Eco-Approach and Departure (EAD) Applications for Connected Vehicles in Real-World Traffic

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EAD at Signalized Intersections

- Collects signal phase and timing (SPaT) and Geographic Information Description (GID) messages using vehicle-to-infrastructure (V2I) communications
- Collects basic safety messages (BSMs) from nearby vehicles using vehicle-to-vehicle (V2V) communications
- Receives V2I and V2V 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
EAD for Fixed Time Signals

- **10-15%** fuel reduction benefit for an equipped vehicle
- **5-10%** fuel reduction benefits for traffic along an uncoordinated corridor

A field study was carried out at the Turner Fairbanks Highway Research Center (TFHRC) in McLean, Virginia, in August, 2012.

Evaluate the benefits of enhancing the application with partial automation: GlidePath
EAD for Fixed Time Signals
EAD for Actuated Signals

- Estimate Green Window
- Real Time SPaT
- Green Window Estimator
- Vehicle Trajectory Planning Algorithm (VTPA)
- State Machine to Turn on/off the Display of Target Speed
- Human-Machine Interface (HMI)
- Car-Following Speed Estimator
- Activity Data of Preceding Vehicle from Radar
- Time-to-Collision Estimator
- Activity Data of Preceding Vehicle Related Parameters
- Extract Subject Vehicle Dynamics
- Instantaneous Speed, RPM and MPG
- Activity Data of Subject Vehicle from OBD

Flowchart:
- Estimation of Distance to Intersection
- Map Information
- Map Matching
- Vehicle Location from GPS
- Distance to Intersection
- Estimate Distance to Intersection
- Historical Database

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EAD in Real-World Traffic
EAD Guidelines for Actuated Signals

The primary objectives of the proposed algorithm:

- Safety: keep safe headway while not exceeding the speed limit and not crossing on red
- Avoid (possibly) unnecessary acceleration and deceleration.
- Avoid or minimize idling at the intersection
- Avoid crawling for a long distance

Source: Barth and Boriboonsomsin (2008)
EAD Strategies for Actuated Signals

(a) Three strategies for EAD

(b) Case I: Minimum time-to-change

(c) Case II: Maximum time-to-change

Figure 6. Flowchart of modified EAD algorithm
State Machine for Target Speed Display

Condition Set 1 — A ∪ B ∪ C ∪ D
A. Vehicle is out of the target corridor
B. DSRC or GPS signal is lost
C. Estimated time-to-collision (TTC) is less than \( T_2 \) seconds
D. Measured distance is less than \( d_1 \) meters

Condition Set 2 is satisfied

“Opt-in” mode (display recommended speed)

“Opt-out” mode (not display recommended speed)

Condition Set 2 — A ∩ B ∩ C ∩ D
A. Vehicle is traveling along the target corridor with good DSRC and GPS signals
B. Estimated time-to-collision (TTC) is greater than \( T_3 \) seconds
C. Measured distance is greater than \( d_2 \) meters
D. Last transition (from “opt-in”) occurred more than \( T_1 \) (e.g., \( T_1=2 \)) seconds ago
Field Testing in Riverside, CA

Field study location in Palmyrita Ave, Riverside CA

Test platform

Roadside and on-board components

Signal controller
Road-side computer and DSRC
On-board DSRC
Vehicle computer
Driver display

OBD data
Radar data
Evaluation Methodology

To comprehensively evaluate possible signal and traffic conditions for eco-approach and departure at an actuated-signalized intersection, we defined four typical scenarios in the test.

<table>
<thead>
<tr>
<th>Cross street</th>
<th>Mild traffic</th>
<th>Heavy traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main street</td>
<td>① Mild traffic</td>
<td>② Heavy traffic</td>
</tr>
<tr>
<td>Mild traffic</td>
<td>Minimum green Minimum red Likely to be leading vehicle Target speed display: On</td>
<td>Minimum green Maximum red Likely to be leading vehicle Target speed display: On</td>
</tr>
<tr>
<td>Heavy traffic</td>
<td>Maximum green Minimum red Likely to be following vehicle Target speed display: Off</td>
<td>Maximum green Maximum red Likely to be following vehicle Target speed display: Off</td>
</tr>
</tbody>
</table>
Results: Trajectories for Scenario 1

- Informed drivers, 35 mph
- Informed drivers, 25 mph
- Uninformed drivers, 35 mph
- Uninformed drivers, 25 mph
Results: Trajectories for Scenario 4

- Informed drivers, 35 mph
- Informed drivers, 25 mph
- Uninformed drivers, 35 mph
- Uninformed drivers, 25 mph
## Results: Percentage Savings of Fuels

<table>
<thead>
<tr>
<th>Main street</th>
<th>Cross street</th>
<th>Mild traffic</th>
<th>Heavy traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>35 mph</strong></td>
<td>G5 G15 R5 R15 Avg</td>
<td>G5 G15 R5 R15 R25 R35 Avg</td>
<td>35 mph 40.3 -8.4 3.8 -9.8 5.9 -0.8 <strong>5.2</strong></td>
</tr>
<tr>
<td>Mild traffic</td>
<td>43.4 13.0 34.1 -9.3 <strong>20.3</strong></td>
<td>41.1 12.0 7.1 7.1 10.2 -0.8 <strong>12.8</strong></td>
<td></td>
</tr>
<tr>
<td>25 mph 19.5 8.3 5.2 6.4 <strong>9.9</strong></td>
<td>25 mph 11.6 8.5 <strong>10.0</strong></td>
<td>25 mph 15.3 37.3 <strong>26.3</strong></td>
<td>25 mph 25.8 20.3 32.6 25.0 <strong>25.5</strong></td>
</tr>
<tr>
<td><strong>25 mph</strong></td>
<td>G25 G35 Avg</td>
<td>G25 G35 R5 R15 Avg</td>
<td>35 mph 0.7 -2.1 17.8 10.2 <strong>6.6</strong></td>
</tr>
<tr>
<td>Heavy traffic</td>
<td>11.6 8.5 <strong>10.0</strong></td>
<td>15.3 37.3 <strong>26.3</strong></td>
<td></td>
</tr>
</tbody>
</table>
Field Testing in Palo Alto, CA

El Camino Real Corridor

Stanford
Cambridge, California
Page Mill (not coordinated, running freely)
Portage/Hansen
Curtner
Matadero
Ventura
Los Robles
Charleston (DSRC disabled)
Maybell

0 500m
Human-Machine Interface (HMI) Design

Case 1: No preceding vehicle. Target speed displayed.

Case 2: With preceding vehicle, Target speed not displayed.
Impact of EAD

- Percentage of low-speed mode (i.e. speed between 0~15 mph) drops significantly
- Percentage of relatively high speed cases is reduced
- The EAD system is activated for 22% of the entire trips, saving 6% energy and reducing 6% of CO₂, 32% of CO, 30% of HC and 24% of NOx.
- For all trips, the proposed system also reduced 2% of fuel and CO₂, 7% of CO, 18% of HC and 13% of NOx.
Conclusion

- The proposed work demonstrated the benefit of the EAD system in the real-world traffic environment where the real traffic and signal condition are complex and unpredictable.

- The proposed system is more efficient for light traffic conditions, but still applicable to congested traffic.

- The performance will be further improved if the activity of preceding vehicles is sensed and integrated into the EAD system (EAD + Eco-ACC).

- More field experiments will be conducted to further investigate the potential of EAD systems, especially for the vehicle in traffic.
Thank you

Questions or Comments?