U.S. Department of Transportation

GlidePath

Connected Automated Eco-Driving using Wireless V2I Communications at Signalized Intersections

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PR08: The Decarbonisation of Road Transport: How Can Eco-Driving Contribute?

AERIS Program Overview

- **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 Zone s Applications
- Eco-Traveler Information Applications
- Incident Management Applications

AERIS Research 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

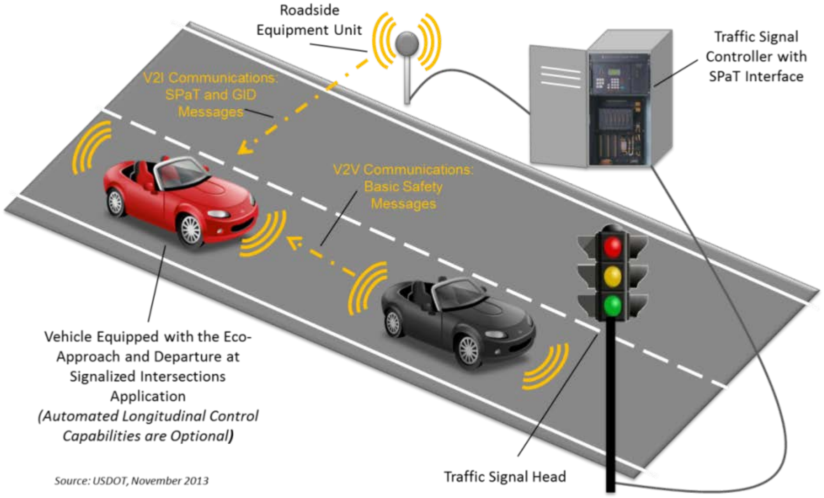
Conduct Preliminary Cost Benefit Analysis
Perform a preliminary cost benefit analysis to identify high priority applications and refine/refocus research

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

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

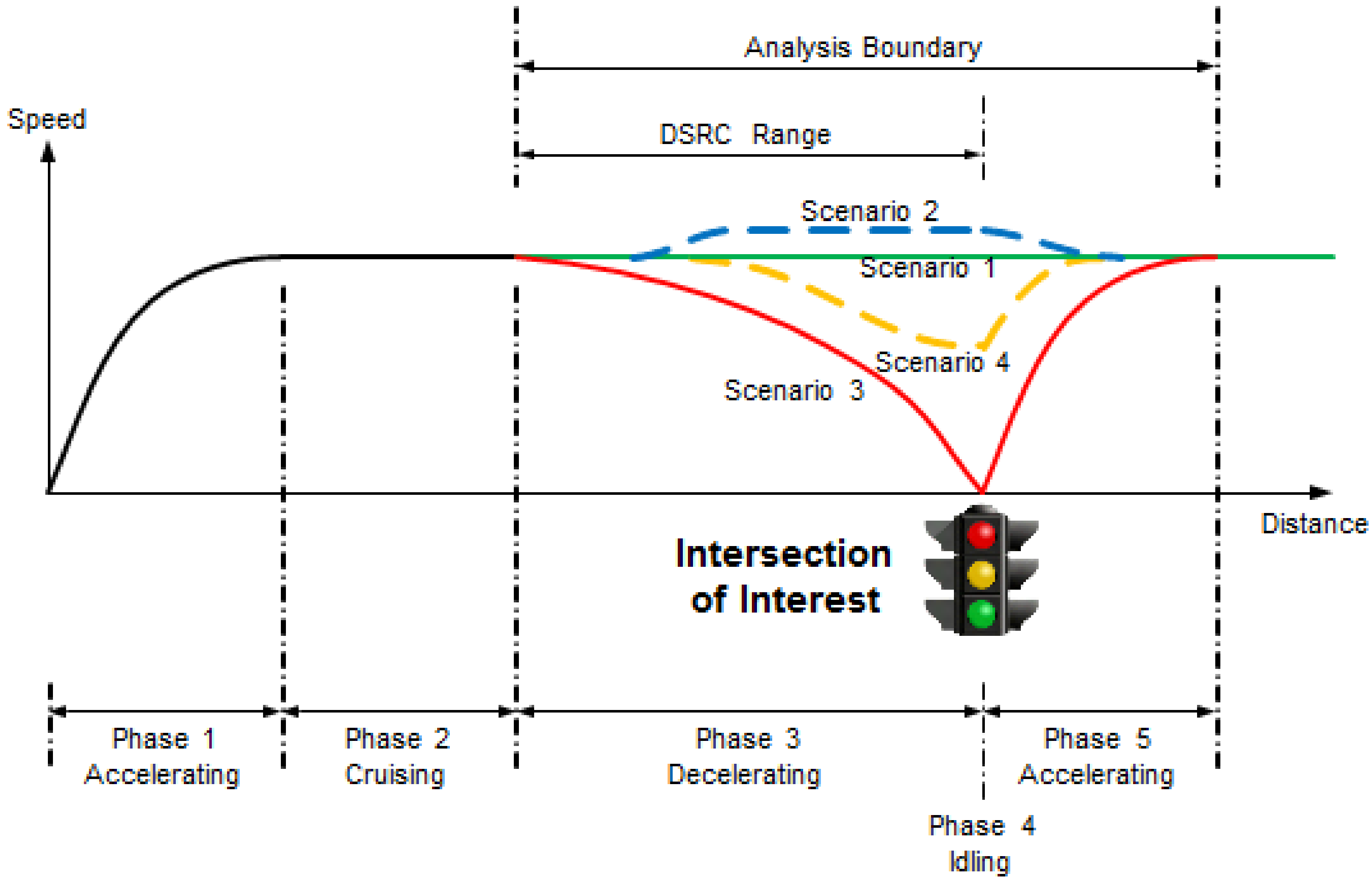
Eco-Approach and Departure at Signalized Intersections

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

Eco-Approach and Departure at Signalized Intersections

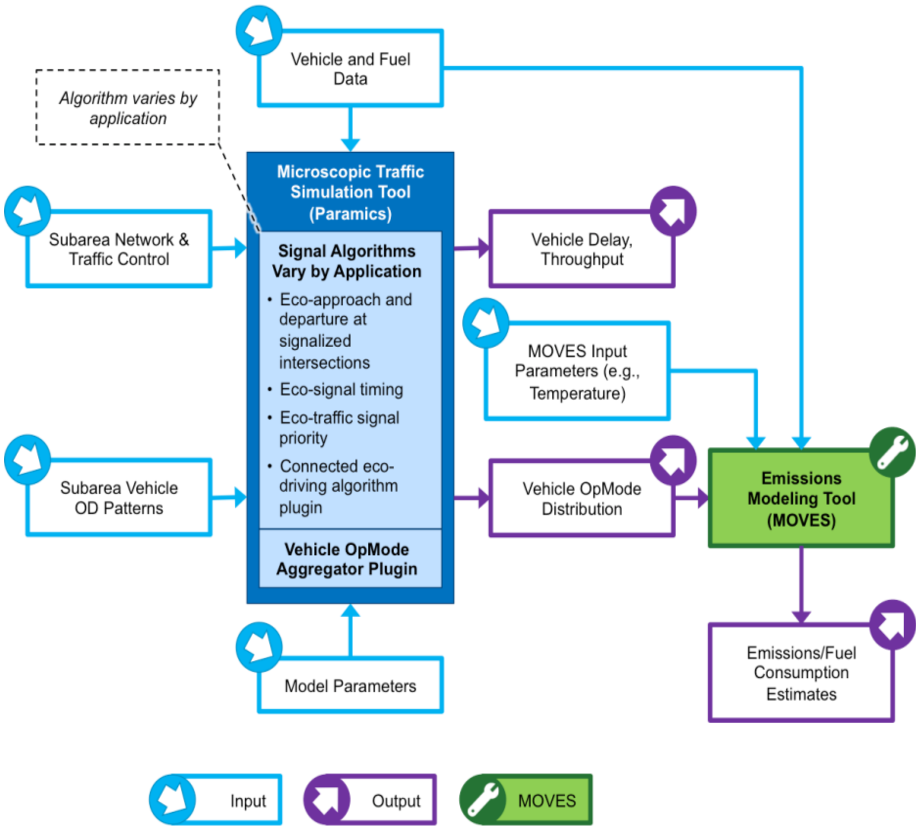


Variations

- **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

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.



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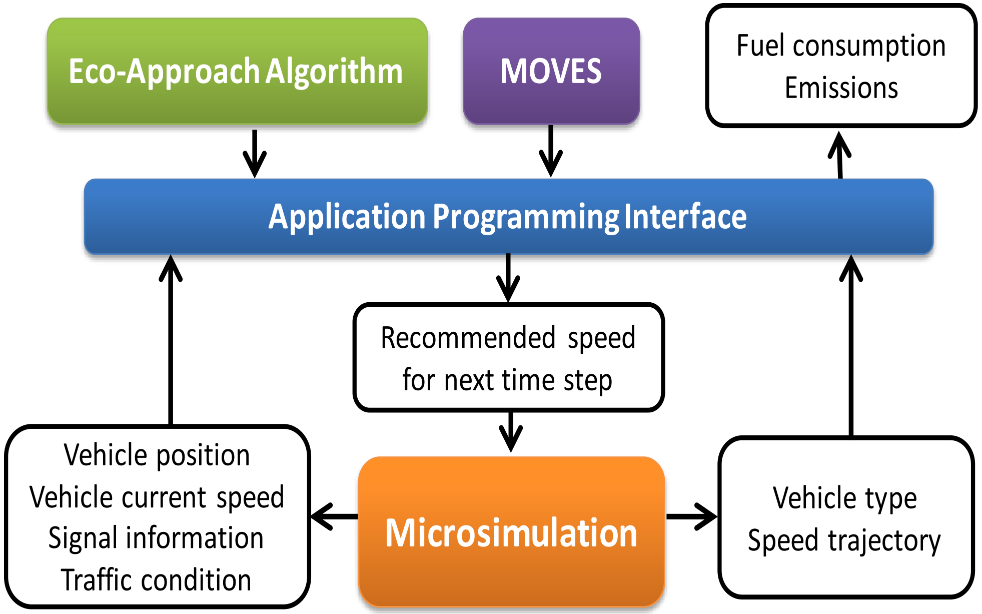
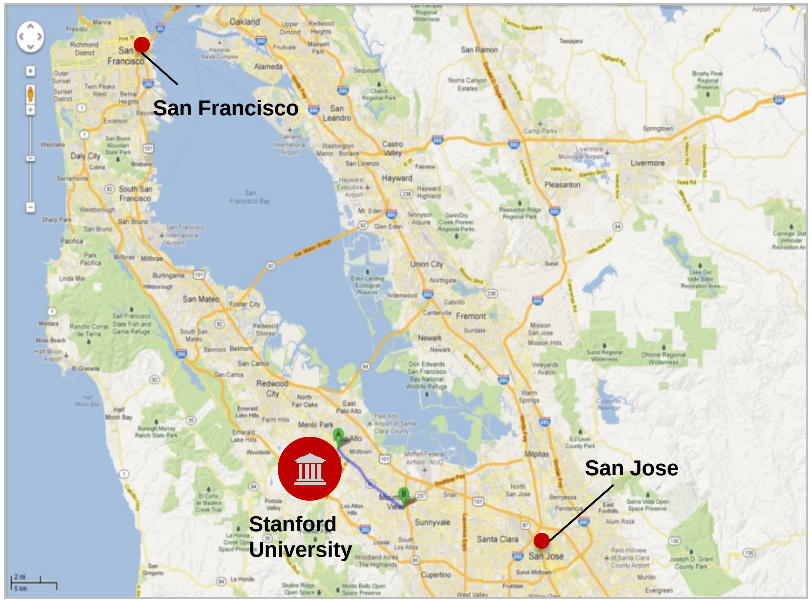
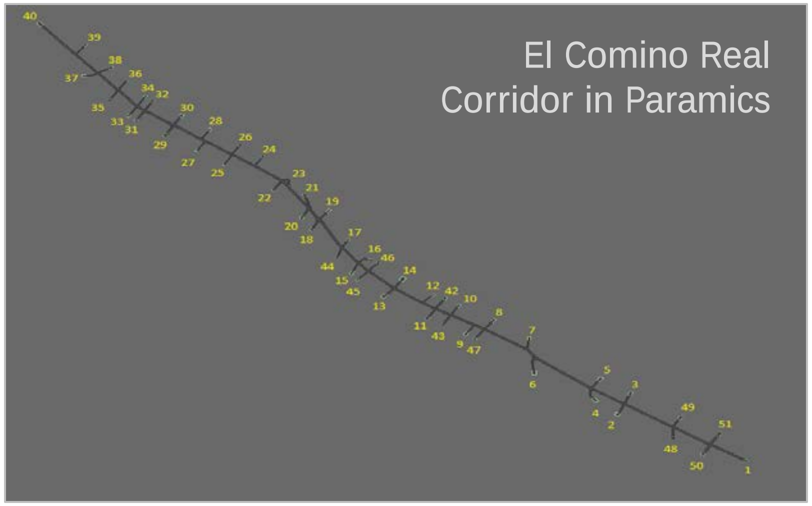


Modeling Network

- **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 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)



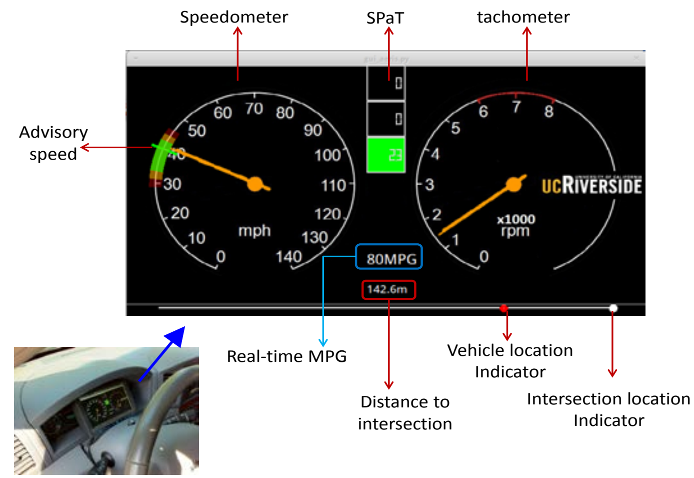


Summary of Modeling Results

- **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

2012 Proof of Concept

- A field test was conducted at 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



Speed (mph)	Avg. Fuel Savings (ml)	Avg. % Improvement
20	13.0	2.5%
25	111	18.1%
30	76.0	11.2%
35	73.8	6.3%
40	107	9.5%

GlidePath Prototype Application

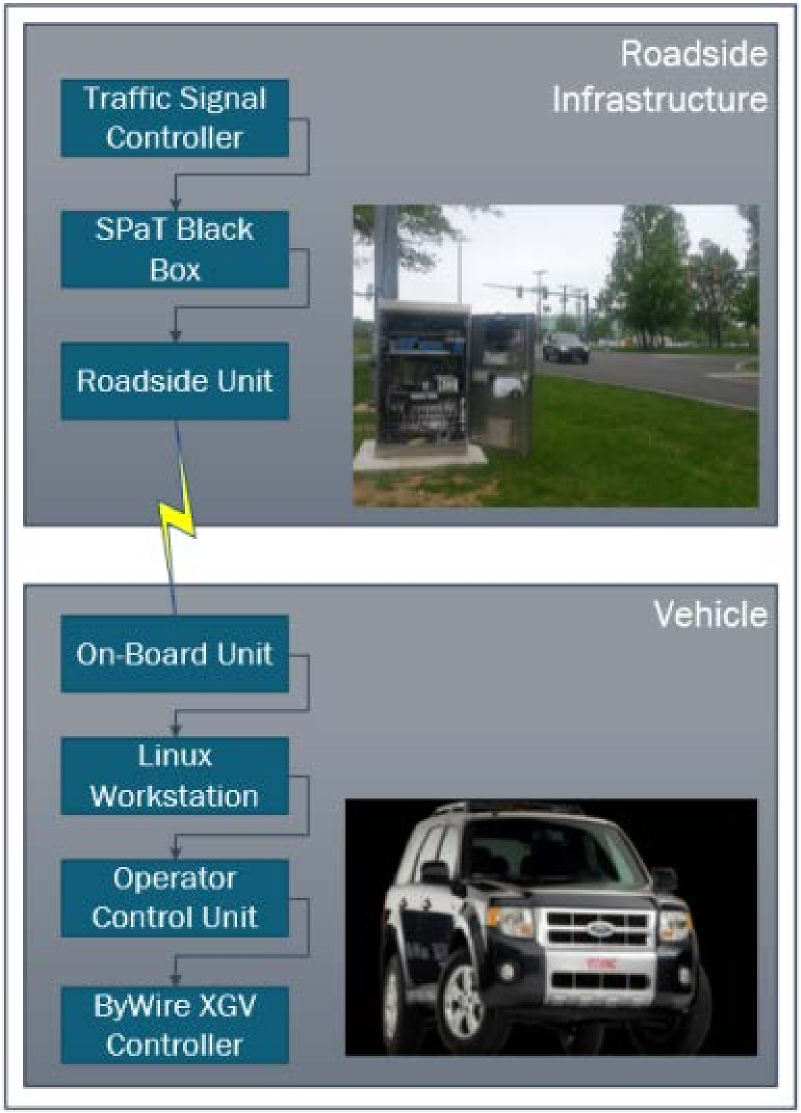
- **Project Objectives**
  - Develop a working prototype GlidePath application with automated longitudinal control for demonstration and future research;
  - Evaluate the performance of the algorithm and automated prototype (specifically, the energy savings and environmental benefits);
  - Conduct testing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

‘Automated’ Vehicle

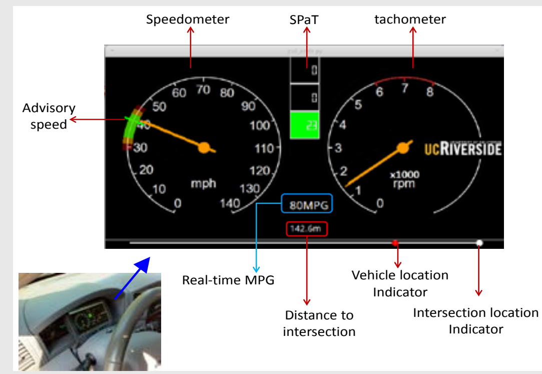
- **Ford Escape Hybrid developed by TORC with ByWire XGV System**
  - Existing Capabilities
    - Full-Range Longitudinal Speed Control
    - Emergency Stop and Manual Override
  - Additional Functionality
    - Computing Platform with EAD Algorithm
    - DSRC OBU
    - High-Accuracy Positioning Solution
    - Driver Indicators/ Information Display
    - User-Activated System Resume
    - Data Logging

GlidePath Field Experiment

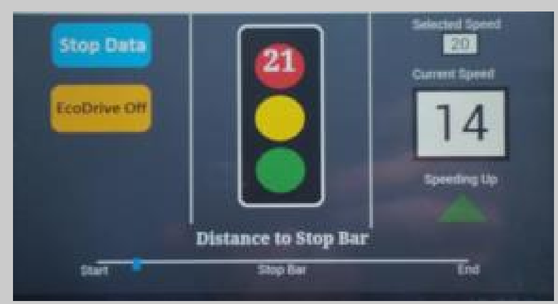
The field experimentation was organized into three stages

Stage I: Manual-uninformed (novice) Driver — Manual

Stage II: Manual-DVI Driver
(2012 AERIS experiment)



Stage III: Automated Driver



Preliminary GlidePath Results

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

Phase	Green						Red						On
Time in Phase (s)	2	7	12	17	22	27	2	7	12	17	22	27	Average
D vs. U	-11.80	-11.75	7.59	5.20	7.56	12.05	25.08	37.80	-18.34	21.71	-0.55	13.53	7.34
A vs. U	4.67	7.55	35.25	20.94	20.28	31.71	32.65	47.91	-3.95	26.48	20.05	22.89	22.20
A vs. D	14.73	17.27	29.93	16.60	13.76	22.36	10.11	16.25	12.16	6.10	20.48	10.83	15.88

- **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

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

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