of Payment of Incentive
7. IVS-DC-07: Receive Notice of Violation
8. IVS-DC-08: Collect Vehicle Diagnostics Data

#### Data Processing Element
1. IVS-DP-01: Process Traffic and Environmental Data for Traveler Information Messages
2. IVS-DP-02: Determine Trip/Route Options
3. IVS-DP-03: Determine Eco-Driving Recommendations
4. IVS-DP-04: Determine Vehicle Criteria for Entering the Low Emissions Zone
5. IVS-DP-05: Determine Vehicle Emissions Data
6. IVS-DP-06: Manage Fee Payment

#### Data Dissemination Element
1. IVS-D-01: Provide Traffic Conditions to the Driver
2. IVS-D-02: Provide Environmental Conditions to the Driver
3. IVS-D-03: Provide Dynamic Low Emissions Zone Parameters to the Driver
4. IVS-D-04: Provide Trip/Route Information to the Driver
5. IVS-D-05: Provide Eco-Driving Information to the Driver
6. IVS-D-06: Disseminate Payment/Incentive Data
7. IVS-D-07: Disseminate Vehicle Status Data
8. IVS-D-08: Disseminate Vehicle Status Environmental Data

#### Driver Interface Element
1. IVS-DI-01: Provide Operator Interface
Dynamic Low Emissions Zones

Version 1.0

Other Centers
(Traffic Management Centers, Emissions Management Centers, ISPs, Enforcement Agencies, etc.)

LEGEND

- energy transfer
- wired or wireless communications
- wireless communications

1. Driver
2. Connected Vehicle Roadway Equipment
3. Cell Tower
4. ITS Roadway Equipment
5. Other Centers (Traffic Management Centers, Emissions Management Centers, ISPs, Enforcement Agencies, etc.)
6. Home or Office
7. Vehicular System
8. In-Vehicle System
9. Operator
10. Other Onboard Sensors
11. Vehicle Diagnostics Systems
12. Dynamic Low Emissions Zone System
### Table 1. Dynamic Low Emissions Zones Data Flows and Actions

<table>
<thead>
<tr>
<th>ID</th>
<th>Actors</th>
<th>Data Flow / Action</th>
<th>Related User Needs</th>
</tr>
</thead>
</table>
| 1  | In-Vehicle System and Driver | In-Vehicle System sends to Driver | • IVS-DC-01: Collected Driver Input  
• IVS-D-01: Provide Traffic Conditions to the Driver  
• IVS-D-02: Provide Environmental Conditions to the Driver  
• IVS-D-03: Provide Dynamic Low Emissions Zone Parameters to the Driver  
• IVS-D-04: Provide Trip/Route Information to the Driver  
• IVS-D-05: Provide Eco-Driver information to the Driver  
• IVS-DI-01: Provide Driver Interface |

- Dynamic Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone)
- Eco-driving recommendations (e.g., recommended driving speeds, driver feedback, etc.)
- Multi-modal options
- Traffic conditions
- Environmental conditions (e.g., code red air quality alerts)
- Road weather conditions
- Incentive received (or fee paid)
- Financial information
- Notice of violation

**Driver Sends to In-Vehicle System**

- Activation of Application (e.g., activate eco-driving application, activate incentive application)
- Updates to configurable parameters for Low Emissions Zone access, fees, and/or incentives
- Origin-Destination (O-D) Information

• IVS-DC-03: Receive Environmental Conditions Data  
• IVS-DC-04: Receive Dynamic Low Emissions Zone Parameter Data  
• IVS-DC-05: Receive Payment or Incentive Request Information  
• IVS-DC-06: Receive Confirmation of |

- Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.)
- Vehicle status environmental data (e.g., BEM data including the vehicle’s fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption)
- Vehicle specific data (e.g., vehicle’s make and model, engine type, number of axles, average emissions, average fuel consumption,
**Dynamic Low Emissions Zone: Establishing a Low Emissions Zone**

1. In-Vehicle Systems collect data from vehicle diagnostic systems and other onboard systems about the vehicle’s emissions and vehicle’s status (e.g., current speed, acceleration, location, etc.). These data are sent to Connected Vehicle Roadway Equipment using DSRC, or other wireless communications. Vehicle emissions data may be collected directly from vehicle diagnostic systems or estimated from other data collected from the vehicle. Estimates for emissions may be based on the vehicle’s speed, acceleration, and engine characteristics. If emissions data cannot be collected or estimated on the vehicle, vehicle status data (e.g., speed, acceleration, engine type, etc.) may be sent to a Connected Vehicle Roadway Equipment and then to the Dynamic Low Emissions Zone System which would estimate vehicle emissions at a center.

2. Other Centers/systems provide traffic, environmental, special event, and transit data to the Dynamic Low Emissions Zone System. These data are sent from center to center. Traffic data includes volumes, speeds, occupancy, travel times, incidents, or other traffic data collected by a Traffic Management Center. These data may be collected using ITS Roadway Equipment such as traffic sensors, probe vehicles, or other ITS technologies. Environmental data includes air quality data or weather data collected by Emissions Management Centers. Finally, transit data includes information about transit routes, transit schedules, and other transit related information from the Transit Management Center.

3. The Dynamic Low Emissions Zone System uses the data collected from Connected Vehicle Roadway Equipment, ITS Roadway Equipment, and Other Centers as well as historical data to determine whether a Low Emissions Zone should be established, and if so, the parameters of the Low Emissions Zone. These parameters include the geographic limits of the Low Emissions Zone, duration of the zone, and fee structure parameters.

4. The Low Emissions Zone is established by the Dynamic Low Emissions Zone System and is approved by the operator. The Dynamic Low Emissions Zone System geo-fences the geographic limits of the zone and assigns parameters including the fee structure for the zone. Once the zone is established, traffic and environmental data continue to be collected and monitored by the Low Emissions Zone operators to track the performance of the Low Emissions Zone.
### Dynamic Low Emissions Zone: Traveler Information

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Step 1 A</td>
</tr>
<tr>
<td>1B</td>
<td>Step 1 B</td>
</tr>
<tr>
<td>1C</td>
<td>Step 1 C</td>
</tr>
<tr>
<td>1D</td>
<td>Step 1 D</td>
</tr>
<tr>
<td>2</td>
<td>Travelers receive pre-trip traveler information about the parameters of the Low Emissions Zone and other traveler information. This information may be received by travelers from the Low Emissions Zone operating agency or other Information Service Provider on their personal computers, cell phones, tablets, television, radio, or 511 traveler information systems. Travelers use this information to plan their trips accordingly. For example, upon receiving information about the Dynamic Low Emissions Zone, travelers may decide to switch their mode to transit or change their departure time to avoid entering the zone while it is commissioned.</td>
</tr>
<tr>
<td>3</td>
<td>In-Vehicle Systems receive information about the parameters of the Low Emissions Zone. This information is presented to drivers to assist them in making informed en-route travel choices as they approach the Low Emissions Zone. Upon receiving this information, drivers may decide to change their route to avoid the Dynamic Low Emissions Zone or decide to switch their travel mode to transit.</td>
</tr>
</tbody>
</table>
## Dynamic Low Emissions Zone: Fee Collection

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>The Dynamic Low Emissions Zone System determines the parameters for the Low Emissions Zone.</td>
</tr>
<tr>
<td>1B</td>
<td>Connected Vehicle Roadside Equipment broadcast messages about the parameters of the Low Emissions Zone. Messages may be broadcast using DSRC communications or other wireless communications. This includes information such as the geographic limits of the Low Emissions Zone, time the zone will be established and decommissioned, and fee structure for entering the zone. This information is received by In-Vehicle Systems.</td>
</tr>
<tr>
<td>1C</td>
<td>ITS Roadway Equipment provide information to travelers about the geographic limits of the Low Emissions Zone, time the zone will be commissioned and decommissioned, and fee structure for entering the zone. Connected Vehicle Roadway Equipment provide information about the fee structure to In-Vehicle Systems as vehicles approach the Dynamic Low Emissions Zone boundary. Drivers are informed that there is a $5.00 fee to enter the Low Emissions Zone; however vehicles meeting the low emissions criteria may enter at a reduced fee of $1.00. Transit Vehicles may enter the Low Emissions Zone at no cost. Connected Vehicle Roadway Equipment also send request for payment messages to in-vehicle systems. These messages request that vehicles provide information about the vehicle’s engine type, average emissions, or other vehicle specific data to determine the fee for individual vehicles.</td>
</tr>
<tr>
<td>2</td>
<td>Connected Vehicle Roadway Equipment provide information about the fee structure to In-Vehicle Systems as vehicles approach the Dynamic Low Emissions Zone boundary.</td>
</tr>
<tr>
<td>3</td>
<td>In-Vehicle Systems send data about the vehicle’s engine type, average emissions, a unique identification number, and payment information via secure communications to Connected Vehicle Roadway Equipment and then to the Dynamic Low Emissions Zone System. Upon receiving this information, the Dynamic Low Emissions Zone System compares these data to the parameters established for the zone and determines the fee for the vehicle.</td>
</tr>
<tr>
<td>4</td>
<td>The Dynamic Low Emissions Zone System requests payment from the financial institution. The financial institution transfers funds to the entity operating the Low Emissions Zone.</td>
</tr>
</tbody>
</table>
In-Vehicle Systems collect data that may be used for receiving incentives or rebates upon leaving the Dynamic Low Emissions Zone. This may include information about:

- **The amount of time spent within the Low Emissions Zone** – This would require the Dynamic Low Emissions Zone System to record the time the vehicle entered and exited the Low Emissions Zone. The Dynamic Low Emissions Zone System would calculate the time the vehicle was in the Low Emissions Zone and if it was less than a pre-determined threshold, the driver of the vehicle would be eligible for an incentive or rebate.

- **Number of miles driven within the Low Emissions Zone** – This would require the In-Vehicle System to record the number of miles driven within the Dynamic Low Emissions Zone System and provide this information to the Dynamic Low Emissions Zone System. If the vehicle traveled less miles in the zone than a pre-determined threshold, the driver of the vehicle would be eligible for an incentive or rebate.

- **Amount of emissions emitted while in the Low Emissions Zone** – This would require the In-Vehicle System to record the amount of emissions emitted while in the Dynamic Low Emissions Zone System and provide this information to the Dynamic Low Emissions Zone System. If the vehicle emitted fewer emissions in the zone than a pre-determined threshold, the driver of the vehicle would be eligible for an incentive or rebate.

Connected Vehicle Roadway Equipment disseminates a message to In-Vehicle Systems requesting them to provide data for incentives or rebates.

In-Vehicle Systems provide data for incentives or rebates to the Dynamic Low Emissions Zone System through Connected Vehicle Roadway Equipment. Upon receiving these data, the Dynamic Low Emissions Zone System determines if an individual vehicle should be given an incentive. If it is determined that the vehicle should receive an incentive, the system provides the incentive to the account of the vehicle.

In-Vehicle Systems provide data for incentives or rebates to the Dynamic Low Emissions Zone System through Connected Vehicle Roadway Equipment. This information would be sent using secure communications to ensure privacy. Upon receiving these data, the Dynamic Low Emissions Zone System determines if an individual vehicle should be given an incentive. If it is determined that the vehicle should receive an incentive, the system provides the incentive to the account of the vehicle. The Dynamic Low Emissions Zone System archives all data related to the incentive request and financial transaction.
Step | Description
--- | ---
1 | The Dynamic Low Emissions Zone requires electronic payment of fees using either Connected Vehicle technologies or a toll tag transponder. **A vehicle not equipped with Connected Vehicle technologies, or other means for paying a toll electronically, approaches the Dynamic Low Emissions Zone. Static Signs and messages on DMS prior to the limits of the Dynamic Low Emissions Zone inform the driver about the upcoming zone and requirement for in-vehicle electronic payment systems or transponders. Signage also informs motorists of alternative routes around the Dynamic Low Emissions Zone to avoid entering the zone in violation of the zone’s parameters.**
2 | The driver decides to enter the Low Emissions Zone. Since the vehicle is not equipped with an in-vehicle electronic payment systems or transponder, it is in violation.
3 | At the entrance on the Dynamic Low Emissions Zone, an ALPR system takes a picture of every vehicle’s license plate. This information is compared to messages collected from vehicles using connected vehicle technologies as they enter the zone and pay their fees. **The Dynamic Low Emissions Zone System cannot match the vehicle’s information to the payment of a fee and determines it is in violation.**
4 | Once the Dynamic Low Emissions Zone System determines that a vehicle is a violator, data about the violation and the vehicle (e.g., the vehicle’s license plate number) are sent to an Enforcement Agency which issues a citation to the owner of the vehicle. **This citation could be given to the vehicle owner by mail, requesting payment for entering the zone.**
# Goals, Objectives, and Performance Measures

<table>
<thead>
<tr>
<th>Goal #1: Reduce Environmental Impacts</th>
<th>Goal #2: Support “Green Transportation Decisions” by Travelers and Operating Entities</th>
<th>Goal #3: Enhance Mobility of the Transportation System (secondary goal)</th>
</tr>
</thead>
</table>
| Reduce Emissions from Surface Transportation Vehicles  
  - Reduce CO₂, CO, NOₓ, SO₂, PM₁₀, PM₂.₅, VOCs  
| Increase Modal Shifts to Transit, Walking, Bicycling, Carpooling, and Vanpooling  
  - Increase non-SOV mode share  
  - Increase transit mode share  
  - Increase active (bicycle/pedestrian) mode share  
  - Increase the number of carpools and vanpools  
| Improve the Efficiency of the Transportation System  
  - Reduce the number of person hours (or vehicle hours) of delay  
| Reduce Energy Consumption Associated with Surface Transportation Vehicles  
  - Reduce excess fuel  
  - Reduce energy consumption  
| Increase Usage of Alternative Fuel Vehicles (AFVs)  
  - Increase usage of personal, transit, and freight AFVs  
| Improve Transit Operating Efficiency  
  - Improve average transit travel time compared to auto in major corridors  
  - Maintain or reduce a travel time differential between transit and auto during peak periods  
| Increase Eco-Driving Awareness and Practice  
  - Increase the number of drivers practicing eco-driving strategies  
| Improve the Efficiency of Freight Operating Efficiency  
  - Decrease hours of delay on selected freight-significant routes  
  - Decrease point-to-point travel times on selected freight-significant routes  
  - Increase ratings for customer satisfaction with freight mobility in the region among shippers, receivers, and carriers  

Dynamic Low Emissions Zones | Policy Considerations

- Would certain vehicle types be allowed to enter the low emissions zone at a higher priority than other vehicle types?

- Are there mobility tradeoffs? If so, how do operating entities make a decision to optimize for the environment instead of optimizing for mobility?

- How can this Transformative Concept facilitate “green” choices by:
  - Drivers,
  - State and local DOT’s operating the transportation system, and
  - Decision Makers?

- How can this Transformative Concept incentivize “green” choices by:
  - Drivers,
  - State and local DOT’s operating the transportation system, and
  - Decision Makers?

- How does open data sharing and standardization be used to support public and private sector deployment?

- Under what situation(s) would an operating entity choose to implement a low emissions zone?

- How do Decision Makers value eco-lanes as an option for investing scarce resources?
Dynamic Low Emissions Zones | Education

- What are the social benefits of “green” transportation decisions?
  - Drivers
  - State and local DOT’s operating the transportation system

- What types of educational campaigns could be used to educate the traveling public to make green transportation choices?

- What types of educational campaigns could be used to educate entities operating the transportation network to optimize for the environment?

- How do you incentivize a choice versus another choice? And how do you get people to act on that choice?

Provide travelers and entities operating the transportation network the information they need to make “green” transportation choices
DYNAMIC LOW EMISSIONS ZONES ANALYSIS PLAN

Balaji Yelchuru, Booz Allen Hamilton
Dynamic Low Emissions Zones Applications

- The Dynamic Low Emissions Zones Transformative Concept:
  - Uses connected vehicle technologies to decrease fuel consumption and GHG and criteria air pollutant emissions.
  - Uses strategies such as dynamic emissions pricing, traveler information and driving recommendations to reduce environmental impacts.

- Applications
  - Dynamic Emissions Pricing
  - Multi-Modal Traveler Information
  - Connected Eco-Driving
<table>
<thead>
<tr>
<th>Application</th>
<th>Part of Trip Chain Affected</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Emissions Pricing</td>
<td><img src="image" alt="Destination Choice" /> <img src="image" alt="Mode Choice" /> <img src="image" alt="Time-of-Day Choice" /> <img src="image" alt="Route Choice" /> <img src="image" alt="Facility Choice" /> <img src="image" alt="Driving Behavior" /></td>
<td>Most parts of trip chain are likely to be impacted to some degree.</td>
</tr>
<tr>
<td>Multi-Modal Traveler Information</td>
<td><img src="image" alt="Destination Choice" /> <img src="image" alt="Mode Choice" /> <img src="image" alt="Time-of-Day Choice" /> <img src="image" alt="Route Choice" /> <img src="image" alt="Facility Choice" /> <img src="image" alt="Driving Behavior" /></td>
<td>Most parts of trip chain are likely to be impacted to some degree.</td>
</tr>
<tr>
<td>Connected Eco-Driving</td>
<td><img src="image" alt="Destination Choice" /> <img src="image" alt="Mode Choice" /> <img src="image" alt="Time-of-Day Choice" /> <img src="image" alt="Route Choice" /> <img src="image" alt="Facility Choice" /> <img src="image" alt="Driving Behavior" /></td>
<td>Route changes may or may not be seen.</td>
</tr>
</tbody>
</table>

- ![Definite Influence](image): Application has a definite influence on the particular trip chain element.
- ![Probable Influence](image): Application has a probable influence on the particular trip chain element.
- ![Possible Influence](image): Application has only a possible influence on the particular trip chain element.
Performance Measures Used for Modeling

**Environmental Measures**

- Fuel Consumption (gallons)
- Emissions
  - CO$_2$ (Carbon Dioxide)
  - PM-10 (Particulate Matter)
  - PM-2.5 (Particulate Matter)
  - NO$_x$ (Oxides of Nitrogen)
  - Non-methane Hydro Carbon
  - CO (Carbon Monoxide)

**Mobility Measures**

- Total Delays
- Intersection Delay
- Travel Times
- Number of Stops

*Mobility Performance Measures not used for AERIS benefit assessment*
AERIS Baseline

- For the purpose of defining AERIS modeling, baseline conditions assume a region that includes both arterial and freeway facilities under “high” levels of traffic.

**Arterial Network**

- Signalized corridor with 2 lanes per direction
- **Speed Limit:** 35-45 mph
- **Traffic Signal Operations:** Uncoordinated, non-optimized, and fixed signal controls
- **Intersection Spacing:** 3-5 intersections/mile
- **Traffic Congestion (high):** 500-600 vehicles/hour/lane

**Freeway Network**

- Basic freeway segment with 3-5 lanes/direction
- **Speed Limit:** 55-65 mph
- **Traffic Congestion (high):** 2,000 vehicles/hours/lane
- **Ramp spacing:** 1 mile
- **Roadway grade:** 0%
Model Region Description | Phoenix, AZ

- Entire Greater Phoenix metropolitan region modeled by Maricopa Association of Governments (MAG), AZ
  - 3000 zones
  - 3.5+ million people, and
  - 15 million trips and transit

- Includes 500 sq. miles of Phoenix region and surrounding regions

- Applications modeled
  - Dynamic Emissions Pricing
  - Multi-Modal Traveler Information
AERIS Hypothesis Overview

- Primary Hypothesis
  - Using connected vehicle data, signal and vehicle operations can be altered to achieve significant environmental benefits.

- Hypothesized environmental benefits are based on % fuel and emissions savings of the same or similar applications reported in literature, or estimated by the research team if no existing information is available.

- For the purposes of developing hypothesis, AERIS environmental benefits are expressed in terms of % savings from AERIS application relative to the baseline.

\[
\begin{align*}
\text{% Fuel Savings} &= 100\% \times \frac{(\text{fuel}_{\text{baseline}} - \text{fuel}_{\text{AERIS}})}{\text{fuel}_{\text{baseline}}} \\
\text{% CO}_2\text{Savings} &= 100\% \times \frac{(\text{CO}_2\text{baseline} - \text{CO}_2\text{AERIS})}{\text{CO}_2\text{baseline}}
\end{align*}
\]
Hypothesis | Dynamic Low Emissions Zones Transformative Concept

- **Hypothesis**
  - *If* all applications in the Dynamic Low Emissions Zones Transformative Concept are implemented together, *then* there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
    - 5%–10% under partial connected vehicle penetration.
    - 10%–15% under full connected vehicle penetration.
  
  % fuel and emissions savings during off-peak hours are expected to be the same or lower.

  Fuel and emissions savings may result from potential mode shift, route changes and changes in driving behavior.
Modeling Approach | Overview

- Dynamic Emissions Pricing and Multi-Modal Traveler Information Applications will be initially modeled and tested individually using Phoenix regional network.
  - Algorithms will be developed and implemented through a DTA tool developed to represent AERIS applications (e.g., VISTA, DYNUS-T).
  - Integrated modeling framework will be used to have a tight connection between demand model and DTA tool.

- Connected Eco-Driving is modeled initially using a corridor network using a microsimulation tool with an emissions tool.
  - For the initial analysis, mode choice and route choice impacts resulting from Connected Eco-Driving application will not be considered as the impact is expected to be minimal.
Bundling of Applications

- After the initial development and testing of individual applications, applications will be modeled together on a combined network/region (Phoenix) to estimate benefits of all applications implemented together.
  - Estimate total benefits of the Transformative Concept
  - Inspect interactions of applications with each other
  - Route choice and mode choice impacts will be captured
  - Regional impacts of Low Emissions Zones applications will be captured
  - Small area microsimulation simulation will be carried out and integrated with demand and DTA tool
Inputs to Demand model
- Employment data
- Socio-economic data
- Land use data

Inputs to DTA model
- Roadway characteristics
- Intersection characteristics (e.g. signal data)

Inputs to Microsimulation model
- Roadway characteristics
- Intersection characteristics (e.g. signal data)

Inputs to Emissions model
- Vehicle and Fuel types
- Weather Data
- Vehicle age distribution

Outputs
- Fuel consumption
- Emissions (e.g. CO₂, Particulate matter, NOₓ, CO)
- Travel Times
- Travel Delay

Data Flow
- Network inputs to DTA tool
- Detailed Network inputs to Microsimulation tool
- Non-transportation data inputs to Emissions Model
- Outputs from demand model (time dependent OD Matrices) being send as input to Dynamic Traffic Assignment (DTA) tool
- Time dependent vehicle flows (by links) fed as an input to the traffic microsimulation tool
- Second-by-second vehicle trajectories sent as an input to the Emissions Model
- Final Emissions Estimates

Feedback loop
- Outputs to Activity Based demand model
- Outputs to Emissions model
- Outputs to Microsimulation model
- Outputs to Demand model

Network inputs to DTA tool
- Output travel demand
- Output travel demand

Detailed Network inputs to Microsimulation tool
- Second by second speed profiles
- Second by second speed profiles

Non-transportation data inputs to Emissions Model
- Non-transportation data inputs to Emissions Model

Emissions model
- MOVES
- MOVES

Data Flow
Modeling Overview

- Use SimTRAVEL Integrated Modeling Framework developed by Arizona State University.
  - SimTRAVEL - *Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land*
  - An Integrated Land Use – Transport Model System with Dynamic Time-dependent Activity-travel Microsimulation

- The multimodal activity-based travel demand model and the DTA model are integrated in a tightly coupled manner.

- Constant communication between the activity-based travel model and the DTA model and captures the dynamic nature of Multi-Modal Traveler Information application.

- Possible to reflect the impact of even slight changes in network conditions on activity schedules and patterns.
Hypothesis | Dynamic Emissions Pricing

- If scalable and movable Low Emissions Zones are established and the vehicles entering the zones are charged a price based on their type and emissions, then there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 3%–5% under partial connected vehicle penetration.
  - 5%–10% under full connected vehicle penetration.

% fuel savings during off-peak hours are expected to be the same or lower as the mode shift and changes in travel patterns may have less effect.
Modeling Approach | Dynamic Emissions Pricing

- Application builds on existing Cordon Pricing Strategies
  - Dynamic Emissions pricing strategies will be scalable and movable

- Geo-fencing
  - Geo-fenced boundaries established on the network

- Vehicle Detection
  - Allows only certain types of vehicles in the zone
  - Provides exemptions for transit vehicles

- Pricing/Incentives
  - Fees charged or incentives provided for vehicles based on emissions data and driving behavior data collected from the vehicle
  - Sensitivity to incentives explicitly modeled

- Pre-trip and en-route traveler information about the Low Emissions Zone to vehicles explicitly modeled
Hypothesis | Multi-Modal Traveler Information

- *If* pre-trip and en-route multi-modal traveler information is provided to encourage environmentally friendly transportation choices such as taking transit and potentially changing travel patterns and mode, *then* there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 3%–5% under partial connected vehicle penetration.
  - 6%–8% under full connected vehicle penetration.

% fuel and emissions savings during off-peak hours are expected to be the same or lower as the mode shift and changes in travel patterns may have less effect.
Modeling Approach | Multi-Modal Traveler Information

- Builds on existing Advanced Traveler Information Systems algorithms.
- Model behavior changes (mode choice, time of day choice and route choice) in response to providing pre-trip and en-route traveler information such as real-time and predicted roadway speeds, transit arrival and departure times and transit schedule.
- Estimate the regional emissions impact of predicted behavior changes.
- Establish a dynamic relationship between demand generation (mode and route choice) and prevailing network performance. Support multi-modal analysis.
Hypothesis | Connected Eco-Driving

- *If* real-time driving advice is provided to drivers based on prevailing traffic conditions and interactions with nearby vehicles and feedback is provided to encourage drivers to drive in a more environmentally efficient manner, *then* there will be emissions reductions and lowered fuel consumption during congested traffic conditions in the range of:
  - 10%–15% under partial connected vehicle penetration.
  - 15%–20% under full connected vehicle penetration.

% fuel and emissions savings assume both freeway and arterial travel.

% fuel and emissions savings during off-peak hours are expected to be the same or lower as the drivers may already be driving at optimal speeds.

Vehicles that are not enabled with connected vehicle technologies are also likely to benefit from improvements in overall traffic flow.
Modeling Approach | Connected Eco-Driving

- Modeled as part of Eco-Signal Operations TC.
- Provide speed advice based on SPaT information and real-time traffic conditions. The application would not be limited to signalized intersections, but instead applicable to all sections of the arterial.
- Use real-time link by link traffic performance measure as feedback/input to vehicles’ speed and acceleration selection process as they traverse the network.
- Use downstream traffic conditions to determine eco-friendly acceleration rates for vehicles.
- Update recommended speeds when the vehicle enters a new roadway link or when the real-time traffic speed information on the current roadway link is updated.
- Avoid stop-and-go driving and instead encourage smooth driving at a constant speed.
Analysis Scenarios

- Modeling will be performed under various settings to test the hypotheses.
- Basic Phoenix region and El Camino Real networks will be used for initial modeling.
- A baseline, “do nothing”, model will be developed to represent the conditions of the analyzed area without the AERIS applications.
- Another set of models will be developed where the applications are implemented and their benefits in terms of emissions and fuel savings are assessed.
Variables or Parameters of Interest

- Facility type, such as freeway, arterial etc.
- Network Characteristics (e.g. speed limit)
- Congestion in terms of volume-to-capacity ratio
- Vehicle mix, % trucks, % alternative fuel vehicles
- Connected vehicle deployment, such as % of signals enabled with roadside equipment (RSE) and number of vehicles equipped with on-board equipment (OBE).
- Compliance rate of drivers
Application Analysis Scenarios | Examples

**Dynamic Emissions Pricing**
- Changing the frequency at which the pricing /incentives are redefined
- Changing the size of Low Emissions Zones
- Changing the criteria for vehicles to enter Low Emissions Zones (e.g. vehicle type)
- Implementation of Low Emissions Zones in highly congested urban area and moderately congested urban area

**Multi-Modal Traveler Information**
- Providing predictive travel-time information to travelers
- Providing information on transit operations including schedule, reduced fares
- Providing information on parking availability

**Connected Eco-Driving**
- Changing the spacing between the signalized intersections
- Baseline speed limits set at different levels
- Include both freeway and arterial travel under different levels of congestion
QUESTIONS?
Break-out Session #3
Dynamic Low Emissions Zones
Break-out Session #2

- **Work in groups (led by group facilitators)**
  - Validate Concept of Operations and Modeling Approach Diagrams – 20 minutes
  - Facilitated discussion around ConOps and Modeling questions – 35 minutes
  - Combine comments for debrief to the larger group – 5 minutes
  - Debrief feedback to whole group – 15 minutes per group
Break-out Session #3

- Workshop participants will be divided among 2 rooms to ensure that everyone has the opportunity to think creatively and constructively.

- The first round of Break-out Groups will facilitate discussion around the Dynamic Low Emissions Zones Transformative Concept.

- Break-out Session Rooms
  - Room #1: Concord
  - Room #2: Lexington
BREAK-OUT SESSION #3
DYNAMIC LOW EMISSIONS ZONES
Next Steps

- Finalize AERIS Concept of Operation Documents
- Finalize AERIS Modeling Analysis Plans
- Begin Modeling AERIS Transformative Concepts and Applications

How to Stay Involved:

- AERIS Program Website: [http://www.its.dot.gov/aeris/index.htm](http://www.its.dot.gov/aeris/index.htm)
- AERIS IdeaScale Site: [https://aeris.ideascale.com](https://aeris.ideascale.com)
- Future AERIS Webinars:
  - Eco-Signal Operations Prototype Development
  - Interim Modeling Results
  - International Activity Update
  - Smart Cities
- Future Workshops
THANK YOU!