Eco-Driving using Wireless V2I Communications at Signalized Intersections

Marcia Pincus
Program Manager, Environment (AERIS), Connected Cities and Evaluation
United States Department of Transportation (USDOT)
marcia.pincus@dot.gov

IBEC3: Evaluation of Connected Automated Driving
AERIS Program Overview

- Vision – Cleaner Air Through Smarter Transportation
- 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.
  - Identify vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-grid (V2G) data (and other) exchanges.
  - Model and analyze connected vehicle applications to estimate the potential environmental 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 Zone Applications
- Eco-Traveler Information Applications
- Incident Management Applications

www.ibec-its.com
AERIS Research Approach

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

Conduct Preliminary Cost Benefit Analysis
Perform a preliminary cost benefit analysis to identify high priority applications and refine/refocus research

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

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

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

www.ibec-its.com
Eco-Approach and Departure at Signalized Intersections

Application Overview

- Collects signal phase and timing (SPaT) and Geographic Information Description (GID) 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

www.ibec-its.com
Eco-Approach and Departure at Signalized Intersections
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**
- **Simulation Modeling vs. Field Studies**
- **Vehicle Control:** driver advice vs. partial automation
- **Communications Method:** short range vs. wide-area
A traffic simulation models (Paramics) was combined with an emissions model (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.
AERIS Modeling Overview

- A traffic simulation models (Paramics) was combined with an emissions model (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
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
2012 Proof of Concept

- A field test was conducted at the Turner Fairbank Highway Research Center (TFHRC) with a single vehicle at a single intersection with no traffic.

- Drivers were provided with speed recommendations using a Driver Vehicle Interface (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>
</tr>
<tr>
<td>35</td>
<td>73.8</td>
<td>6.3%</td>
</tr>
<tr>
<td>40</td>
<td>107</td>
<td>9.5%</td>
</tr>
</tbody>
</table>
GlidePath Prototype Application

Project Objectives

- Develop a working prototype GlidePath application with the Eco-Approach and Departure Algorithm and **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.

*The GlidePath prototype is state of the art and the first of its kind.*
GlidePath 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
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.
‘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 Eco-Approach and Departure Algorithm
    - DSRC OBU
    - High-Accuracy Positioning Solution
    - Driver Indicators/Information Display
    - User-Activated System Resume
    - Data Logging

www.ibec-its.com
# GlidePath Field Experiment

The field experimentation was organized into three stages:

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage II: Manual-DVI Driver</td>
<td><img src="image1.png" alt="Diagram" /></td>
</tr>
<tr>
<td>(2012 AERIS experiment)</td>
<td></td>
</tr>
<tr>
<td>Stage III: Automated Driver</td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

---

www.ibec-its.com
Preliminary GlidePath Results

Summary of Preliminary Results
- DVI-based driving provided a 7% fuel economy benefit
- Partially automated driving provided a 22% benefit

Lessons Learned
- Minimizing controller lag is important
- Precise positioning is important near the intersection stop bar

Table 2. Relative savings in fuel consumption (%) between different driving modes

<table>
<thead>
<tr>
<th>Phase</th>
<th>Green</th>
<th>Red</th>
<th>On</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time in Phase (s)</td>
<td>2</td>
<td>7</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>D vs. U</td>
<td>-11.80</td>
<td>-11.75</td>
<td>7.59</td>
<td>5.20</td>
</tr>
<tr>
<td>A vs. U</td>
<td>4.67</td>
<td>7.55</td>
<td>35.25</td>
<td>20.94</td>
</tr>
<tr>
<td>A vs. D</td>
<td>14.73</td>
<td>17.27</td>
<td>29.93</td>
<td>16.60</td>
</tr>
</tbody>
</table>
Next Steps

- Opportunities for Future Research with the GlidePath Prototype
  - Multiple Equipped Vehicles
  - Multiple Intersections / Corridor
    - Controlled Environment
    - Real-World Corridor with Traffic
  - Actuated Traffic Signal Timing Plans
  - Integration of Cooperative Adaptive Cruise Control (CACC) capabilities with the prototype

- Continue to Engage the Automotive Industry
  - AERIS initiated a project for CAMP to assess the Eco-Approach and Departure at Signalized Intersections application
Contact Information

Marcia Pincus
Program Manager, Environment (AERIS), Connected Cities and Evaluation

United States Department of Transportation (USDOT)
Intelligent Transportation Systems (ITS) Joint Program Office (JPO)

Email: marcia.pincus@dot.gov