Welcome to Today’s T3 Webinar

Signal Timing Optimization Using Connected Vehicle Technology

August 13, 2018 1:00 pm

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Signal Timing Optimization Using Connected Vehicle Technology

Xiao (Joyce) Liang
PhD Candidate, Penn State University
XXL61@psu.edu

USDOT T3e Webinar
August 13, 2018
Traffic Operations Group at Penn State

Murat Bayrak  
Network wide infrastructure improvements

Josh Killian  
Predicting transit dwell times

Joyce Liang  
Signal control utilizing CAVs

Kan Wu  
Transit signal priority at intersections and arterials

Guanhao Xu  
Macroscopic traffic flow models

Rebecca Yocum  
Macroscopic traffic flow models

Yinghai Yu  
Weather impacts on traffic flow

Zhengyao Yu  
Resilience of urban street network configurations
Urban Mobility, Optimization and Control, Statistical Modeling of Transportation Systems

Vikash Gayah

Prediction of:
- safety performance
- transit system evolution
- mode choice
- driver behavior

Statistical modeling of transportation data

How can we optimize traffic control at signalized intersections accounting for various vehicle types?

Large-scale transportation system behavior

Optimization frameworks for transportation systems

Design, control and management of safe, efficient and reliable transportation systems

Organization of street networks

How can we model behavior of large-scale transportation systems?

How does street layout impact efficiency, environmental impacts, safety, and network reliability?

Prediction of:
- safety performance
- transit system evolution
- mode choice
- driver behavior
Managing Transportation Infrastructure

Multi-modal Traffic Interactions

Traffic Safety

Traffic Management and Control

Infrastructure Management

Public Transportation

Managing Transportation Infrastructure

Public transportation systems on urban networks
What are the effects of different types of public transportation systems on general traffic on a network?

Bus priority
How can traffic operations at a signalized intersection be optimized considering both cars and buses?

Multi-modal safety
Can we define different metrics for measuring safety of multiple modes?

Making better management decisions
Can we optimize the maintenance and repair decisions for infrastructure?

Car to car communications
Can we use new technology to improve traffic operations?

Data collection / inspection / condition surveys
Performance modeling & prediction
Maintenance / repair / reconstruction decision making & inspection decision making

Ilgin Guler
Utilizing Connected Vehicle Technology to Improve Signal Operations

- **Objective:** To optimize traffic operations (minimize delay and number of stopping maneuvers) at an intersection by using information from connected vehicles such as the position and speed of individual vehicles and autonomous vehicle presence.

- **Strategy:** Joint optimization of signal timing using CV information and trajectory/speed guidance to AVs
Outline

• Background introduction

• Proposed method

• Results and discussion

• Extension to the proposed method
Introduction

• Three traditional traffic signal control methods:

  • Fixed-time

  • Actuated

  • Adaptive
Introduction

Connected vehicles:
• Share information with infrastructure.

Autonomous vehicles:
• Connected vehicles
• Self-driving
• Trajectories can be controlled.
Introduction

Connected vehicle technology can be used to:

- Modify trajectory of fully autonomous vehicles (safety application)  
  Li and Wang, 2006; Zohdy and Rakha, 2012; Lee and Park, 2012

- Optimize phases (cycle length and green splits) of a signal (operations application)  
  Grandinescu et al., 2007; He et al., 2012; Lee et al., 2013; Goodall et al. 2013

- Optimize vehicle discharge sequence (operations application)  
  Dresner and Stone, 2004; Wu et al. 2007; Cai et al., 2012
Goal

• To optimize traffic operations at an intersection
  • Minimize average vehicle delay
  • Minimize average number of vehicle stops

• Method:
  • Utilizing connected vehicle information, such as the position and speed of individual vehicles, to optimize signal plan
  • Trajectory design of autonomous vehicles.
Signal Control Algorithm

- Three types of vehicles are considered:
  - Traditional vehicles,
  - Connected but non-autonomous vehicles (connected vehicles), and
  - Autonomous vehicles

- Inputs:
  Information obtained from connected vehicles:
  1. The time it enters the “zone of interest”
  2. The distance from the intersection at which it comes to a stop (if a queue exists)
  3. Real-time location, speed, acceleration…
Signal Control Algorithm

Control Layer

Trigger events:
1) new arrival of CAVs into the zone of interest, or 2) a CAV stops

Input: Observed vehicles in the zone of interest

Proposed platoon-based algorithm:

Step 1: Platoon identification
Compare spacing or headway of consecutive vehicles with a critical, pre-determined value

Step 2: Departure sequence optimization
Identify the departure sequence of platoons with minimum delay.

Step 3: Longitudinal trajectory guidance
Design speed for first AV in each platoon to minimize number of stops

Output:
Optimal departure sequence and designed speed of lead AVs in each platoon

Simulation Layer

Continue the program until all vehicles have passed the stop line.

Switch traffic signal, if needed, based on the optimal departure sequence.

Determine whether a trigger event happens. If so, enter the control layer.

Update the acceleration rate, speed and location of all vehicles at each time step (50 ms) based on IDM.
Step 1: Traditional Vehicle and Platoon Identification

- Traditional vehicles are identified if a CAV stops behind it.
- Cars are platooned based on
  - Minimum spacing (stopped vehicles)
  - Minimum headway (moving vehicles)
Step 1: Traditional Vehicle and Platoon Identification

Time $t_1$

Time $t_2$

Time $t_3$

Light blue: connected but not autonomous

Yellow: traditional vehicles.

Rectangle: No platoon

Oval: Platoon
Step 2: Solution Method to Identify Optimum Signal Phasing Plan

- Estimate delays of departure sequences to identify the optimal departure sequence that will result in minimum delay.

- Enumeration method: simply identifies all possible combinations of platoon departure sequences.
Step 2: Solution Method to Identify Optimum Signal Phasing Plan

- Enumeration:
- 6 possible departure combinations considered:
  - 1,2,3,4
  - 1,2,4,3
  - 1,3,2,4
  - 2,1,3,4
  - 2,1,4,3
  - 2,4,1,3

Signal phasing and timing plan:
Step 3: Longitudinal Trajectory Guidance

• Input:
  • Optimum signal phase and signal timing plan
  • Expected departure time

• Modify car trajectories to:
  • Let vehicles pass the intersection at a specific time.
  • Slow down to avoid stopping during red time, or
  • Speed up to not waste green time
Step 3: Longitudinal Trajectory Guidance

- Accounts for realistic acceleration or deceleration of cars

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t₀: current time
tₑ: expected departure time
v₀: current speed
v_d: designed speed
Step 3: Longitudinal Trajectory Guidance

Dark blue: autonomous vehicles.
Light blue: connected but not autonomous
Yellow: conventional vehicles.
Rectangle: No platoon
Oval: Platoon
Result: Benefits of Platooning
Result: Benefits of Platooning

A critical headway of 2.5 seconds and critical spacing of 15 meters is chosen since it provides significant computational efficiency without much change to average delay or stop.

Average delay increases slightly as more cars are platooned together.

Average number of stops increase as more cars are platooned together but the magnitude of increase is small.
Result: Sensitivity of algorithm to penetration ratio

Computation time significantly increases as more cars are connected, and also as more are autonomous.

Average delay reduces with more information, but marginal benefits after 40% connected ratio are very small.

Average number of stops decreases as more cars are autonomous.
Extensions: 1. More complicated intersection configurations

- Four-multi-lane-approach intersections
- Multiple lanes collapsed into one
- Four approaches folded into two
Extensions: 1. More complicated intersection configurations
Extensions: 2. More phase options
Extensions: 3. Other vehicle types

- Human-driven vehicles that receive guidance
  - Reaction time
  - Speed acceptance
  - Execution error

<table>
<thead>
<tr>
<th>Level</th>
<th>Automation Type</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>Zero autonomy; the driver performs all driving tasks.</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.</td>
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<tr>
<td>4</td>
<td>High Automation</td>
<td>The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.</td>
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Conclusions

• Methodology can:
  • Identify non-connected vehicles using data from CVs
  • Group vehicle into platoons that naturally discharge together
  • Optimize platoon discharge sequence to minimize vehicle delays
  • Alter vehicle trajectories to minimize number of stops

• Methodology used to examine trade-off between computational complexity and operational performance
Conclusions

• Platoon-based algorithm provides significant reductions in computational time over vehicle-based methods with minimal changes to average vehicle delay or number of stopping maneuvers.

• The algorithm provides larger and more significant operational benefits as the penetration rate of CAVs increases.

• However, the marginal benefits are much smaller after the fleet is composed of 40% CAVs, since platoons are well-identified at this penetration rate.

• As the penetration rate of AVs increases, trajectory guidance for them can provide significant reductions in number of stops.

• The algorithm can be extended to more complicated signal configuration and more phase options.

• Future work: Adding pedestrians, buses, emergency vehicles, etc.
Thanks!

Xiao (Joyce) Liang
XXL61@psu.edu