Next Generation Traffic Control with Connected and Automated Vehicles

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Current Traffic Signal Systems

- An open loop control system.
- Majority of transportation agencies DO NOT monitor or archive traffic signal data.
- Benefit/Cost ratio of signal re-timing is about 40:1; but usually traffic signal systems will be re-timed every 2 ~ 5 years.
SMART Signal System Development
— Funded by USDOT/MnDOT (2005-2014)

Nowadays many new controllers can provide high resolution data

Event-based high resolution data

TS-1 type cabinet

MnDOT Implementation
Traffic Signal Performance Measurement

Queue Estimation

Arterial Travel Time Estimation


Commercial Cloud-based Solution

LTD Performance Measure System Architecture

LTD Database Server

LTD Performance Measure Webserver

LTD Local Server

DOT Firewall

TCP/IP

HTTP
Connected Vehicles

A connected vehicle system is based on wireless communication among vehicles of all types and the infrastructure.

The wireless communications technology could include:

- 5.9 GHz DSRC
- LTE-V and 5G cellular networks
- Other wireless technologies such as Wi-Fi, satellite, and HD radio

Source: USDOT
Connected and Automated Vehicles

**Connected Vehicle**
Communicates with nearby vehicles and infrastructure; Not automated

**Connected Automated Vehicle**
Leverages autonomous automated and connected vehicles

**Autonomous Vehicle**
Operates in isolation from other vehicles using internal sensors

Source: USDOT
Safety Pilot Model Deployment at Ann Arbor

• Funded by USDOT (August 2012 – May 2015)
  – Now becomes AACVTE (2015-18)
• 2843 vehicles equipped
  – Passenger cars, trucks, buses, motorcycles, and a bike
• 73 lane-miles of roadway
  – 27 roadside installations
• Collected over 110 Billion DSRC basic safety messages over 38 Million miles of driving
Vehicle-to-Infrastructure (V2I)

- 19 Intersections
- 3 Curve-related sites
- 3 Freeway sites
- All DSRC communications logged
Traffic Control with Connected Vehicles

RSE: Roadside Equipment
OBE: Onboard Equipment
CV Data Collection Devices

CV-CID

Econolite CoProcessor
Evolution to Next Generation Traffic Control Systems

Current Practice - Fixed time/actuated/adaptive Signal

Detector-free signal operation

Spatiotemporal signal control

Lane reassignment

Signal-free intersection

Infrastructure Adaption

Connected and Automated Vehicles

Connected Vehicles

Regular Vehicles
Why Detector-Free is Important?

• Many traffic signals in the US are fixed-time. To retime these signals, manual data collection has to be conducted.
• For vehicle-actuated or adaptive signals, vehicle detectors have to be maintained properly, which is also costly.
• Connected vehicles are mobile sensors. Potentially we can use connected vehicle data to evaluate traffic signal performance, retime traffic signal, or control traffic signal in real time.
Key Problem: Traffic Volume Estimation

- If traffic volumes are known, then there are known optimization methodologies to retime the traffic signals.
- How to estimate arrivals using CV data with low penetration?
Methodology

- Traffic arrivals follow cyclic patterns.
- Aggregate historical CV data for estimation.
- Assume arrivals follow time (in signal cycle) dependent Poisson process.

\[ N(t) \sim \text{Poisson}(\Lambda(0, t)) \]

\[ \Lambda(t_1, t_2) = \int_{t_1}^{t_2} \lambda p(t) \, dt = \lambda \int_{t_1}^{t_2} p(t) \, dt \]

Time-dependent factor

\[ p(t) \propto \sum_{i=1}^{N} I\{t_{f,i} = t\} \]
Likelihood of Observations

• Observations from CV w/ stop:
  \[ Y = \{n_{y,1}, n_{y,2}, \ldots n_{y,n}; P(t_{y,1}), \ldots, P(t_{y,n})\} \]

• “Censored” observations from CV w/o stop:
  \[ Z = \{n_{z,1}, n_{z,2}, \ldots, n_{z,m}; P(t_{z,1}), \ldots, P(t_{z,m})\} \]

• Likelihood:
  \[
  L(Y, Z|\lambda) = \prod_{i=1}^{n} \{p(n_{y,i}|\lambda \times P(t_{y,i}))\} \prod_{j=1}^{m} \left\{ \sum_{k=0}^{n_{z,i}} p(k|\lambda \times P(t_{z,i})) \right\}
  \]

  Use Expectation Maximization (EM) for estimation.
Case Study - Int. Plymouth & Green

- Int. Plymouth & Green
- Date: 04/25/16-05/13/16
Validation of Estimation

- Observed data collected on 04/25/16 and 04/26/16

10% Overall MAPE
Transition to Next Generation Traffic Control Systems

Infrastructure Adaption

- Connected and Automated Vehicles
- Connected Vehicles
- Regular Vehicles

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Lane reassignment

Signal-free intersection
Formulation

• Bi-level optimization:
  ✓ Upper level: signal optimization
    - Objective: minimize delay/maximize throughput
    - Determine signal parameters
    - Decide platoon length
  ✓ Lower level: trajectory control
    - Objective: minimize fuel consumption/emission
    - Generate compact platoon
    - Control platoon leading vehicle speed
Upper Level: Green Time Optimization

\[ g_{\text{new}} = g_{\text{cur}} \]

\[ 2 = 1 + 3 \]
Lower Level: Vehicle Trajectory Control

Final state Obj:
Reach the intersection at the saturation flow speed without any stop

Vehicle trajectory Obj:
Minimize acceleration and deceleration fluctuation to reduce emission
From Temporal Control to Spatiotemporal Control
Cooperative Driving on Dedicated Road for CAV

- Platoon control
- Signal optimization

Through cars
Left-turn cars
Cooperative Driving on Dedicated Road for CAV

- Platoon control
- Signal optimization

- Through cars
  - Left-turn cars
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Mcross

• Mcross: Maximum Capacity inteRsection Operation Scheme for Signals
• A novel intersection operation scheme that can maximize the capacity with CAVs.
• Lanes are dynamically assigned to CAVs according to traffic volume and turning ratio, so that all lanes can be utilized
• Serve EB/WB traffic within in one phase (may contain several sub-phases)
Mcross example

Green time needed for conventional intersection:

Through phase  
Left-turn phase

Through cars  
Left-turn cars

Green time needed for Mcross intersection:
Mcross example

Green time split for conventional intersection:

- Through phase
- Left-turn phase

Green time needed for Mcross intersection:

- Through cars
- Left-turn cars
Mcross example

Green time split for conventional intersection:

- **Through phase**
- **Left-turn phase**

Green time needed for Mcross intersection:

- **All-in-1 phase**
Mcity

• Safe, repeatable, off-roadway test environment for AVs: simulated city
• Technology research, development, testing, and teaching
  – Construction commenced July 15 2014
  – Grand opening: July 20, 2015
Mcity
Conclusion

• Connected and automated vehicle technology will transform the surface transportation system and significantly impact on our society. It will also transform the traffic control industry.

• It brings a set of completely new research questions during the transitional process from human driven vehicles to autonomous vehicles.

• An interesting time for transportation research …
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