Two-Way Transit Signal Priority Algorithm for Optimizing Transit Reliability and Speed

A Deep Reinforcement Learning Approach

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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.

Source: https://www.thestar.com/news/gta/2020/11/27/the-ttc-wants-to-test-platoons-of-driverless-buses.html

https://www.thestar.com/opinion/star-columnists/2017/12/15/are-we-sure-ttc-fare-evasion-happens-as-often-as-we-think-it-does.html

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.

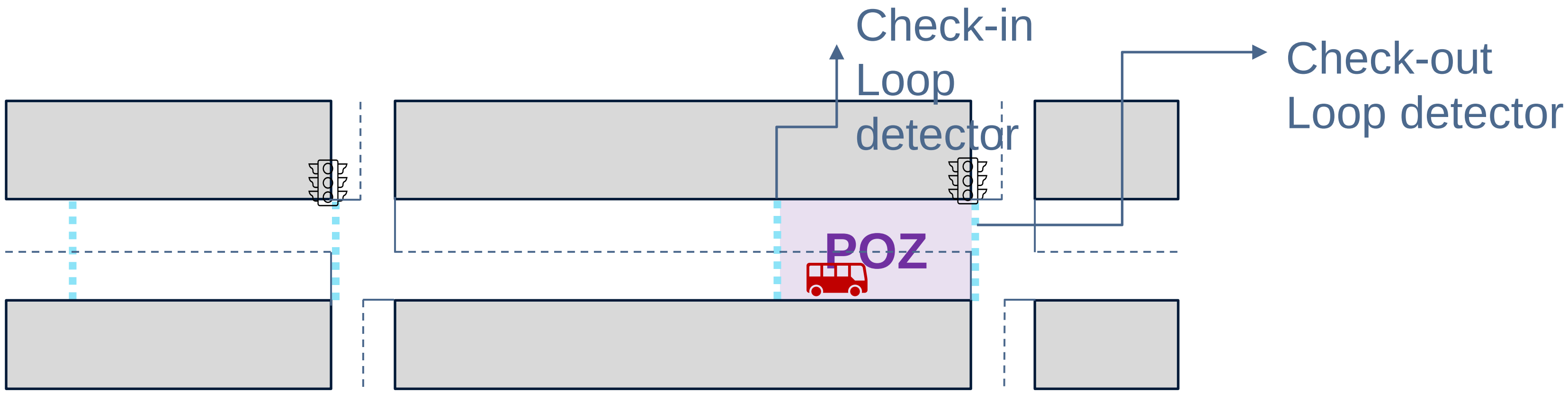
    Scenario B

    $h_{in} < h_s$:

    - To improve speed or reduce signal delays, the TSP system should expedite this bus. $\neq$
    - 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

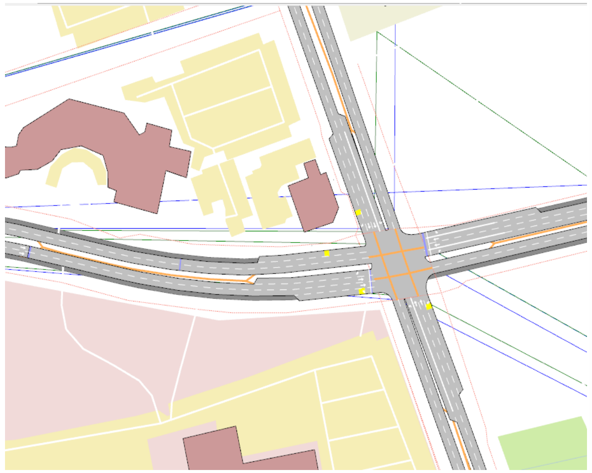


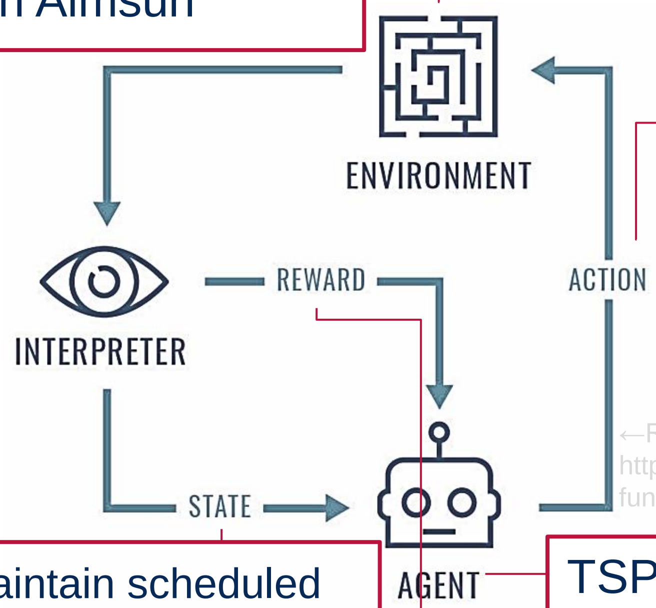
- Model-free deep reinforcement learning
- Efficient for large state space

Model Formulation

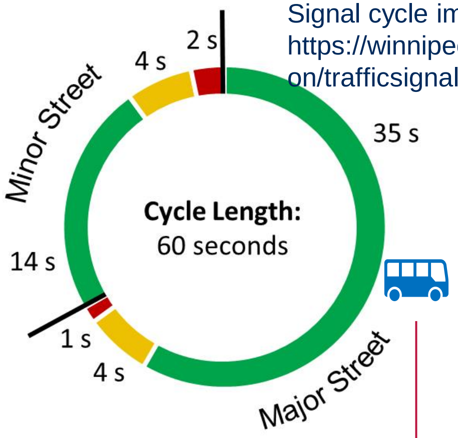
One-Way DRL Agent

Transportation network simulated in Aimsun





←RL image: https://shield.ai/content/2018/11/20/shield-ai-fundamentals-on-reinforcement-learning



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

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

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

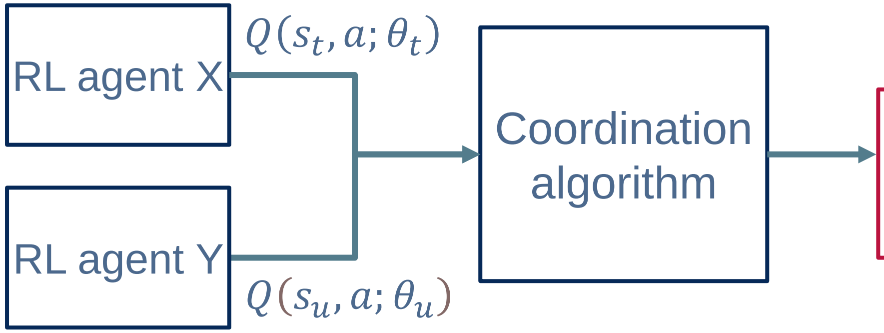
TSP control system

reward =
$w_h(headway\ improvement) -$

Source: Pawel Czerwinski, unsplash.com

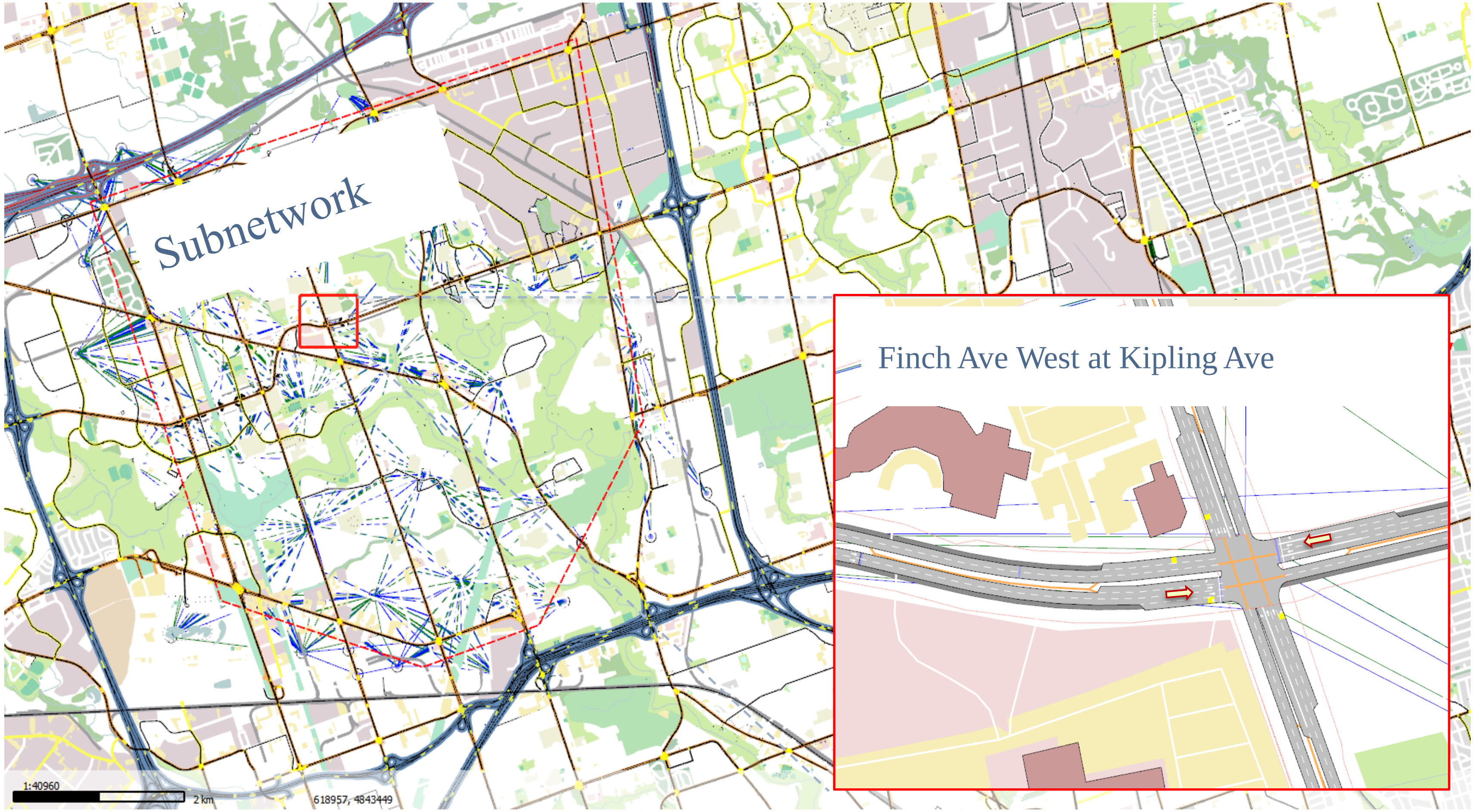
Model Formulation

Coordination Algorithm

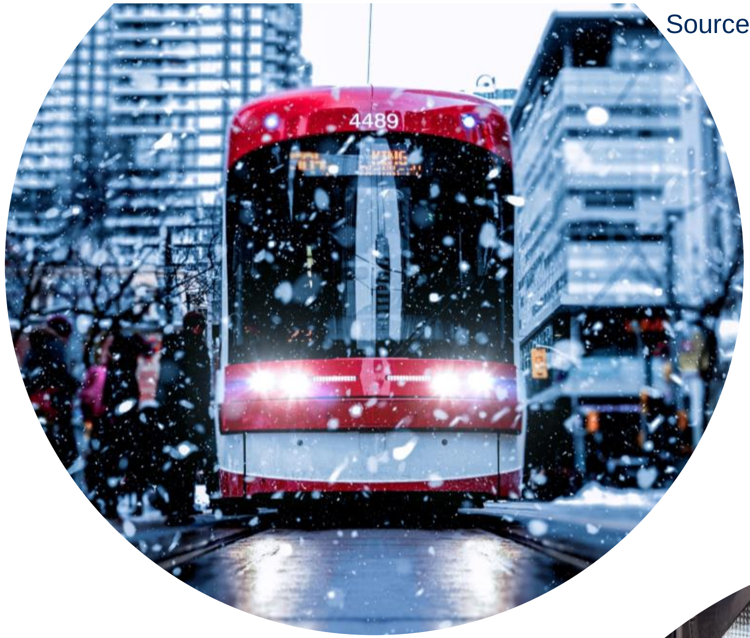


Action: $\boldsymbol{a'_t}$
$$= \underset{a}{argmax}\left[w_x Q(s_t, a; \theta_t) + w_y Q(s_u, a; \theta_u)\right]$$

Simulation case study



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



Source: Andre Furtado, unsplash.com

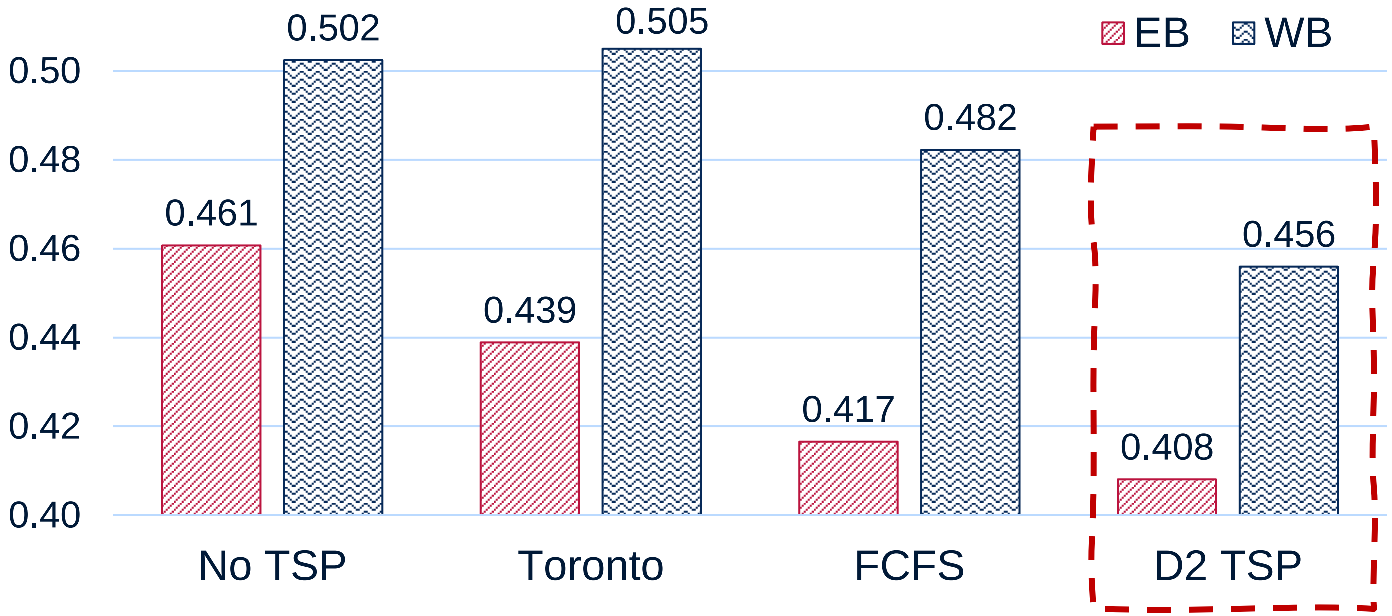
Results

- Base scenarios
  - No TSP
  - TSP in field (Toronto TSP)
  - DRL agents + FCFS logic (FCFS TSP)
- Proposed scenario
  - DRL agents + coordination algorithm (D2 TSP)

Source: Pawel Czerwinski unsplash.com

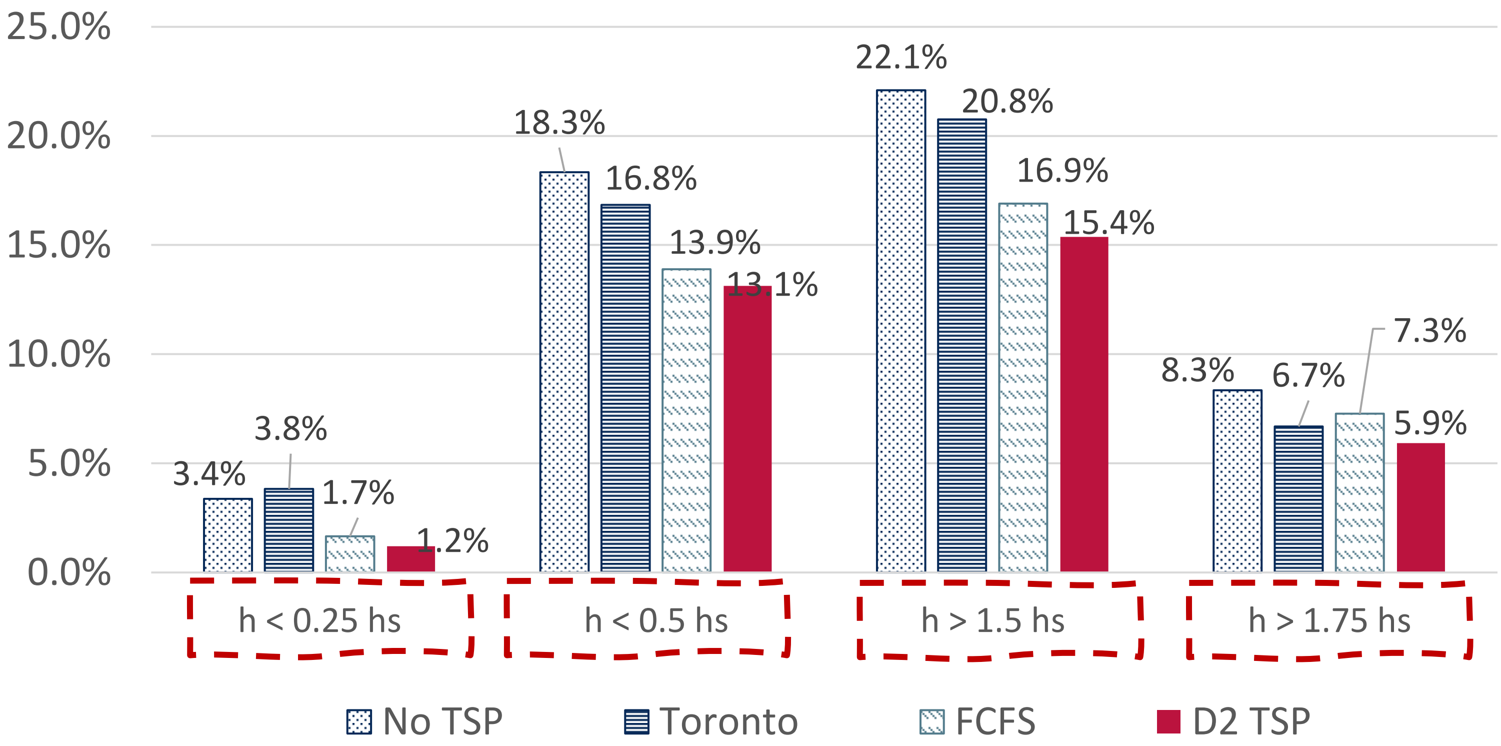
Results

Coefficient of Variation of Headway



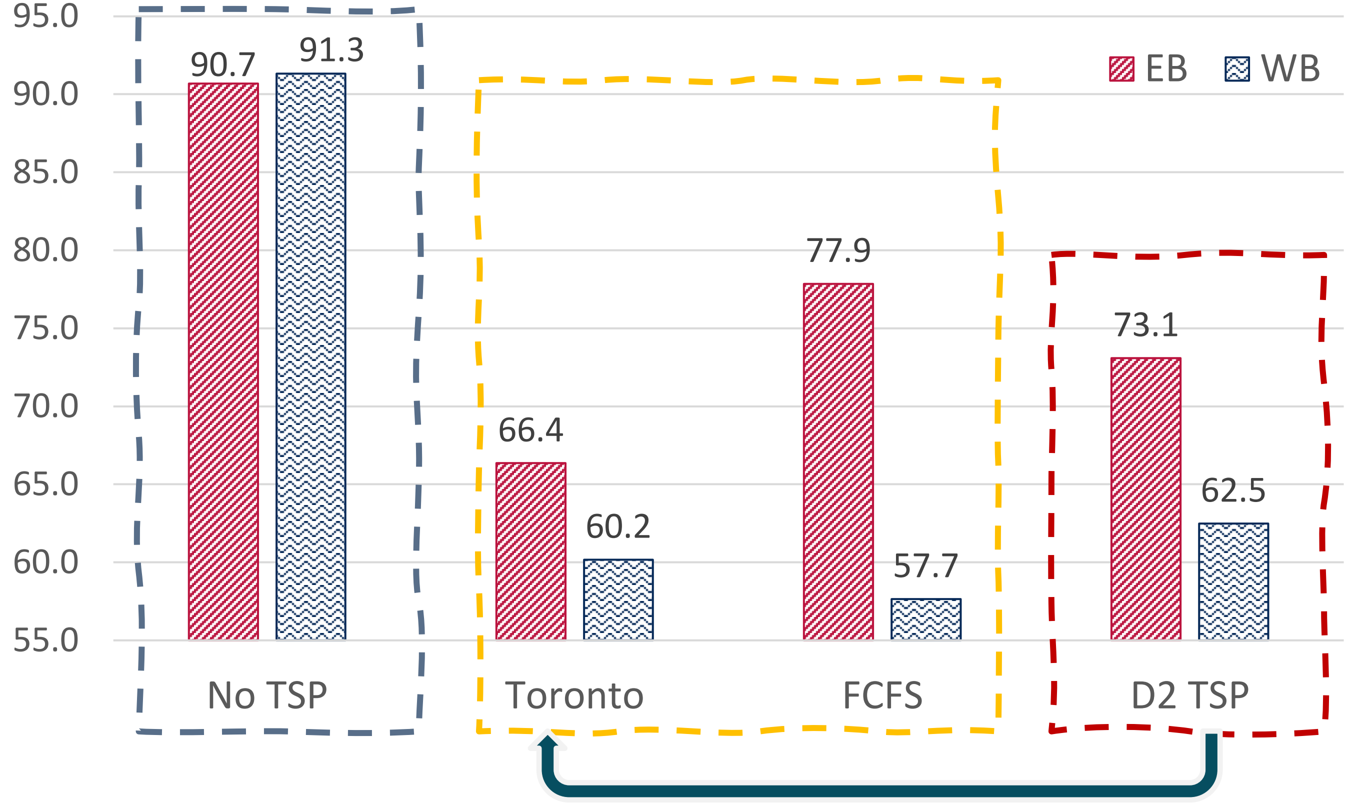
Results

% of Extreme Headways



Results

Travel Time

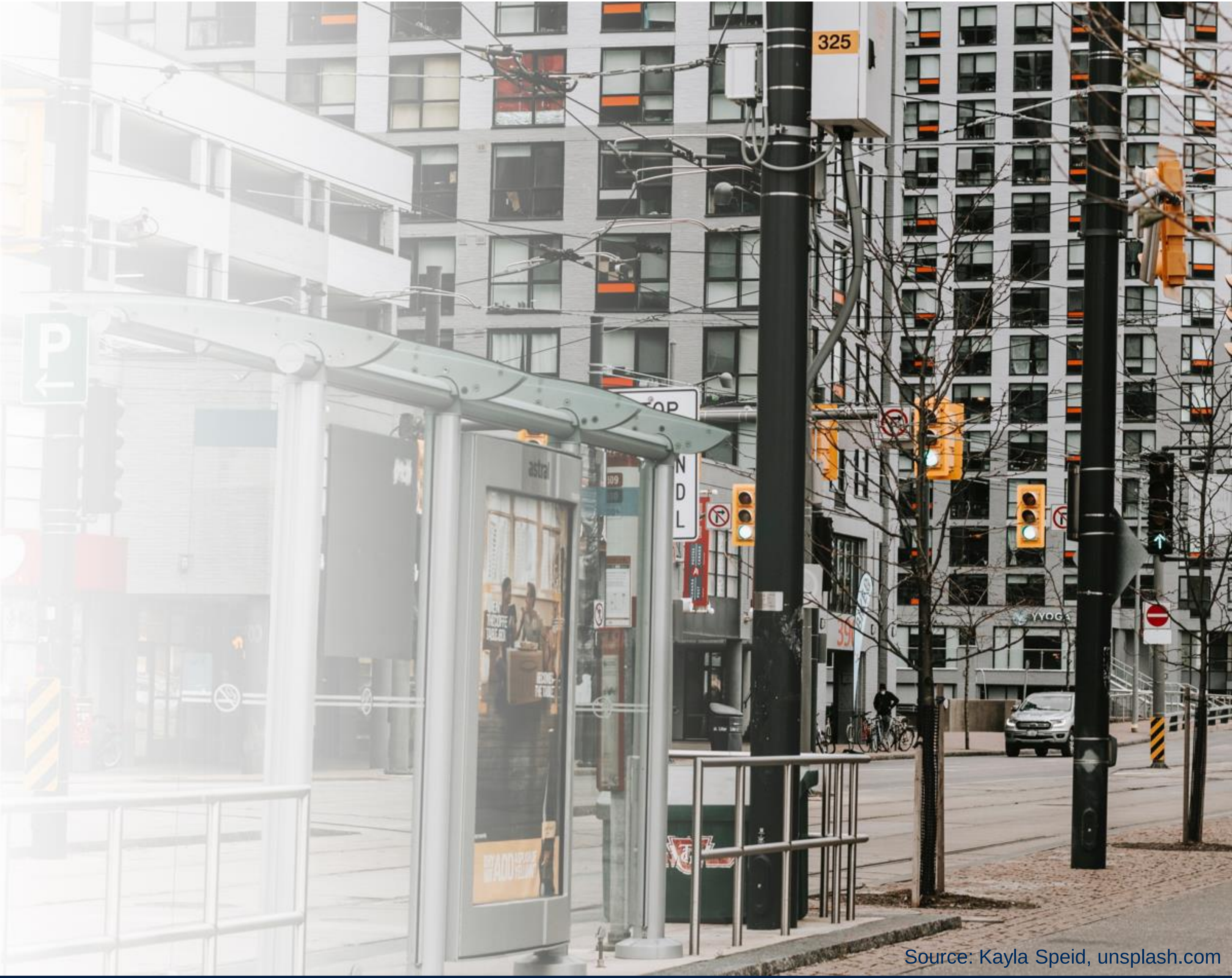


9 s travel time ↑,
23 s stdev of h dev↓ = 10 s waiting time↓

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”



Source: Kayla Speid, unsplash.com

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

Source: Nong Vang, unsplash.com


Source: chuttersnap, unsplash.com

THANK YOU!

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