Eco-Driving using Wireless V2I Communications at Signalized Intersections

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IBEC3: Evaluation of Connected Automated Driving

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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

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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

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AERIS Research Approach

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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

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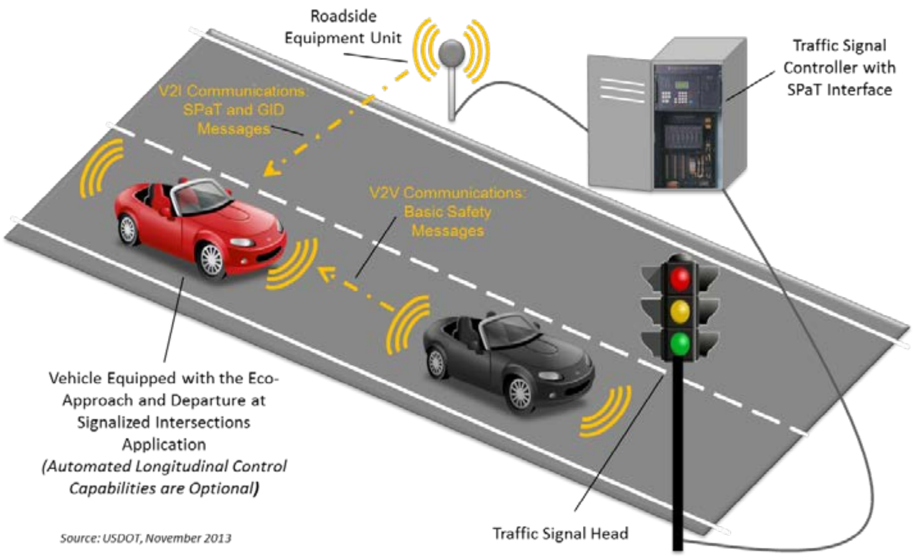
Application Overview

- 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

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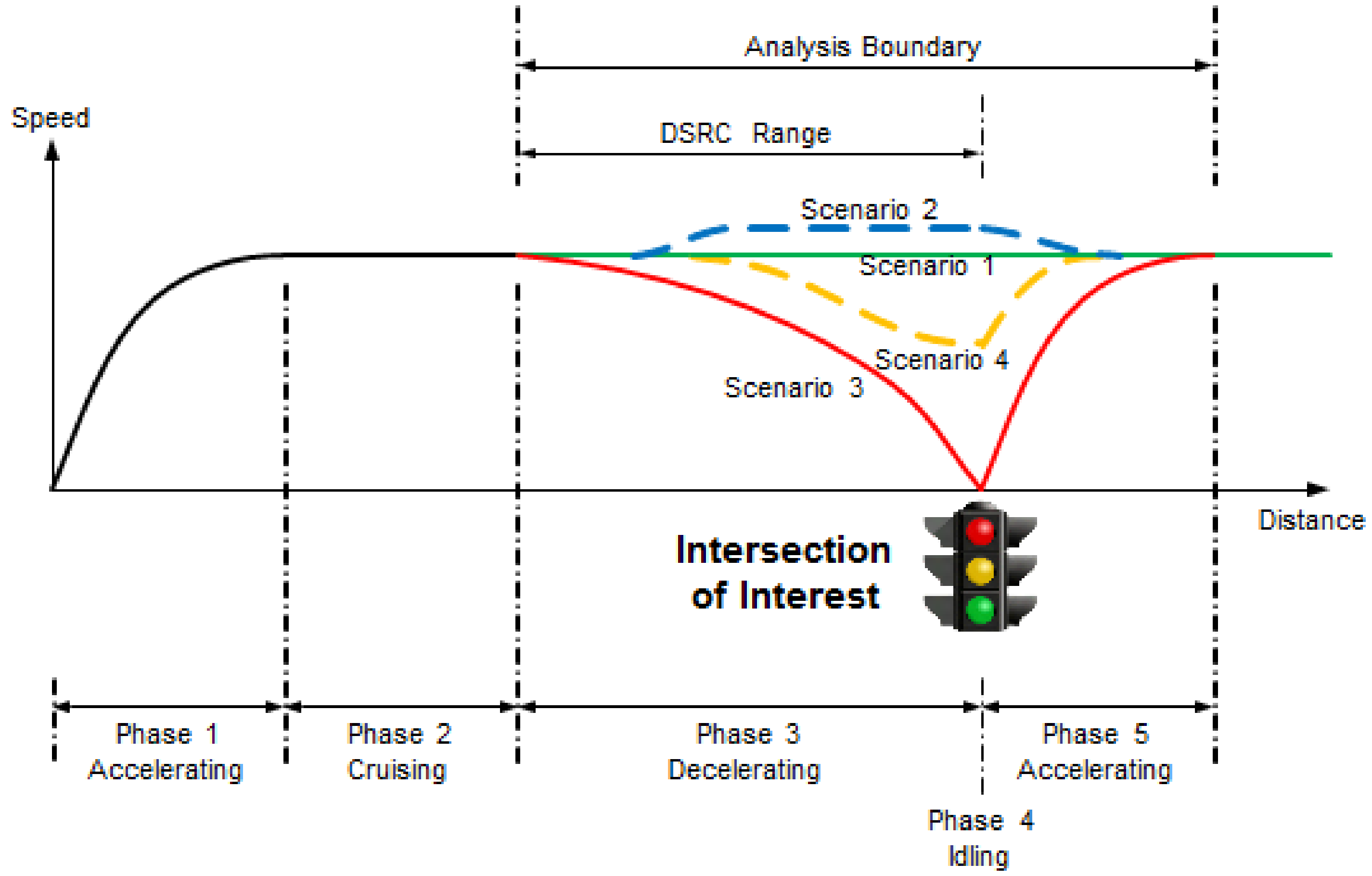

Variations

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- **Signal timing scheme matter**s: 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

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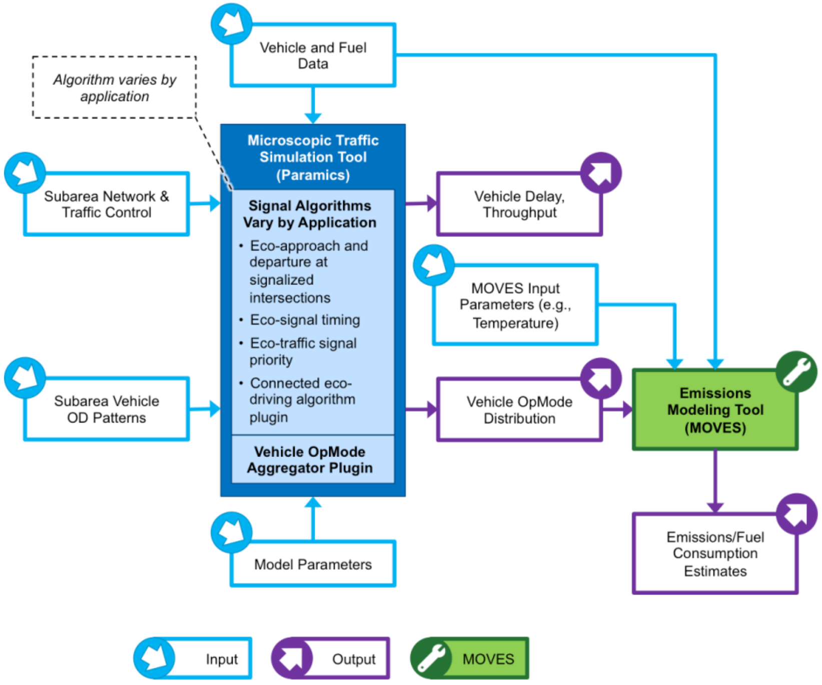
- A traffic simulation models (Paramics) was combined with an emissions model (EPA's MOVES model) to estimate the potential environmental benefits
- Application algorithms were developed by the AERIS team and implemented as new software components in the traffic simulation models
- Modeling results indicate a possible outcome – results may vary depending on the baseline conditions, geographic characteristics of the corridor, etc.



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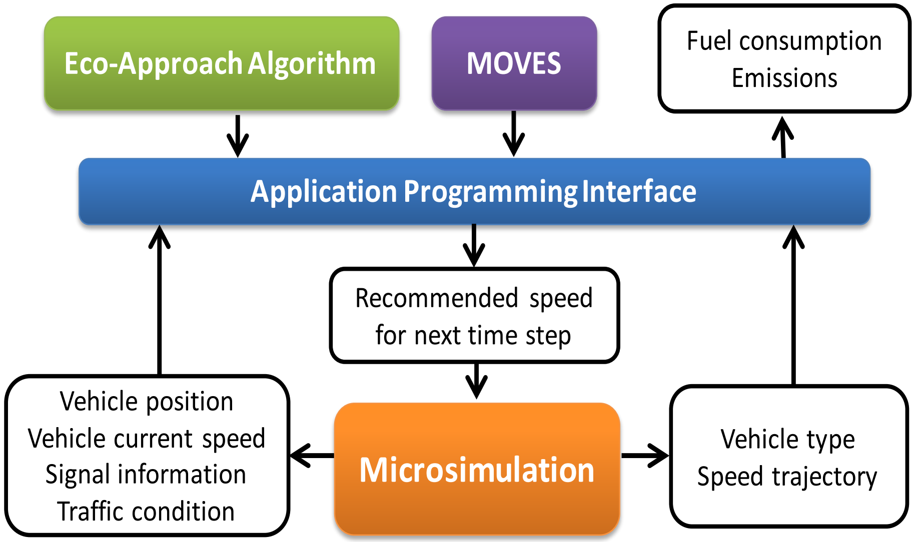

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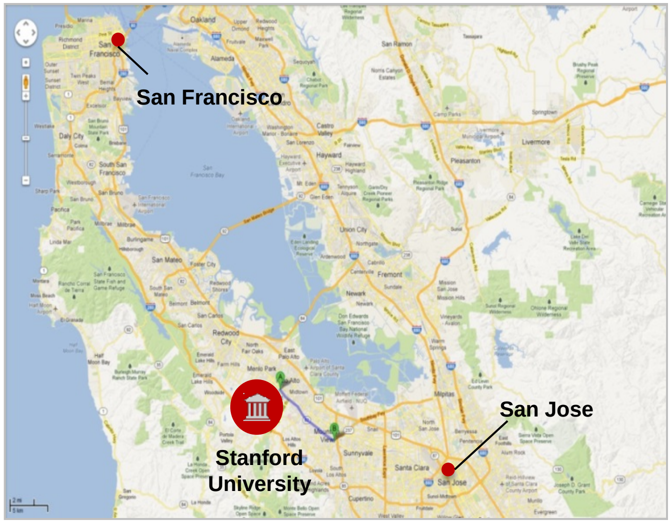
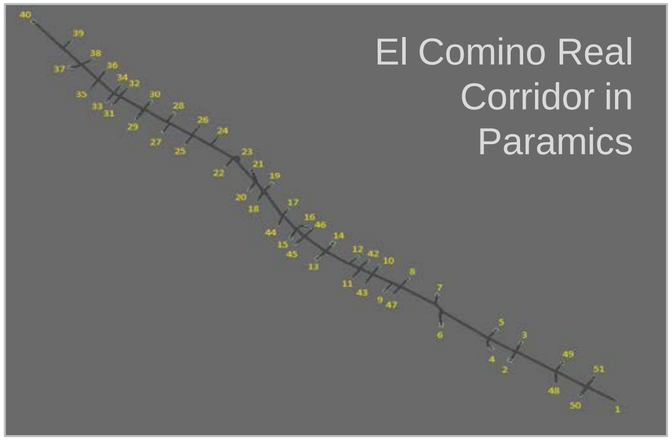
Modeling Network

- 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





Summary of Modeling Results

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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

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- 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)

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%

- 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

GlidePath Prototype Application

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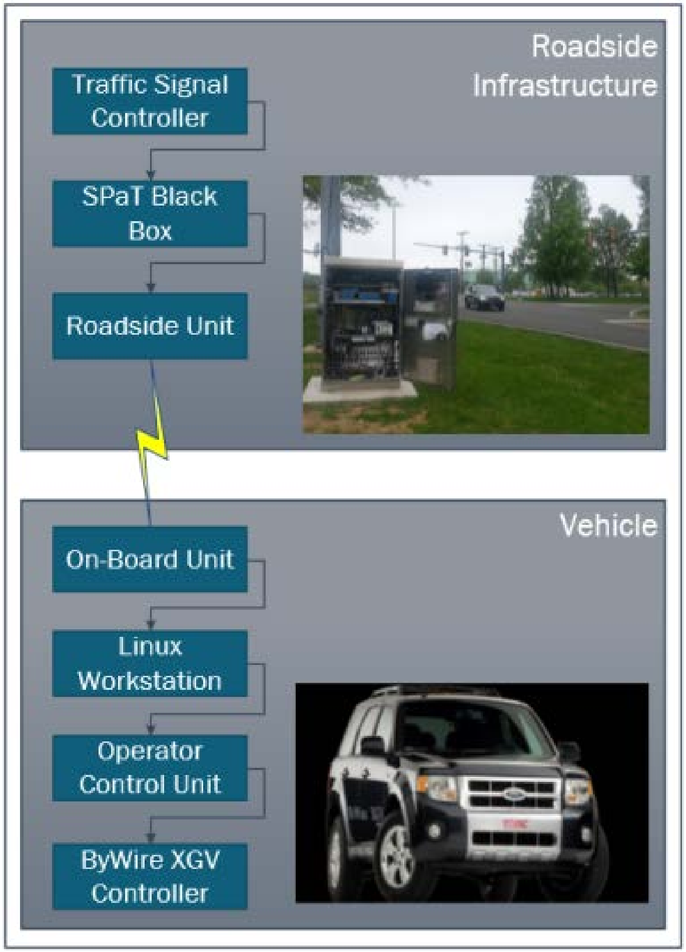
- Project Objectives
  - Develop a working prototype GlidePath application with the Eco-Approach and Departure Algorithm and **automated longitudinal control** for demonstration and future research
  - Evaluate the performance of the algorithm and automated prototype (specifically, the energy savings 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

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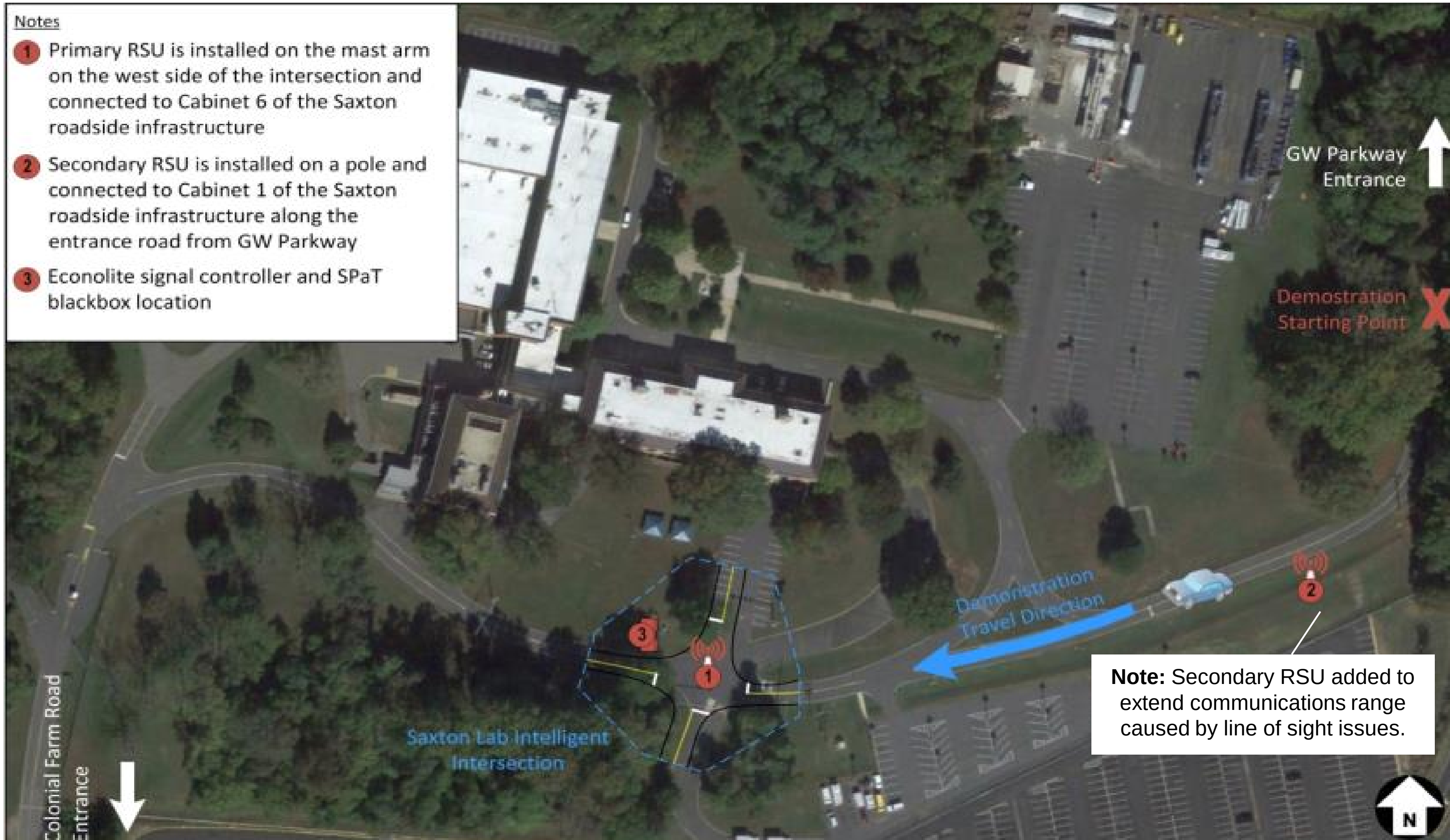

‘Automated’ Vehicle

- 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

GlidePath Field Experiment

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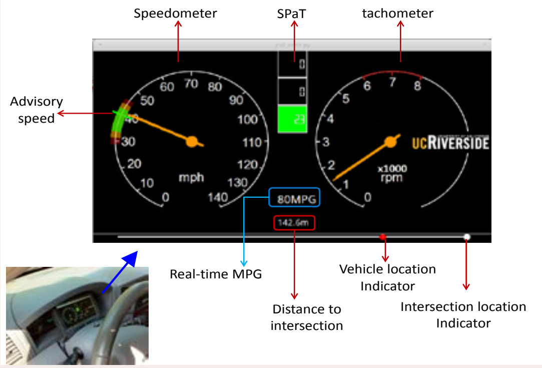
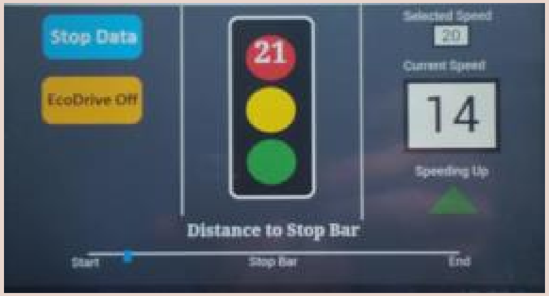
The field experimentation was organized into three stages

Stage I: Manual-uninformed (novice) Driver	Manual
Stage II: Manual-DVI Driver (2012 AERIS experiment)	
Stage III: Automated Driver	

Preliminary GlidePath Results

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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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