Two-Way Transit Signal Priority Algorithm for Optimizing Transit Reliability and Speed
A Deep Reinforcement Learning Approach

Wen Xun Hu, Chuhan Chen, Hirotaka Ishihara, Islam Taha, Amer Shalaby and Baher Abdulhai
Motivation

The transit reliability and speed are performance indicators.

Transit services are vulnerable to variability and delays.

No strategies can adaptively improve headway regularity and reduce signal delays simultaneously.

The conventional TSP only aims at reducing delays.

Multiple TSP requests from different approaches are commonly handled by FCFS logic.

Model of the dynamics of transportation environment.
Objectives

- **Dual-objective TSP**
  - Adaptively optimize reliability (i.e., headway regularity) and reduce signal delays simultaneously

- **Coordination of opposite directions**
  - Develop an algorithm to coordinate TSP in opposite directions of the same intersection based on real-time bus performance
Objectives

- High speed, poor reliability
  - Pros
    - Reduced in-vehicle travel time
  - Cons
    - Long waiting time
    - Uneven bus loads (e.g., crowding)
    - Operating costs
    - etc.


Objectives

- **Reliability vs. Speed**
  - **One direction**
    
    **Scenario A**
    A bus arrives at the intersection with a headway ($h_{in}$) > scheduled headway ($h_s$).
    - To improve speed and reduce headway deviation, the TSP system should expedite this bus.

    **Scenario B**
    $h_{in} < h_s$:
    - To improve speed or reduce signal delays, the TSP system should expedite this bus.
    - To reduce headway deviation, the TSP system should hold back (i.e., slow down) this bus.

  - **Opposite directions**
    - More conflicting scenarios
Model Formulation

One-Way DRL Agent

- Model-free deep reinforcement learning
- Efficient for large state space
Model Formulation

One-Way DRL Agent

Transportation network simulated in Aimsun

- Target travel time to maintain scheduled headway at check-out
- Number of vehicles in the POZ
- Time to the end of 1st available green

Green phase:
-20, -15, -10, -5, 0, +5, +10, +15, +20 sec

TSP control system

reward = \( w_h (headway \text{ improvement}) \)

Source: Pawel Czerwinski, unsplash.com

Signal cycle image:
https://winnipeg.ca/publicworks/transportation/trafficsignals/trafficsignaloperation.htm

-RL image:
https://shield.ai/content/2018/11/shield-ai-fundamentals-on-reinforcement-learning
Model Formulation

Coordination Algorithm

Action: \( a'_t = \arg\max_a [w_x Q(s_t, a; \theta_t) + w_y Q(s_u, a; \theta_u)] \)

- RL agent X: \( Q(s_t, a; \theta_t) \)
- RL agent Y: \( Q(s_u, a; \theta_u) \)
Simulation case study

- Aimsun Next Microsimulation
- Intersection in Toronto
- Bus line: 36 Finch West
Results

- Base scenarios
  - No TSP
  - TSP in field (Toronto TSP)
  - DRL agents + FCFS logic (FCFS TSP)

- Proposed scenario
  - DRL agents + coordination algorithm (D2 TSP)
Results

Coefficient of Variation of Headway

<table>
<thead>
<tr>
<th></th>
<th>EB</th>
<th>WB</th>
</tr>
</thead>
<tbody>
<tr>
<td>No TSP</td>
<td>0.461</td>
<td></td>
</tr>
<tr>
<td>Toronto</td>
<td>0.439</td>
<td>0.505</td>
</tr>
<tr>
<td>FCFS</td>
<td>0.417</td>
<td>0.482</td>
</tr>
<tr>
<td>D2 TSP</td>
<td>0.408</td>
<td>0.456</td>
</tr>
</tbody>
</table>
Results

% of Extreme Headways
Results

Travel Time

9 s travel time ↑,
23 s std dev of h dev↓ = 10 s waiting time↓
Conclusions

The proposed Two-Way TSP (D2 TSP)

- Generates the best headway performance in both directions
  - Effective in reducing headway variability and % of extreme headways
- Brings noticeable reduction in travel time compared with “No TSP”
Future Work

▪ Coordinated TSP systems to enhance the benefit on transit reliability and speed at the route level

▪ Use connected vehicle technologies for detection and communication

▪ Integrate TSP design with other route strategies
THANK YOU!

wenxun.hu@mail.utoronto.ca