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

- **Vision – Cleaner Air Through Smarter Transportation**
  - Encourage the development and deployment of technologies and applications that support a more sustainable relationship between surface transportation and the environment through fuel-use reductions and more efficient use of transportation services.

- **Objectives – Investigate whether it is possible and feasible to:**
  - Identify connected vehicle applications that could provide environmental impact reduction benefits via reduced fuel use, improved vehicle efficiency, and reduced emissions.
  - Facilitate and incentivize “green choices” by transportation service consumers (i.e., system users, system operators, policy decision makers, etc.).
  - Identify vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-grid (V2G) data (and other) exchanges via wireless technologies of various types.
  - Model and analyze connected vehicle applications to estimate the potential environmental impact reduction benefits.
  - Develop a prototype for one of the applications to test its efficacy and usefulness.
AERIS Operational Scenarios

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

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

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

**ECO-TRAVELER INFORMATION**
- Connected Vehicle-Enabled Data Collection: Probe and Environmental Data
- Multimodal Traveler Information
- Eco-Smart Parking
- AFV Charging/Fueling Information, Reservations, and Payment
- Dynamic Eco-Routing
- Connected Eco-Driving – Gamified / Incentives-based Apps
- Gamified / Incentives-based Multimodal Traveler Information

**ECO-INTEGRATED CORRIDOR MANAGEMENT**
- Eco-ICM Decision Support System (similar to ICM)
- Eco-Signal Operations Applications
- Eco-Lanes Applications
- Low Emissions Zones Applications
- Eco-Traveler Information Applications
- Incident Management Applications
APPLICATION OVERVIEW, INITIAL FIELD EXPERIMENT, AND MODELING
Eco-Approach and Departure at Signalized Intersections

Application Overview

- Collects signal phase and timing (SPaT) messages and MAP messages using vehicle-to-infrastructure (V2I) communications

- Receives V2I and V2V (future) messages, the application performs calculations to determine the vehicle’s optimal speed to pass the next traffic signal on a green light or to decelerate to a stop in the most eco-friendly manner

- Provides speed recommendations to the driver using a human-machine interface or sent directly to the vehicle’s longitudinal control system to support partial automation
Eco-Approach and Departure at Signalized Intersections
Factors and Variations

- **Signal timing scheme** matters: fixed time signals, actuated signals, coordinated signals
- **Single intersection** analysis and **corridor-level** analysis
- **Congestion level:** how does effectiveness change with amount of surrounding traffic
- **Single-vehicle** benefits and **total link-level** benefits
- **Driver vehicle interface** or some degree of **automation**
- **Simulation Modeling:** multiple vehicles, examining the sensitivity of other variables
- **Field Studies:** typically limited to a few instrumented single vehicles, constrained infrastructure
2012 Field Experiment at TFHRC

- A field experiment was conducted at Turner Fairbank Highway Research Center (TFHRC) with a single equipped vehicle (Jeep Grand Cherokee) at a single intersection with no traffic
  - Drivers were provided with speed recommendations using a DVI incorporated into the speedometer (driver advisory feedback)
  - The field experiment resulted in up to 18% reductions in fuel consumption
  - It was difficult for drivers to follow the recommended speed on the “speed advice speedometer”
  - Having drivers follow speed recommendations also creates driver distraction

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Avg. Fuel Savings (ml)</th>
<th>Avg. % Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>13.0</td>
<td>2.5%</td>
</tr>
<tr>
<td>25</td>
<td>111</td>
<td>18.1%</td>
</tr>
<tr>
<td>30</td>
<td>76.0</td>
<td>11.2%</td>
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<tr>
<td>35</td>
<td>73.8</td>
<td>6.3%</td>
</tr>
<tr>
<td>40</td>
<td>107</td>
<td>9.5%</td>
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</table>
# Related Activities

## Single Vehicle

<table>
<thead>
<tr>
<th>Fixed-time Signals</th>
<th>Actuated Signals</th>
</tr>
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<tbody>
<tr>
<td><strong>Field Study 2012</strong> (FHWA EAR P1, AERIS)</td>
<td><strong>Field Studies 2014/2015</strong> (FHWA-EAR-P2 @ PATH FHWA-EAR-P2 @UCR)</td>
</tr>
<tr>
<td><strong>Simulation Modeling 2012</strong> (AERIS)</td>
<td><strong>Limited Simulation Modeling 2014</strong> (FHWA-EAR-P2)</td>
</tr>
<tr>
<td><strong>GlidePath 2015</strong></td>
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</tbody>
</table>

## Vehicle in Traffic

<table>
<thead>
<tr>
<th>Simulation Modeling 2013 (AERIS sensitivity analysis)</th>
<th>Field Studies 2014/2015 (FHWA-EAR-P2 @ PATH FHWA-EAR-P2 @UCR)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Study/Demo 2015</strong> (FHWA-EAR-P2 ECR)</td>
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</table>

## Vehicle Control

- **Driver with DVI**
- **Automated Longitudinal Control (i.e., GlidePath)**
- **Automated Longitudinal Control with V2V**
AERIS Modeling Overview

- A traffic simulation models (e.g., Paramics) was combined with an emissions model (e.g., EPA’s MOVES model) to estimate the potential environmental benefits.

- Application algorithms were developed by the AERIS team and implemented as new software components in the traffic simulation models.

- Modeling results indicate a possible outcome – results may vary depending on the baseline conditions, geographic characteristics of the corridor, etc.
Modeling Network

- **El Camino Real Network**
  - Signalized, urban arterial (27 intersections) in northern California
  - 6.5 mile segment between Churchill Avenue in Palo Alto and Grant Road in Mountain View
  - For the majority of the corridor, there are three lanes in each direction
  - Intersection spacing varies between 650 feet to 1,600 feet
  - 40 mph speed limit
  - Vehicle demands and origin-destination (OD) patterns were calibrated for a typical weekday in summer 2005 (high volumes on the mainline)
  - Vehicle mix (98.8% light vehicles; 1.2% heavy vehicles)
Summary of Modeling Results

- Summary of Modeling Results
  - 5-10% fuel reduction benefits for an uncoordinated corridor
  - Up to 13% fuel reduction benefits for a coordinated corridor
    - 8% of the benefit is attributable to signal coordination
    - 5% attributable to the application

- Key Findings and Takeaways
  - The application is less effective with increased congestion
  - Close spacing of intersections resulted in spillback at intersections. As a result, fuel reduction benefits were decreased somewhat dramatically
  - Preliminary analysis indicates significant improvements with partial automation
  - Results showed that non-equipped vehicles also receive a benefit – a vehicle can only travel as fast as the car in front of it

The Eco-Signal Operations Modeling Report is in the USDOT Publication Process
GLIDEPATH PROTOTYPY APPLICATION
Project Objectives

- Develop a working prototype GlidePath application with automated longitudinal control for demonstration and future research;
- Evaluate the performance of the algorithm and automated prototype (specifically, the energy savings and environmental benefits);
- Conduct testing and demonstrations of the application at TFHRC

Period of Performance

- May 2014 through December 2015

The GlidePath prototype is state of the art and the first of its kind
### GlidePath Prototype Application

#### Project Partners

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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</thead>
<tbody>
<tr>
<td>Marcia Pincus</td>
<td>ITS JPO, AERIS Program Manager</td>
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<tr>
<td>Osman Altan</td>
<td>Project Manager</td>
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<td>Robert Ferlis</td>
<td>Technical Director</td>
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<tr>
<td>Benjamin McKeever</td>
<td>Team Leader</td>
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<td>Randall VanGorder</td>
<td>Saxton Lab COR</td>
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<tr>
<td>Brian Philips</td>
<td>Human Factors SME</td>
</tr>
<tr>
<td>Taylor Lochrane</td>
<td>Project Reviewer</td>
</tr>
<tr>
<td>Daniel Dailey</td>
<td>Project Reviewer</td>
</tr>
<tr>
<td>Brian Kerr</td>
<td>Facilities Manager</td>
</tr>
<tr>
<td>J.D. Schneeberger</td>
<td>Technical Support</td>
</tr>
<tr>
<td>Drennan Hicks</td>
<td>Technical Support</td>
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</tbody>
</table>

#### Others: Tony Ahmad, Chris Armstrong, and Julie Evans (formerly Leidos)

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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<tbody>
<tr>
<td>John Stark</td>
<td>Software Architect</td>
</tr>
<tr>
<td>David Ference</td>
<td>Software Developer</td>
</tr>
<tr>
<td>Kyle Rush</td>
<td>Software Developer</td>
</tr>
<tr>
<td>Frank Perry</td>
<td>DSRC SME</td>
</tr>
<tr>
<td>Dana Duke</td>
<td>Engineering Technician</td>
</tr>
<tr>
<td>Matthew Barth</td>
<td>Professor</td>
</tr>
<tr>
<td>Guoyuan Wu</td>
<td>Research Faculty</td>
</tr>
<tr>
<td>Various Graduate Students</td>
<td></td>
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<tr>
<td>Mike Avitable</td>
<td>Engineering Manager</td>
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</tbody>
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**UC Riverside**

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**TORC**

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**Noblis**

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**Leidos**
GlidePath Prototype Application

Project Approach

- Regional Architecture(s)
- Feasibility Study / Concept Exploration
- Lifecycle Processes
- System Validation Plan
- System Validation
- System Verification Plan (System Acceptance)
- System Verification & Deployment
- Subsystem Verification Plan (Subsystem Acceptance)
- Subsystem Verification
- Software / Hardware Development
- Field Installation
- Implementation
- Operations and Maintenance
- Changes and Upgrades
- Retirement / Replacement
- Document/Approval

AERIS Eco-Signal Operations ConOps

GlidePath Requirements Document

GlidePath Design Document

GlidePath Testing and Acceptance
GlidePath Prototype Application
High-Level System Architecture

- Component Systems
  - Roadside Infrastructure
    - Signal Controller
    - SPaT Black Box
    - DSRC RSU
  - Automated Vehicle
    - Existing Capabilities
    - Additional Functionality
  - Algorithm
    - Objective
    - Input
    - Output
GlidePath Prototype Application
Components – Architecture

1. Traffic Signal Controller
   - The roadside unit transmits SPaT and MAP messages using DSRC.

2. SPaT Black Box

3. Roadside Unit
   - Evaluation: Data post-processed by UC-Riverside using EPA’s MOVES Model
   - Backhaul: Communications back to TFHRC

4. Onboard Unit

5. Onboard Computer with Automated Longitudinal Control Capabilities

6. Driver-Vehicle Interface
   - Stop Data
   - EcoDrive OFF
   - Selected Speed
   - Current Speed
   - Distance to Stop Bar
   - Speeding Up

7. Evaluation: Data post-processed by UC-Riverside using EPA’s MOVES Model

U.S. Department of Transportation
GlidePath Prototype Application
Components – Roadside Infrastructure

Notes:
1. Primary RSU is installed on the mast arm on the west side of the intersection and connected to Cabinet 6 of the Saxton roadside infrastructure.
2. Secondary RSU is installed on a pole and connected to Cabinet 1 of the Saxton roadside infrastructure along the entrance road from GW Parkway.
3. Econolite signal controller and SPaT blackbox location.

Note: Secondary RSU added to extend communications range caused by line of sight issues.
GlidePath Prototype Application
Components – Automated Vehicle

- **Ford Escape Hybrid developed by TORC with ByWire XGV System**
  - Existing Capabilities
    - Full-Range Longitudinal Speed Control
    - Emergency Stop and Manual Override
  - Additional Functionality
    - Computing Platform with EAD Algorithm
    - DSRC OBU
    - High-Accuracy Positioning Solution
    - Driver Indicators/Information Display
    - User-Activated System Resume
    - Data Logging
GlidePath Prototype Application
Components – Vehicle Instrumentation
**Objective:** Optimize environmental performance of a vehicle approaching a signalized intersection

**Input:**
- Vehicle Location (distance to intersection)
- Vehicle Speed
- Signal Phase and Timing (SPaT) and MAP Messages
- Scenario/Environmental Thresholds:
  - Maximum speed, acceleration, deceleration, jerk, etc.

**Output:**
- Speed Trajectory
  - Target Speed updated at 10Hz
  - Target Acceleration/Deceleration transitions to minimize fuel consumption and bound “jerk” (da/dt) for passenger comfort
The vehicle passes through the intersection on the green phase without having to slow down or speed up.

Environmental benefits result from maintaining speed and reducing unnecessary accelerations.
GlidePath Prototype Application
Scenario 1 – Maintain Speed to Pass Through
• The vehicle needs to safely speed up to pass through the intersection on a green phase

• Energy savings result from the vehicle avoiding a stop and idling at the intersection
GlidePath Prototype Application
Scenario 3 – Coast to Stop at Intersection

- The vehicle cannot make the green light and needs to slow down to stop at the signalized intersection
- Energy savings result from slowing down sooner and coasting to the stop bar
- Once stopped, the vehicle could engage engine start-stop capabilities
- The driver must re-engage automated longitudinal control capabilities to restart the vehicle
• The vehicle needs to slow down to pass through the intersection on a green phase
• Energy savings result from the vehicle avoiding stopping and idling at the intersection
GlidePath Prototype Application
Scenario 4 – Slow Down to Pass Through Intersection
GLIDEPATH EXPERIMENTAL DESIGN, RESULTS, AND NEXT STEPS
The field experimentation will be organized into three stages

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Stage II: Manual-DVI Driver (2012 AERIS experiment)</td>
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<tr>
<td>Stage III: Automated Driver</td>
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</tbody>
</table>
Scenarios will be run in each of the three (3) stages:

- **Stage I:** Manual-uninformed driver
- **Stage II:** Manual-DVI driver
- **Stage III:** Automated driver
The Comprehensive Modal Emissions Model (CMEM) is an emissions estimation modeling tool developed by University of California, Riverside.

CMEM serves as a foundational pre-cursor to the U.S. Environmental Protection Agency’s MOtor Vehicle Emission Simulator (MOVES).

Energy and emissions are estimated directly from the GlidePath vehicle trajectory data.
### Table 1. Example driver’s fuel consumption (g/mi) for different entry time (speed 20 mph)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Green</th>
<th>Red</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 2 vs. Stage 1 (DVI vs. Uninformed Driver)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-11.80</td>
<td>-11.75</td>
<td>7.59</td>
<td>5.20</td>
</tr>
<tr>
<td>Stage 3 vs. Stage 1 (Automated vs. Uninformed Driver)</td>
<td>4.67</td>
<td>7.55</td>
<td>35.25</td>
</tr>
<tr>
<td>Stage 3 vs. Stage 2 (Automated vs. DVI)</td>
<td>14.73</td>
<td>17.27</td>
<td>29.93</td>
</tr>
</tbody>
</table>

- Four different drivers were part of the experimentation, each conducting Stage I, II, and III at two different speeds (20 mph and 25 mph)
- **General Results thus far:**
  - DVI (Stage II) improved fuel economy over uninformed driving (Stage I) by only 5% on average, with a wide range of responses (18% standard deviation)
  - Some drivers with the DVI (Stage II) performed worse than uninformed driving (Stage I)
  - Automation (Stage III) improved fuel economy over uninformed driving (Stage I) by 20% on average, within a narrow range of responses (6% standard deviation)
GlidePath Prototype Application
Lessons Learned

- Minimizing controller lag on the vehicle is important.
- The Eco-Approach and Departure at Signalized Intersections algorithm and vehicle control perform well with 2-meter positioning accuracy; however, precise positioning is more important near the intersection stop bar.
- “Creep” towards the intersection can feel very un-natural (under scenario 4).
Related Activities
International

- Europe
  - Europe has a similar connected vehicle concept called: **Green Light Optimal Speed Advisory (GLOSA) System**
  - GLOSA is integrated into their Compass4D Research Program, spanning seven different cities across Europe
  - GLOSA has been deployed and operating in several of the Compass4D cities
  - Initial results: Energy savings from 0.8%-11.9% overall and up to 19% for individual vehicles
  - Small differences: application integrated with vehicle start-stop technology
  - US EAD algorithm and GLOSA algorithm are similar due to joint work of the EU/US Sustainable Working Group (SWG)

- Japan
  - Japan is carrying out a similar eco-approach and departure application
  - National Institute of Advanced Industrial Science and Technology
  - Part of overall roadway “**Traffic Speed Management System**”
GlidePath Prototype Application

Potential Next Steps

- Multiple equipped vehicles (and unequipped vehicles) at single intersection
- Integration of V2V cooperative adaptive cruise control (CACC) capabilities
- Multiple intersections / corridor
  - Controlled environment
  - Real-world corridor with traffic
- Actuated Traffic Signal Timing Plans
- Consideration of queue lengths (and dissipation of queues) at the stop bar
- The Federal Highway Administration (FHWA) has initiated a project with CAMP* under the V2I Program to further assess this application

*CAMP: Crash Avoidance Metrics Partnership, a consortium of 10 automakers
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