Towards Cooperative Vehicle and Intersection Control: An Energy Efficient Approach

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Future Intersection in Action

Credits: Black Sheep Productions
Related works

- Control on **either** Infrastructure or Vehicle side
  - Signal Control: Adaptive Traffic Signal
    - Actuated Signal
    - SCATS, SCOOT, RHODES
    - Detecting vehicles through V2I communications
  - Vehicle Speed Control: Eco-Signal & Eco-Driving

![Distance-Time Diagram of Eco-Driving](image)
Cooperative Vehicle and Intersection Control (CVIC)

- **Our idea:** *Jointly* control both the traffic signal and vehicles

- **Our Model**
  - An isolated intersection
  - Vehicles can communicate with the intersection controller (V2I)
  - Vehicles do not overtake others near the intersection
  - Traffic consists of trucks and passenger vehicles
A two-level approach

1. Intersection control:
   - Given:
     - Expected arrival time of each vehicle, vehicle type
   - Find:
     - Traffic signal timing (explicitly schedule each vehicle)
   - Objective:
     - Minimize energy consumption for all vehicles (global level)

2. Vehicle speed control:
   - Given:
     - Scheduled time to pass the intersection, the leading vehicle’s positions
   - Find:
     - Speed plan
   - Objective:
     - Minimize energy consumption for a vehicle (local level)
Solution

- **CVIC = MEETS + ECC**
- **Multi-modal Energy Efficient Traffic Signal (MEETS) Control Strategy**
  - Energy loss for a vehicle comes from:
    - 1) the loss of kinetic energy if the vehicle has to stop at the intersection
    - 2) engine idling during the time of waiting
  - A dynamic programming approach to minimize total energy loss for all vehicles
- **Eco-Cruise Control (ECC) for Speed Planning**
  - Keep track of the reference speed, and avoid colliding with the leading vehicle by Model Predictive Control
  - Minimize the mechanical work that has been used for braking
Results

Results in the low traffic flow scenario (300/400 veh/ln/hr) with all passenger vehicles

Left: Queue length of different strategies over time
Right: Total gas consumptions of different strategies over time
Comparison of the driving behavior of 10 vehicles
Left: Vehicle traces without ECC controller
Right: Vehicle traces with ECC
Results in the high traffic flow scenario (600/800 veh/ln/hr)
Left: Total energy consumptions of different strategies with all passenger vehicles
Right: Total energy consumptions of different strategies with 5% heavy-duty trucks
Future Energy Projections

- **Parameter settings:**

<table>
<thead>
<tr>
<th></th>
<th>HEV</th>
<th>EV</th>
<th>Con.V</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Con.V dominant</strong></td>
<td>0</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td><strong>xEV dominant</strong></td>
<td>37.3%</td>
<td>39.6%</td>
<td>23.1%</td>
</tr>
</tbody>
</table>

Projected Vehicle Composition\(^1,2\)

1 Ref: “Vehicle Technologies Program Government Performance and Results Act (GPRA) Report for Fiscal Year 2015” Argonne National Laboratory

2 Assumption on PHEV: 2/3 time works as EV, 1/3 time as HEV

- **Result:**

Average and standard deviation of energy consumption per vehicle in the low traffic flow scenario (300/400 veh/ln/hr)
Sensitivity tests

- How would different penalty factors on stopping xEVs vs. Con.Vs affect the result?

- The difference is negligible in our test, because:
  - With CVIC, not many vehicles need to be stopped
  - The projected traffic consists mainly of advanced vehicles (77% are EV or HEV)

Average and standard deviation of energy consumption in the high traffic flow scenario (600/800 veh/ln/hr)
Sensitivity tests

- Will the CVIC system with reduced penalty for stopping xEVs cause a longer delay for those vehicles?

- For similar reasons, the average travel time is very close
  - Under the scenarios investigated, CVIC will not increase the travel time for advanced vehicles

Average and standard deviation of travel time in the high traffic flow scenario (600/800 veh/ln/hr)
Limitations

- **Current CVIC design will not suggest a vehicle to speed up**
  - For eco-driving applications, it is possible for a vehicle to avoid stopping by speed-up before signal turns red

- **Speed plan can be more energy efficient**
  - Design the speed plan is to solve an optimal control problem (not MPC), but it requires an analytic model on fuel consumption
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Q&A