GlidePath Prototype Application

Automated Eco-Friendly Cruise Control using Wireless V2I Communications at Signalized Intersections

October 28, 2015

AERIS RESEARCH PROGRAM

USDOT Connected Vehicle Research

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

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 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

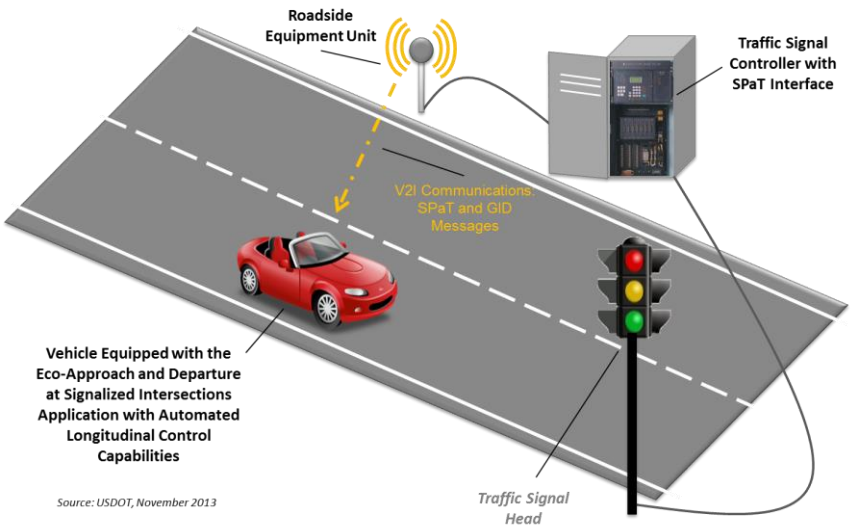
Develop a prototype for one of the applications to test its efficacy and usefulness.

APPLICATION OVERVIEW, INITIAL FIELD EXPERIMENT, AND MODELING

Eco-Approach and Departure at Signalized Intersections

Application Overview

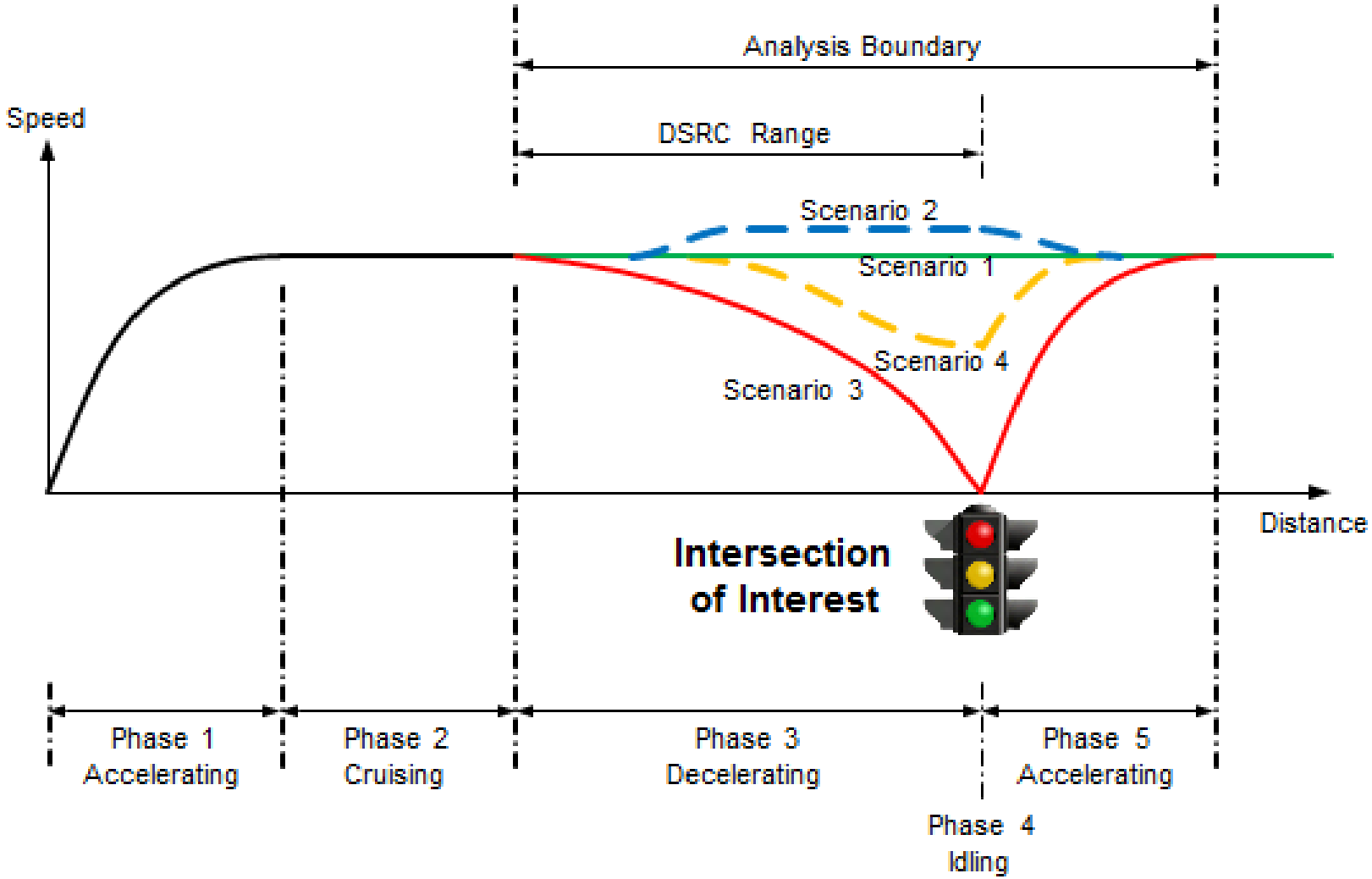
- Collects signal phase and timing (SPaT) messages and MAP messages using vehicle-to-infrastructure (V2I) communications



Source: USDOT, November 2013

- 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

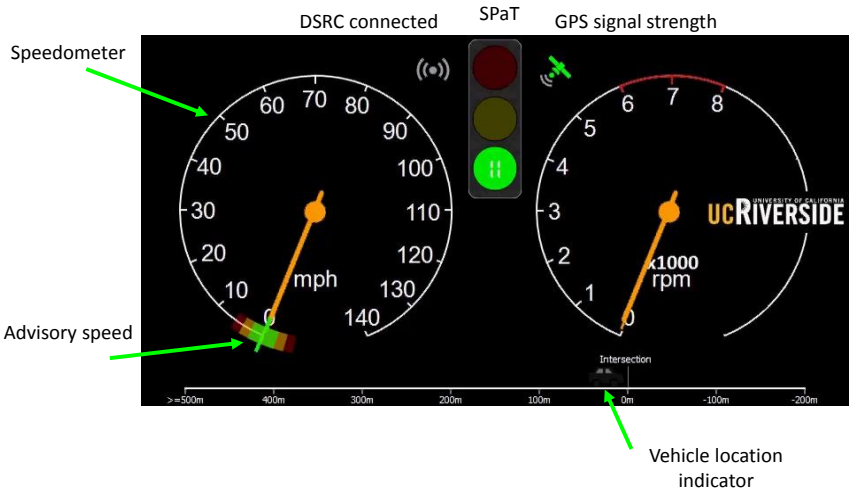


Factors and Variations

- **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

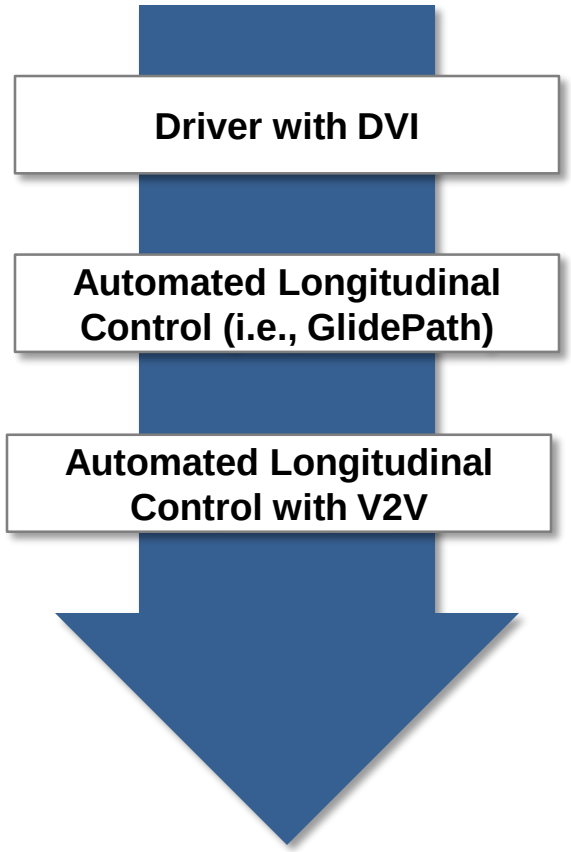


Speed (mph)	Avg. Fuel Savings (ml)	Avg. % Improvement
20	13.0	2.5%
25	111	18.1%
30	76.0	11.2%
35	73.8	6.3%
40	107	9.5%

Related Activities

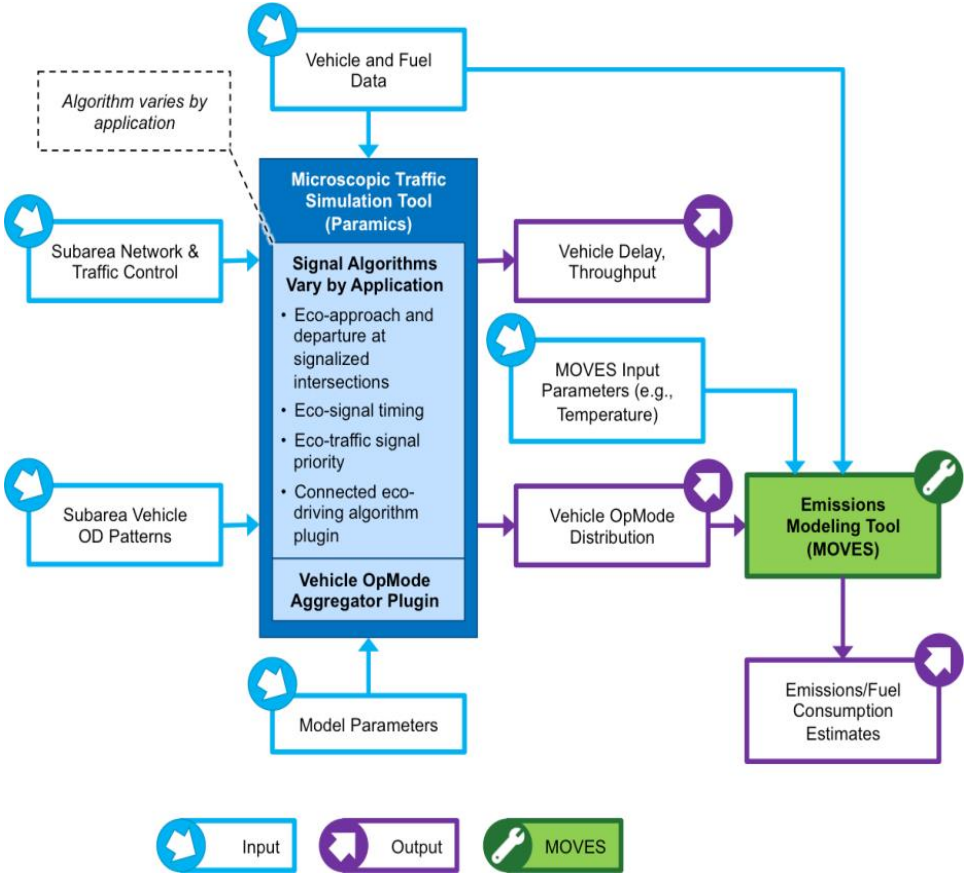
	Fixed-time Signals	Actuated Signals
Single Vehicle	***Field Study 2012*** *(FHWA EAR P1, AERIS)* ***Simulation Modeling 2012*** *(AERIS)* ***GlidePath 2015***	***Field Studies 2014/2015*** *(FHWA-EAR-P2 @ PATH FHWA-EAR-P2 @UCR)* ***Limited Simulation Modeling 2014*** *(FHWA-EAR-P2)*
Vehicle in Traffic	***Simulation Modeling 2013*** *(AERIS sensitivity analysis)*	***Field Studies 2014/2015*** *(FHWA-EAR-P2 @ PATH FHWA-EAR-P2 @UCR)* ***Field Study/Demo 2015*** *(FHWA-EAR-P2 ECR)*

Vehicle Control



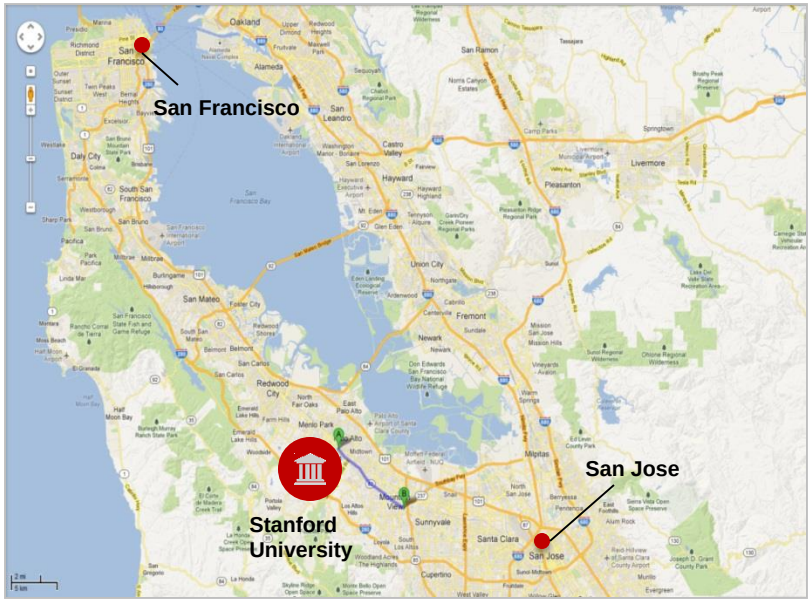
AERIS Modeling Overview

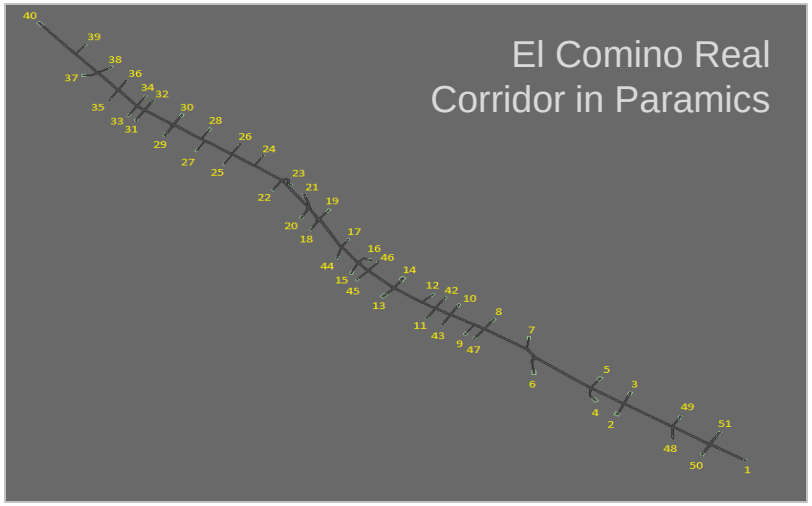
- A traffic simulation models (e.g., Paramics) was combined with an emissions model (e.g., EPA's MOVES model) to estimate the potential environmental benefits
- Application algorithms were developed by the AERIS team and implemented as new software components in the traffic simulation models
- Modeling 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 PROTOTYPE APPLICATION

GlidePath Prototype Application

Objectives and Period of Performance

- **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

Name	Role
Marcia Pincus	ITS JPO, AERIS Program Manager
Osman Altan	Project Manager
Robert Ferlis	Technical Director
Benjamin McKeever	Team Leader
Randall VanGorder	Saxton Lab COR
Brian Philips	Human Factors SME
Taylor Lochrane	Project Reviewer
Daniel Dailey	Project Reviewer
Brian Kerr	Facilities Manager

J.D. Schneeberger	Technical Support
Drennan Hicks	Technical Support

Name	Role
John Stark	Software Architect
David Ference	Software Developer
Kyle Rush	Software Developer
Frank Perry	DSRC SME
Dana Duke	Engineering Technician

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

Matthew Barth	Professor
Guoyuan Wu	Research Faculty
Various Graduate Students	

Mike Avitable	Engineering Manager

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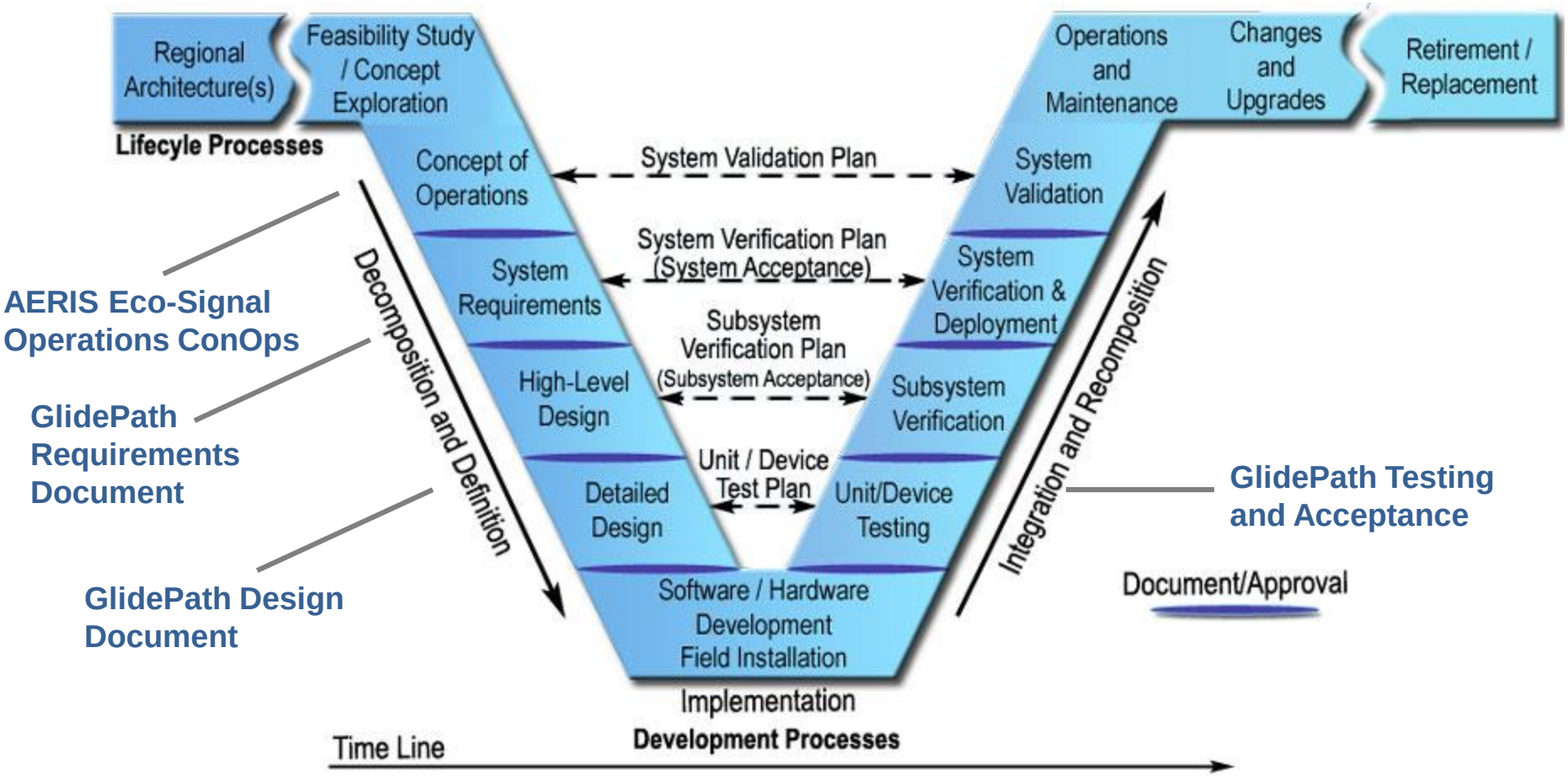
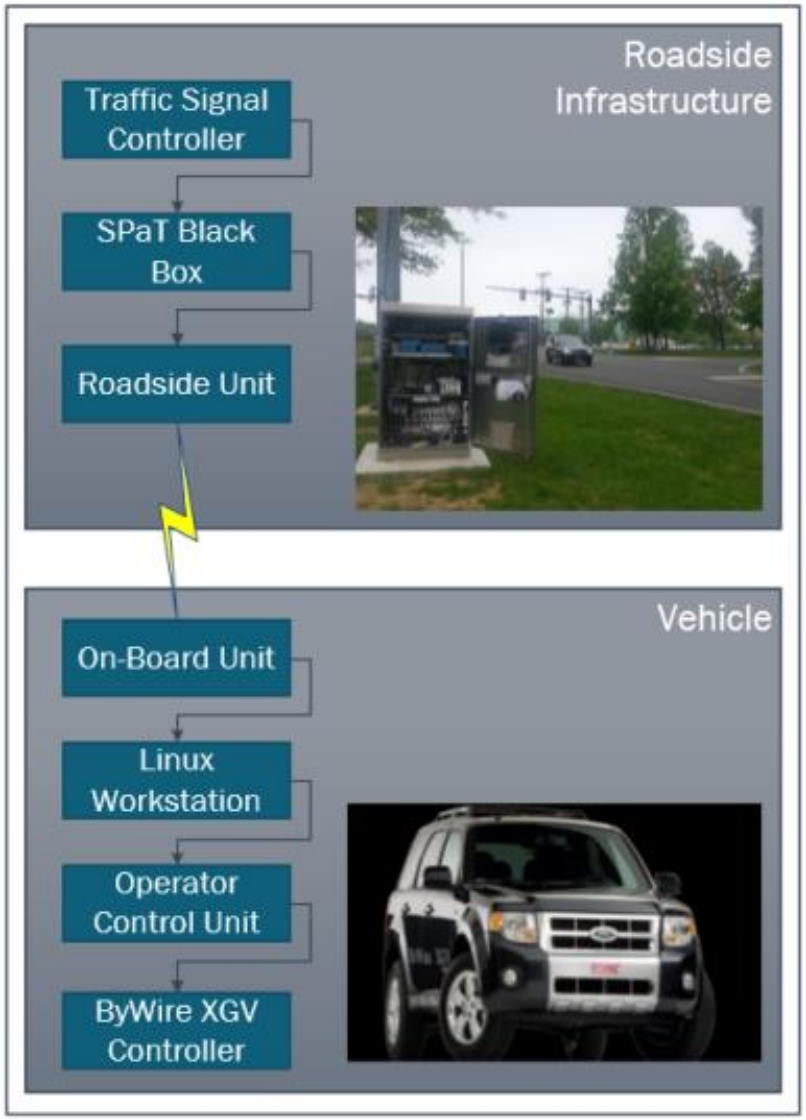
Project Approach



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



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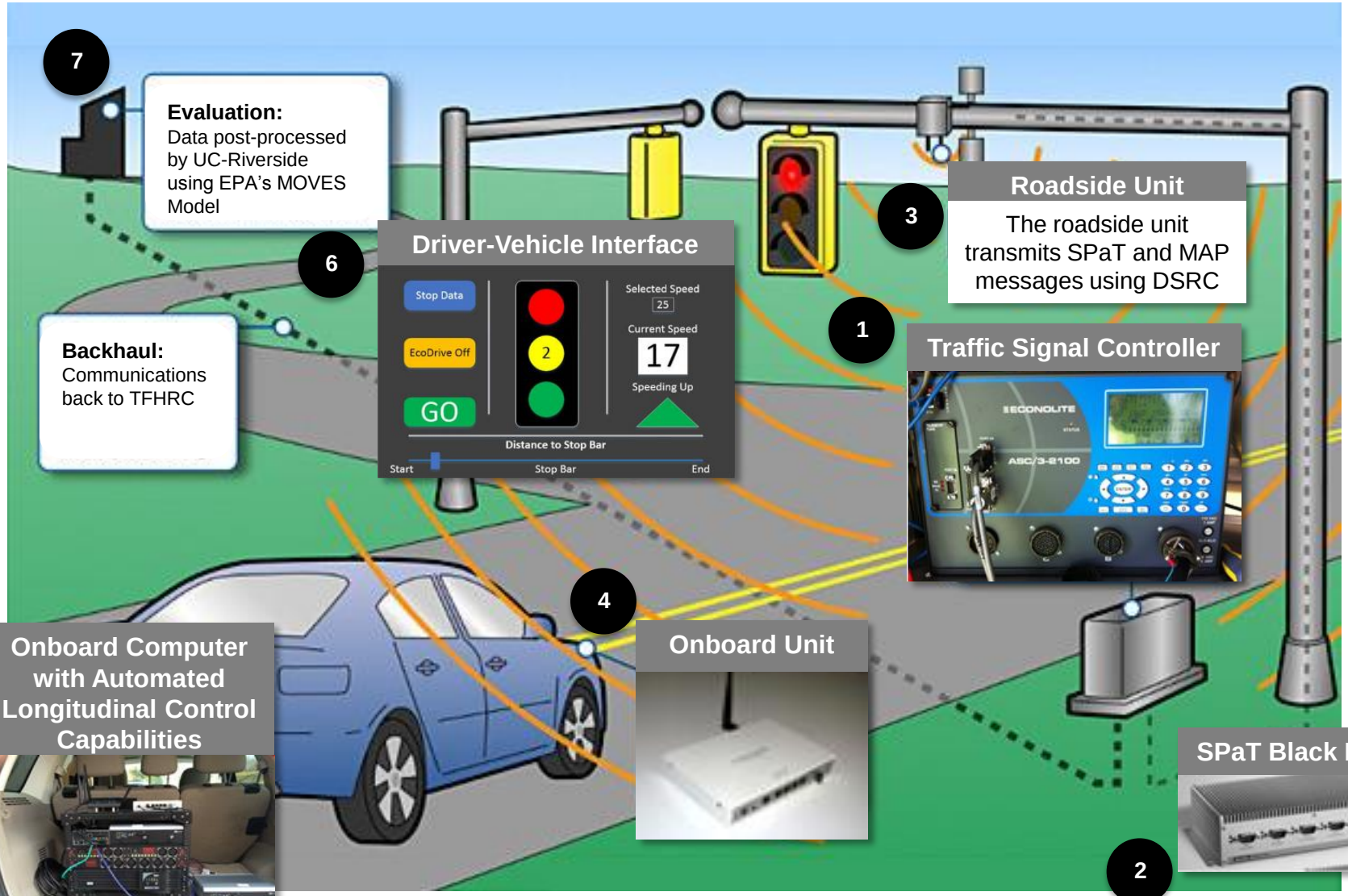
Components – Architecture



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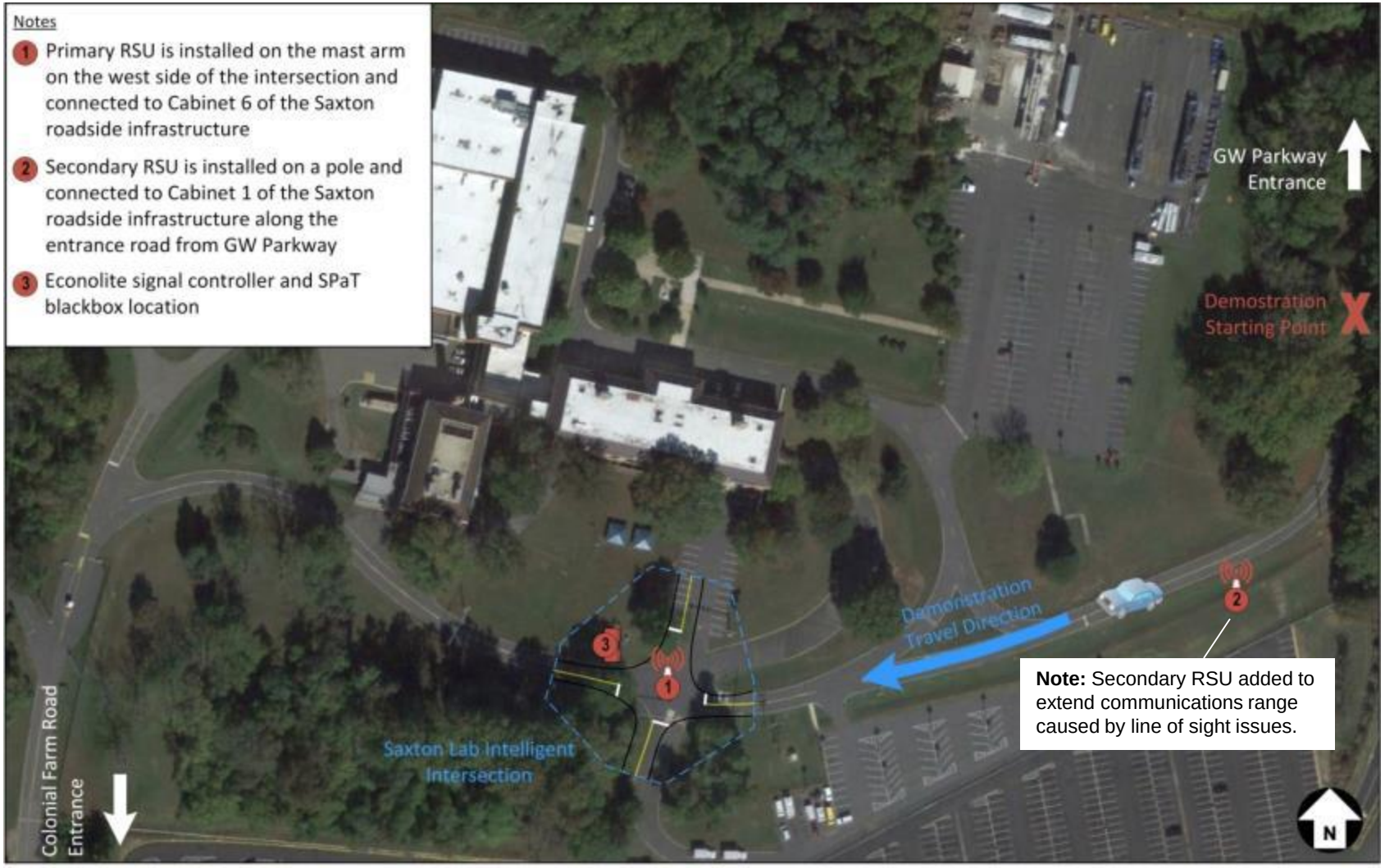
Components – Roadside Infrastructure



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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

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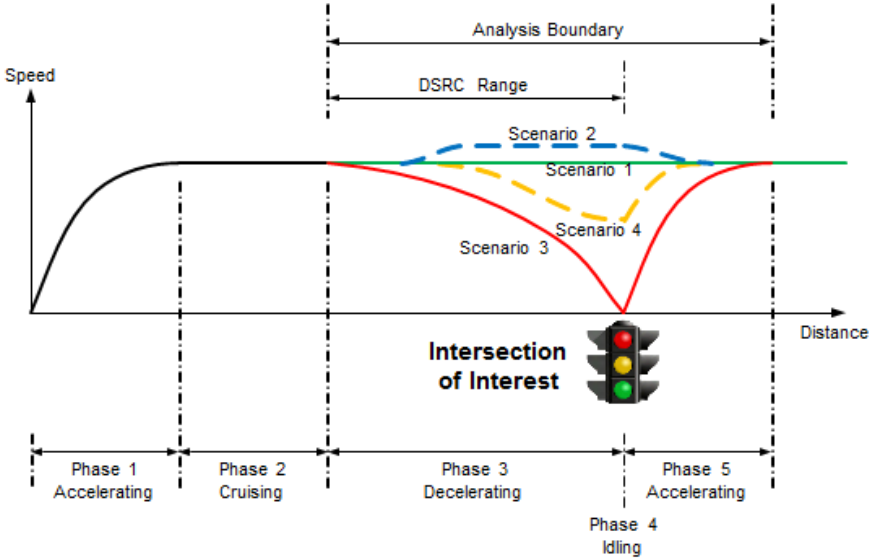
Components – Algorithm

- **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.

Scenario Overview



- **Output:**
  - Speed Trajectory
    - Target Speed updated at 10Hz
    - Target Acceleration/Deceleration transitions to minimize fuel consumption and bound “jerk” (da/dt) for passenger comfort

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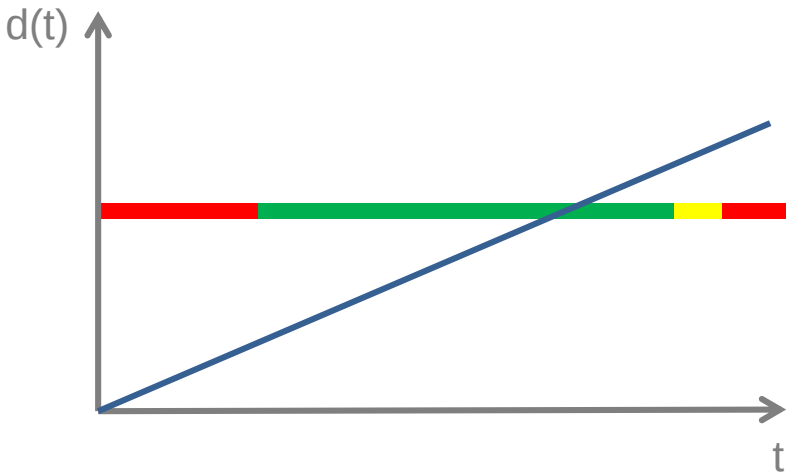
Scenario 1 – Maintain Speed to Pass Through



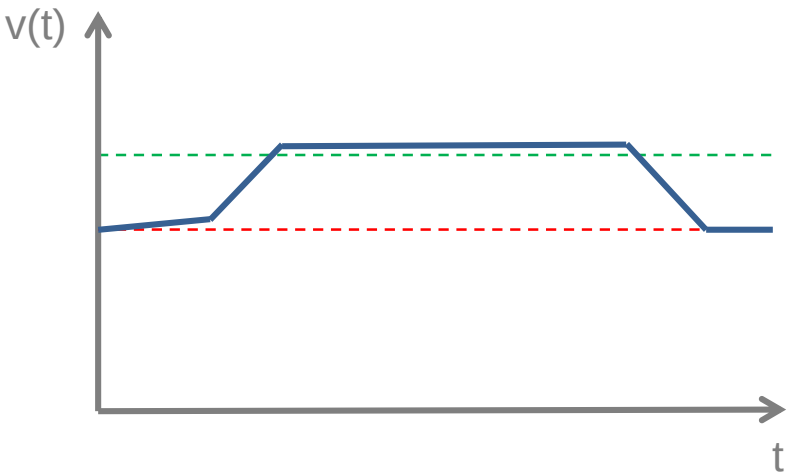
- **The vehicle passes through the intersection on the green phase without having to slow down or speed up**
- **Environmental benefits result from maintaining speed and reducing unnecessary accelerations**

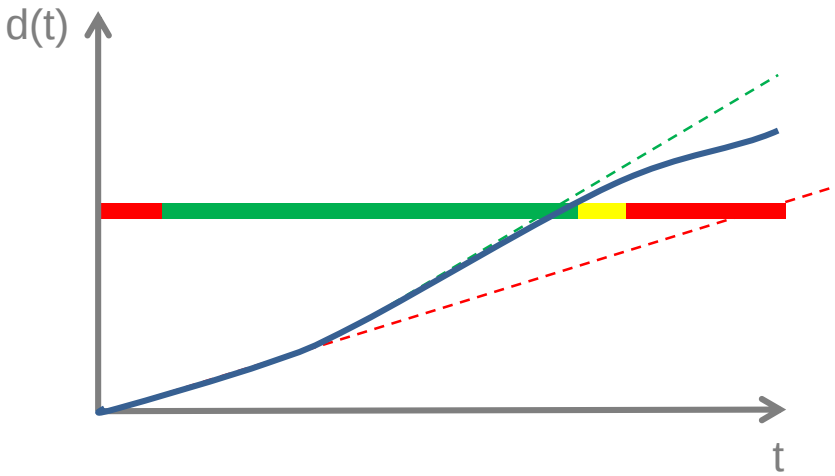
GlidePath Prototype Application

Scenario 1 – Maintain Speed to Pass Through

GlidePath Prototype Application

Scenario 2 – Speed Up to Pass Through Intersection





- **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 2 – Speed Up to Pass Through Intersection

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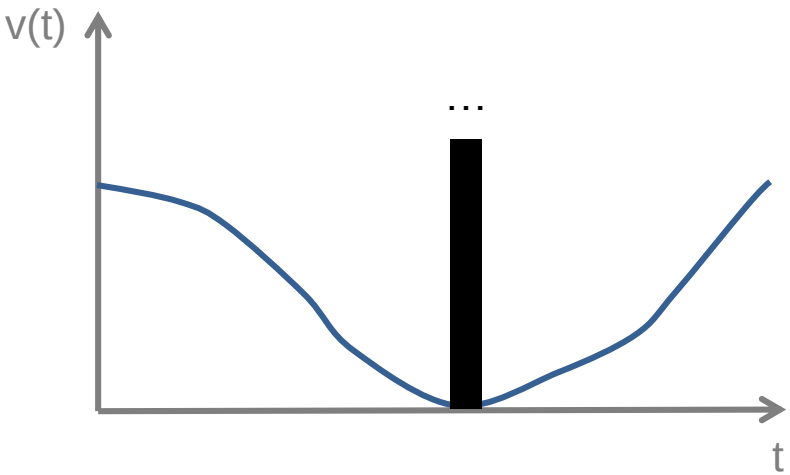
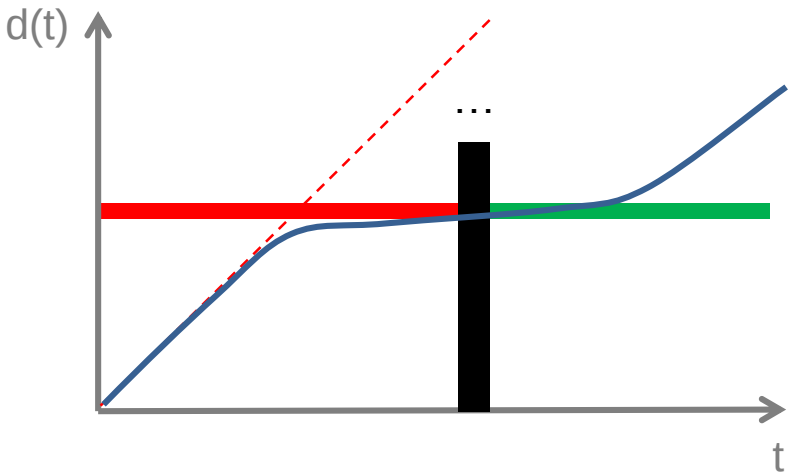
Scenario 3 – Coast to Stop at Intersection





- **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**

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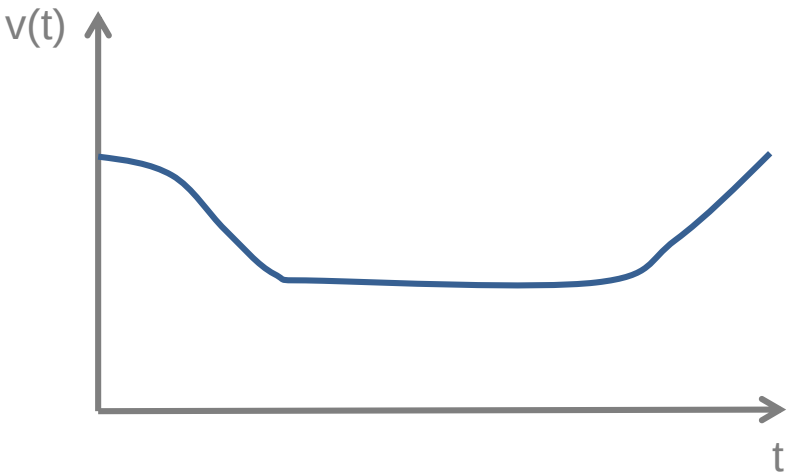
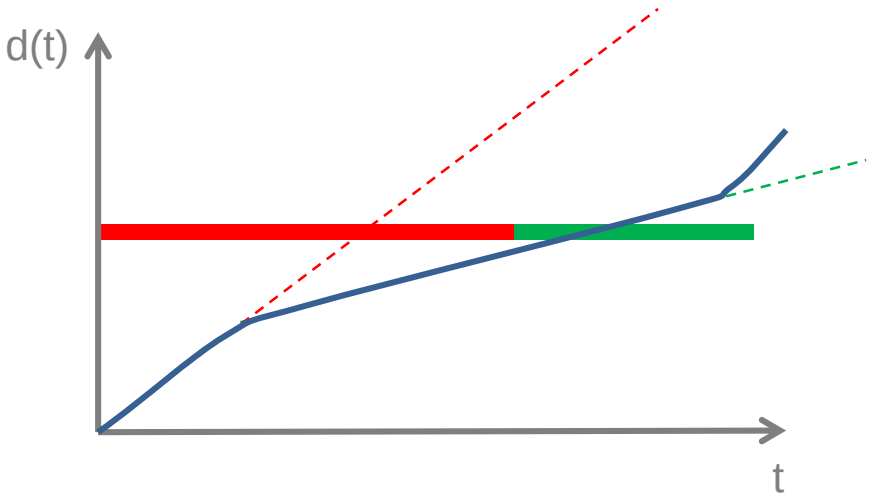
Scenario 3 – Coast to Stop at Intersection

GlidePath Prototype Application

Scenario 4 – Slow Down to Pass Through Intersection





- **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**

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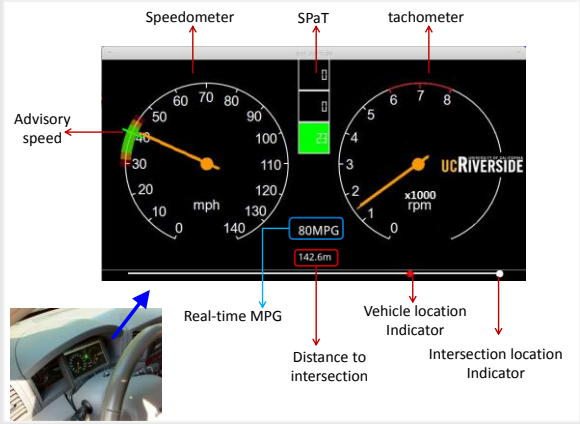
Scenario 4 – Slow Down to Pass Through Intersection

GLIDEPATH EXPERIMENTAL DESIGN, RESULTS, AND NEXT STEPS

GlidePath Prototype Application

Experimental Approach

The field experimentation will be organized into three stages

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

GlidePath Prototype Application

Experimental Design

Expected Scenario Outcome for Test Runs

Current Phase	Red						Y	Green				
V \ t	0	5	10	15	20	25	30	35	40	45	50	55
20 mph	Scenario 1					Scenario 2		Scenario 4				S3
25 mph	S4	Scenario 1						Scenario 3			Scenario 4	
30 mph (trials)	Scenario 4		Scenario 1						Scenario 3			S4

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

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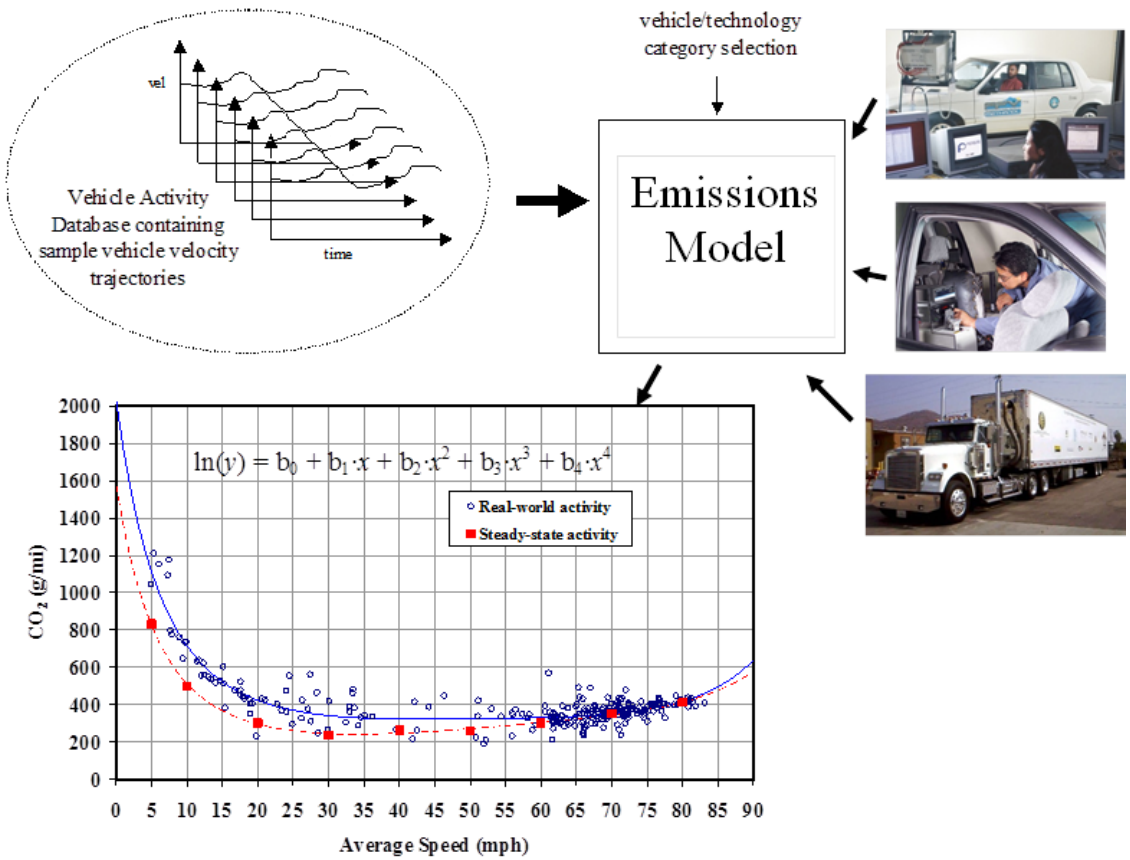
Energy and Emissions Estimation Methodology



- 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

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Preliminary Results

Table 1. Example driver's fuel consumption (g/mi) for different entry time (speed 20 mph)

Phase	Green						Red						Avg.
Time (s)	**2**	**7**	**12**	**17**	**22**	**27**	**2**	**7**	**12**	**17**	**22**	**27**	
Stage 2 vs. Stage 1 (DVI vs. Uninformed Driver)	-11.80	-11.75	7.59	5.20	7.56	12.05	25.08	37.80	-18.34	21.71	-0.55	13.53	**7.343**
Stage 3 vs. Stage 1 (Automated vs. Uninformed Driver)	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**
Stage 3 vs. Stage 2 (Automated vs. DVI)	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**

Scenario 1 Scenario 2 Scenario 3 Scenario 4

- 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)

compass4D

Piloting Cooperative Services for Deployment

- **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**"

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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

For More Information on GlidePath

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