Traffic Control and Management with Vehicle Automation and Connectivity for the 21st Century

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Congestion Solutions

Intelligence

More Supply

Less Demand
Our Hierarchical Traffic Control Approach

- **Networkwide:**
  - Demand Management Focus
  - Dynamic Trip Pricing

- **Nodes and Junctions:**
  1. Adaptive Traffic Signals on Arterials
  2. Freeway Control
Part I
Deep Learning for Adaptive Traffic Signal Control

Soheil Alizadeh and Baher Abdulhai
Can Traffic Lights Learn?
AI: Reinforcement Learning

Traffic Environment (Real or Simulated)

State & Reward

Action

RL Software Agent

Traffic Simulation Environment
New Opportunities:
Emergence of New Technologies and Deep Reinforcement Learning

• Emergence of Deep Neural Networks
• Emergence of Deep Learning
New Opportunities:
Emergence of New Technologies and Deep Reinforcement Learning

• Emergence of Deep Neural Networks
• Emergence of Deep Learning
• Evolution of sensor technologies
New Opportunities:
Emergence of New Technologies and Deep Reinforcement Learning

• Emergence of Deep Neural Networks
• Emergence of Deep Learning
• Evolution of sensor technologies
• Rich Microdata and Deep Learning:
  • No need for defining or measuring queue
  • No need for data pre-processing
  • Straight from rich sensory data to control
Why Deep Convolutional Neural Networks?
Why Deep Learning?

THE PERSON IN THE DRIVER’S SEAT IS ONLY THERE FOR LEGAL REASONS.

HE IS NOT DOING ANYTHING. THE CAR IS DRIVING ITSELF.
Intelligent Traffic Signal with VACs and DRL
Like Image Inputs to a Deep Neural Network

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Like VACs: Inputs to a DRL Traffic Signal Controller
The Resulting System

MiND: Multimodal intelligent Deep ATSC
### Performance in Simulation

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<th>[sec] / (vs. Actuated)</th>
<th>Actuated</th>
<th>Cont. RL</th>
<th>MInd</th>
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<tr>
<td></td>
<td></td>
<td>100%</td>
<td>80%</td>
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<tr>
<td>Intersection Delay</td>
<td>72.0</td>
<td>56.6 (21.39%)</td>
<td>54.3 (24.62%)</td>
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<tr>
<td>Network Travel Time</td>
<td>153.2</td>
<td>137.2 (10.44%)</td>
<td>135.2 (11.42%)</td>
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<td>Precision</td>
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<tr>
<td>Noise</td>
<td>0%</td>
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<tr>
<td>Intersection Delay</td>
<td>56.4 (-3.01%)</td>
</tr>
<tr>
<td>Network Travel Time</td>
<td>137.7 (-0.97%)</td>
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Part II
Freeway Management with Vehicle Automation and Communication Systems (VACS)

Lina Elmorshedy and Baher Abdulhai
Motivation

- VACS evolved with focus on the individual vehicle – convenience & safety
- May or may not help traffic
- Why?

Opportunities and challenges

What is needed?
1. Modelling VACS (Quantifying Transformation)
2. Control with VACS (Enabling Positive Transformation)
Traffic Management (TM) Components with VACS

1. Adaptive Cruise Control (ACC).

2. Cooperative Adaptive Cruise Control (CACC).

3. Dynamic Speed Adaptation (DSA).

4. Cooperative merging and lane changing (CM & LC)
ACC

- Adaptive Cruise Control (ACC)
  - Maximum Speed + Time gap.
  - Gap/Headway sensors.
  - Speed control mode.
  - Headway/Space control mode.

ACC Challenges & Opportunities

- **ACC**: Efficiency depends on system parameters selected.

- **Challenges**:
  - 2 sec default time-gap (vs. 1.2 sec for manual vehicles).
  - Capacity reduction.

- **Opportunities**:
  - Capacity increase for time-gaps <1.2 sec

*Ntousakis et al., 2015*
CACC Challenges & Opportunities

- Cooperative ACC (CACC)
  - Communication among vehicles
  - Follow the platoon
  - Smaller headway
    - e.g. 0.5 sec

- Challenges
  - Needs high market penetration rates. *Van Arem et al., 2007*
  - Very small time gaps: merging problems.
  - Need for modified infrastructure: dedicated CACC lanes.
  - Underutilized dedicated lanes problem.

- Opportunities
  - Very small time-gaps: Capacity increase
DSA Challenges & Opportunities

- **Dynamic Speed Adaptation**
  - Variable Speed Limits (VSLs)
  - Regulate mainstream flow to avoid capacity drop.
  - With VACS: automatic compliance.

- **Challenges**
  - No automation: VSLs Compliance Rates.

- **Opportunities**
  - Imposing VSLs – more strict AV compliance.

Papageorgiou (2018)
CMLC Challenges & Opportunities

Cooperative merging and lane changing
- Cooperative Merging (CM): Assist driver to merge
- Cooperative lane changing: Equalizing densities across lanes

- Challenges
  - Capacity reduction if more conservative merging or lane-changing systems.

- Opportunities
  - Capacity Increase: Merging sequence algorithms to minimize unnecessary decelerations
  - Equalize densities/flows across lanes.

*Rios-Torres et al., (2017)*

*Roncoli et al., (2016)*
VACS for Traffic Control
Promising Early Results in Literature

- ACC Exploitation
  - *Spiliopoulou et al.*, 2017 (adapt time-gaps to traffic conditions)
VACS for Traffic Control
Promising Early Results in Literature

- Ramp Metering (RM) + VSLs + Lane Change

Roncoli et al., (2015)
iCity - CATTs – In progress

Phase 1
Quantifying Transformation

Project 1.5:
- Dynamic transportation system modelling of the GTHA in the context of automation.

Phase 2
Enabling Positive Transformation

Project 2.2:
- Traffic control and management of transportation systems under automation.
Enabling Positive Transformation on the Gardiner and QEW

- Ramp Metering with Variable Speed Limits (Point-level- Cooperative)

- Optimization of ACC systems parameters
  - Time-Gap, other parameters (acceleration, deceleration)

- Automated merging
Enabling Positive Transformation
Desired Collective Behaviour

Approaching congestion:
• Reduce speed via VSLs
• Reduce deceleration
• Minimum headways

Bottleneck (Merging vehicles):
• Increase headways

Bottleneck downstream:
• Minimum headways
• Increase acceleration at head of congestion
Methodology

- Exploring deep learning.
Part III
Trip Reservation Integrated with Trip-Level Congestion Pricing (TRiP):
The Context of Pervasive Connectivity, Driving Automation and MaaS

Ahmed Aqra and Baher Abdulhai
Motivation

1. A potential sharp increase in vehicles kilometre travelled (VKT)

2. The pervasive connectivity will make the implementation of the new strategies of demand management possible
Potential Impacts of Disruptive Mobility

- Increase in Vehicle Kilometers Traveled (VKT)
  - Roaming: The current hired rate of ride sourcing companies is only 50%.
  - Zero Occupant Vehicles (ZOV) are coming with autonomous vehicles.
  - Latent demand (more people will have an access to cars)
  - Mode shift to the car (potentially away from transit)
Enabling Positive Transformation: From RaaS to MaaS and XaaS

1. Ministry of Transportation
2. Municipalities
3. Private Road Operators (i.e., 407)

1. Car Sharing Companies such as GM Maven, Zipcar.
2. Private Citizens

1. On-Demand Shared-Economy-Based Social Taxi such as Uber, Lyft, etc.
2. Micro-Transit Services

Emerging Business Model based on 3Ps (Public-Private Partnership) model, such as "Whim app"
Trip Reservation integrated with trip-level congestion Pricing (TRiP)

- **TRiP** is a network-wide traffic control and management mechanism in the era of Pervasive Connectivity, Driving Automation and MaaS

- **TRiP** aims to dynamically distribute travel demand over *space* (path choice), *time* (departure time choice) and *mode* (sharing ride choice) to prevent demand for auto travel from exceeding the capacity.
Protect Capacity

Link Level

Network Level
TRiP as a Traffic Control Strategy

- Intersection
- Traffic Signal
- Freeway
- Ramp Metering
- Network
- TRiP Metering
TRiP as Congestion Pricing Methodology

RaaS

- Facility Based (Tolled Expressway)
- Zone (Cordon) Based (Stockholm)
- Zone (Area) Based (London)
- Network wide (TRiP)
Potential Pricing Structure

(1) Location and time-dependent dynamic trip pricing
(2) Price-escalating reservation system
## Research Questions

<table>
<thead>
<tr>
<th>Pricing Capacity</th>
<th>Disaggregate Level (Link Price) Spatiotemporal</th>
<th>Aggregate Level (Zone Price) Temporal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disaggregate Level (Link Level Capacity)</td>
<td>Reserve <strong>time</strong> slot and <strong>path</strong> / Spatiotemporal demand pacing to protect capacity of <strong>all</strong> links.</td>
<td>Reserve a <strong>time</strong> slot / Temporal demand pacing to protect capacity of the <strong>busy</strong> links.</td>
</tr>
<tr>
<td>Aggregate Level (Network Capacity)</td>
<td>Reserve <strong>time</strong> slot and <strong>path</strong> / Spatiotemporal demand pacing to protect the <strong>network</strong> capacity.</td>
<td>Reserve a <strong>time</strong> slot / Temporal demand pacing to protect the <strong>network</strong> capacity.</td>
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Thank you