Eco-Approach and Departure at Signalized Intersections: Preliminary Modeling Results

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

Fall/Winter Webinar Series
November 20, 2013
Presentation Overview

- General Eco-Approach and Departure Concept
- Variations on a Theme: Dimensions of Analysis
- Simulation Modeling Setup and General Results
- Simulation Modeling Sensitivity Analysis
- General Conclusions
- Enhanced Concepts: Combining with Connected Eco-Driving and Cooperative Adaptive Cruise Control
Eco-Approach and Departure Concept

Application utilizes traffic signal phase and timing (SPaT) data to provide driver recommendations that encourage “green” approaches to signalized intersections

example scenarios:

1) Coast down earlier to a red light;
2) Modestly speed up to make it (safely) through the intersection on green

Source: USDOT
Eco-Approach and Departure at Signalized Intersections

Vehicle Equipped with the Eco-Approach and Departure at Signalized Intersections Application (CACC capabilities optional)

V2I Communications: SPaT and GID Messages

V2V Communications: Basic Safety Messages

Traffic Signal Controller with SPaT Interface

Roadside Equipment Unit

Source: Noblis, November 2013
Signal Phase and Timing (SPaT)

• Data are broadcast from road side equipment (connected to traffic signal controller) to vehicles (I2V communications)
• SPaT information consists of intersection map, phase and timing (10 Hz), and localized GPS corrections
• Can be broadcast locally via Dedicated Short Range Communication (DSRC) and/or cellular communications
Variations on the General Concept

- **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**: pros and cons
- **Vehicle Control**: driver advice vs. partial automation
- **Communications Method**: short range vs. wide-area
- **Analysis Approach**: increasing incremental complexity and using previous results as “building blocks”
Eco-Approach Scenario Diagram

Intersection of interest

Analysis Boundary

DSRC Range

Vehicle 2

Vehicle 1

Vehicle 3

Vehicle 4

Intersection of Interest

Phase 1
Accelerating

Phase 2
Cruising

Phase 3
Decelerating

Phase 4
Idling

Phase 5
Accelerating
Eco-Approach Driving Scenario 1 (cruise)

- Vehicle is able to pass through the intersection on green phase
- does not need to slow down or speed up
- Best scenario for fuel economy
Eco-Approach Driving Scenario 2 (speed up)

- Vehicle needs to safely speed up to pass through the intersection on green phase
- Energy savings due to not having to stop and idle
Eco-Approach Driving Scenario 3 (coast down, stop)

- Vehicle needs to slow down to stop at the intersection
- Energy savings due to slowing down sooner
Eco-Approach Driving Scenario 4 (coast down, no stop)

- Vehicle needs to slow down to pass through the intersection on green phase
- Energy savings due to not having to idle
Velocity Planning Algorithm

- **Target velocity** is set to get through the green phase of the next signal (time-distance calculation)
- **Initial velocity** may be above or below target velocity

\[ d_0 \]
\[ v_c \rightarrow \quad \text{Suggested optimal speed} \]
\[ v_p \rightarrow \quad \text{Car Following Logic} \]
\[ t_H \text{ or } d_s \rightarrow \quad v_{\text{limit}} \]

\[ v_c = \text{the current vehicle velocity} \]
\[ v_p = \text{the velocity of the preceding vehicle} \]
\[ v_{\text{limit}} = \text{local speed limit} \]
\[ t_H = \text{safe headway time} \]

**References**


Previous Studies & Results with Algorithm

Initial Simulation:

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references:


Real-World Results of FHWA EAR project with BMW, UC Berkeley at Richmond Field Station (4/2012):

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reference:

average fuel saved: 18%
Driver Interface used in Demonstration

- Speedometer
- SPaT
- tachometer

Advisory speed

Real-time MPG

Distance to intersection

Vehicle location Indicator

Intersection location Indicator
Simulation Modeling
Modeling Objectives

- Conduct detailed simulation modeling and test benefits under different traffic conditions, network conditions, technology penetration rates, and other variables
- Modeling initially focused on a “generic intersection”
- Simulation parameters (car-following logic, lane-change behavior) calibrated using NGSIM data sets
- Modeling focused on El Camino Real network with real-world traffic and network data (Palo Alto, CA)
- Later tie-in with travel demand models and other AERIS concepts
Modeling Setup

- **Paramics traffic simulation model** with API plug-ins (eco-approach method, energy/emissions models)
Region of Modeling: El Camino Real in Northern California
Modeling Tools and Interaction

Eco-Approach Algorithm

MOVES

Fuel consumption
Emissions

Application Programming Interface

Recommended speed for next time step

Microsimulation

Vehicle position
Vehicle current speed
Signal information
Traffic condition

Vehicle type
Speed trajectory
Videos

baseline

eco approach & departure
General Modeling Results:
Hypothetical 11-Signalized Intersection Corridor

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How would this benefit a user?

- Six-mile corridor, average traffic congestion
- Light-duty vehicle, 24 mpg, gasoline costs $4/gallon
- Unequipped vehicle spends $1 in fuel to traverse corridor
- Equipped vehicle spends ~$0.87 in fuel to traverse corridor
- Driving 16,000 miles/year → $346 of savings per year
- SUV vehicle: savings of $560/year
- Fleet operator (150 vehicles): $84,000/year
Modeling Results: Multiple Intersections

Uncoordinated Signal Control:
- Signal timing is set to be uncoordinated between intersections (no “green wave”)
- Eco-approach algorithm applied on all three intersections, cross traffic included in analysis
- The links in this network are short, which affects the effectiveness of the eco-approach algorithm
- Typical Fuel (CO₂) Savings: 5% - 10% overall

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<th>Energy(kJ/mi)</th>
<th>CO₂ (g/mi)</th>
<th>CO (g/mi)</th>
<th>HC (g/mi)</th>
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Modeling Results: Multiple Intersections

**Coordinated Signal Control:**

- Signal timing is set to be coordinated between intersections (real-world)
- Coordinated signal control results in ~8% fuel reduction over uncoordinated
- Eco-approach algorithm applied on all three intersections, cross traffic included in analysis
- Fuel (CO₂) Savings: 4% - 5% overall

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<th>Scenario</th>
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Modeling Results: Penetration Rate

![Graph showing energy saving and penetration rate for coordinated and uncoordinated signal control with different V/C ratios.](image)

**Uncoordinated Signal Control**

**Coordinated Signal Control**
Modeling Results: Individual vs. Network Benefits

Total network savings is slightly higher than sum of equipped vehicle savings

reference:
Modeling Results: Communications

Communication Range Analysis

Communication Delay Analysis
Simulation Modeling Conclusions (1 of 2)

• In general, 5%-10% fuel savings can be achieved with 100% penetration rate of technology
• Eco-approach and departure technology provides an additional 4%-5% improvement on top of a coordinated corridor
• Coordinated signal control by itself results in approximately 8% fuel/emissions reduction over uncoordinated
• Smaller penetration rate of technology still has a positive network effect (non-equipped vehicles also have a slight benefit)
• Eco-approach and departure is less effective with increased congestion
Simulation Modeling Conclusions (2 of 2)

- Application benefits are sensitive to communications range (when is the information received by the vehicle)
- Application benefits are not very sensitive to communications delay
- General Eco-Approach and Departure Application could be accomplished without DSRC, instead using a cellular communications network
- Enhanced Application (with CACC, etc.) would likely require DSRC or a hybrid communication strategy
Enhanced Simulation Modeling
Inserting Eco-Approach and Departure into Connected Eco-Driving Application

- Eco-Speed Harmonization
- Eco-Approach /Departure
- Eco-Driving Feedback System

Connected Eco-Driving
Connected Eco-Driving Application

- Eco-speed harmonization for freeways
- Eco-approach and departure (inside V2I communication range)
- Eco-speed harmonization for arterials (outside V2I communication range)
- Eco-Driving feedback for the whole network
CACC-assist and Eco-Approach and Departure

- Note that we have been modeling vehicles in the eco-approach and departure scenarios such that the vehicles follow the speed profiles exactly as specified.

- TFHRC demonstration: when a driver followed the “speed-advice” speedometer, it was often difficult to follow the recommended speed.

- Results: typical drivers can’t follow the planned trajectories exactly. Comparing typical driver following speed advice with exact trajectory following, following exact trajectories results in a 5% improvement in fuel savings. (2014 TRB paper)

- Consider having CACC-assistance when following trajectories.
Evaluating benefits of CACC-assist

• Initial Simulation Experiments:
  - Isolated intersection
  - One lane in each direction
  - Link lengths 680m (before and after intersection)
  - Speed limit 40mph
  - Mainline through signal: green 30s, red 60s
  - Traffic demand: 1200 veh/lane/hour
  - Typical queues at red lights: ~10 vehicles
  - We varied reaction time and headway
CACC-Based Eco-Approach and Departure

- For isolated intersection
  - Approach: platoon-based eco-approach
  - Departure: platoon discharges with minimum headway
Results: Comparing driver HMI and CACC-assist

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**Improvements due to smoothness, less idle time, better throughput**
Lessons Learned:

- The Eco-Approach and Departure Application is very promising, showing fuel and CO$_2$ reductions in the range of 5% to 10%, depending on conditions.

- The application has the potential to be a near-term deployable connected vehicle application:
  - low cost
  - doesn’t require high penetration rates
  - doesn’t require new communication infrastructure at every intersection
Future Work:

- Integrate modeling of the Eco-Approach and Departure Application with other Eco-Traffic Signal Applications to determine composite benefits

- Continue to evaluate the benefits of enhancing Eco-Approach and Departure with partial automation (CACC)

- Place research results in context with other research programs, e.g., domestic and international

- Demonstrate the concept with an AERIS Prototype
## Future Work: Analyzing other Dimensions

### Single Vehicle

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### Vehicle in Traffic

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<td>Simulation modeling 2013 (AERIS sensitivity analysis)</td>
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### Vehicle Control:

- **Driver with HMI**
  - ACC-assist
  - ""
  - CACC-assist
Research Team

- **University of California-Riverside:**
  - Matthew Barth (principal investigator)
  - Kanok Boriboonsomsin (research faculty)
  - Guoyuan Wu (research faculty)
  - Haitao Xia (graduate student)

- **Booz Allen Hamilton:**
  - Balaji Yelchuru
  - Sean Fitzgerel
  - Sudeeksha Murari

- Many others have contributed:
  - AERIS research team partners
Contact Information

Eco-Approach and Departure at Signalized Intersection:
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Upcoming AERIS Webinars

Webinar #2: Incorporation of Stakeholder Input Into the AERIS Program
   Wednesday, December 4th, 2013 at 1:00 pm ET

Webinar #3: Preliminary Eco-Traffic Signal Timing Modeling Results
   Wednesday, January 29th, 2013 at 1:00 pm ET

Webinar #4: Preliminary Eco-Traffic Signal Priority (for Transit and Freight) and Connected Eco-Driving Modeling Results
   Wednesday, February 12th, 2014 at 1:00 pm ET

Webinar #5: A Comparison of US and EU Connected Vehicle Environmental Research Activities
   Wednesday, March 12th, 2014 at 1:00 pm ET

Registration
   Persons planning to participate in the webinar should register online at
   www.itsa.org/aerisfall2013