Improved Transit Route Operations through Signal Priority and Bus Bridging Decision Support

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Outline

Transit Research Program Overview

Improved Transit Route Operations through Signal Priority

Bus Bridging Decision Support
Past & Ongoing Research

- **iCity: Urban Informatics for Sustainable Metropolitan Growth** (IBM, City of Toronto, ESRI) – Transit Management Projects

- **Nexus: Connected Simulation Platform for Operational Management and Planning of Transit Networks** (Arup)

- **Joint Optimization of Route Design and Schedules for Fixed Route Transit Systems** (Trapeze)

- **Canadian Ridership Trends Analysis** (CUTA)
Improved Transit Route Operations through Signal Priority

Wenxun Hu (wenxun.hu@mail.utoronto.ca)
Transit Signal Priority (TSP)

A set of operational improvements that use technology to reduce dwell time at traffic signals for transit vehicles.

Methods include holding green lights longer or shortening red lights.
TSP in Toronto

1. Request Loop
   must be passed over before Decision Point

3. Cancel Loop
   terminates extension in
   Green/Walk (go to FDW)

Priority Operating Zone (POZ)
Motivation

Reliability and speed are performance indicators important for both transit agencies and passengers.

Transit services are vulnerable to variability and delays, especially in busy networks.

The conventional TSP only aims at reducing delays.

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

Develop adaptive TSP for improved reliability (regular headways) and speed

Validate the proposed TSP algorithm in the micro-simulation environment using an intersection in Toronto as a case study
Goals

Without TSP

Conventional TSP

Proposed TSP

Delay & headway deviation reduced

Time when the previous bus leaves the intersection

Distance

POZ

Check-in loop

Check-out loop

example

late

early

Scheduled headway
Method – Deep Learning

**APPROACH**

**Bus checks in:** collect data of the environment state, including information on traffic flow, bus headways, and traffic signal timing

**Information sent to the learning agent:** traffic signal control system

**Take an action:** decide on the length of green phase extension

**Bus checks out:** calculate headway to prior bus

**Next bus checks in:** collect data of the new state, calculate reward of action $A_t$, update the action-value function

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**Check-in loop detector**

**Check-out loop detector**

**Deep learning algorithm to learn the best action**
Case Study

- Finch Ave West & Kipling Ave
  - TSP installed
  - Bus line: 36 Finch West
  - poor reliability

Check-in loop detector: 185m upstream of the intersection

Check-out loop detector: 2m past stop line

Far-side WB bus stop

Near-side EB bus stop

Aimsun Next interface
Case Study

- **Base cases**
  - No TSP
  - Existing TSP algorithms used in Toronto
    - Algorithm A and B
    - Simulation shows
      - no improvement in headway regularity
      - Time spent in POZ
        - Algorithm A: 78 sec (45% shorter than No TSP)
        - Algorithm B: 114 sec (19% shorter than No TSP)
Case Study

- Proposed adaptive TSP (still in training)
  - Reward
    - Maximize $r = w_1(|h_{in} - h_{sc}| - |h_{out} - h_{sc}|) - w_2tt$
    - 1st term: headway improvement, absolute value of check-in headway deviation minus check-out deviation
    - 2nd term: time spent in the POZ (tt)
    - Ws: weights
Summary

<table>
<thead>
<tr>
<th></th>
<th>No TSP</th>
<th>TSP Algm. A</th>
<th>TSP Algm. B</th>
<th>Proposed TSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average headway improvement per bus</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>10s</td>
</tr>
<tr>
<td>Average time in POZ per bus</td>
<td>141s</td>
<td>78s</td>
<td>114s</td>
<td>~80s</td>
</tr>
</tbody>
</table>

- Algorithm A and B provide green extension to buses when the POZ is active at predetermined decision point(s) in regardless of the headway.
- No headway/reliability improvement using TSP algorithm A or B.
- The proposed TSP:
  - improves headway
  - Time spent in POZ is comparable to algorithm A.
Next Step

- Test the effectiveness of the proposed TSP algorithm in scenarios with near- and far-side bus stops
- Develop coordinated route-based TSP
Bus Bridging Decision Support

Alaa Itani (alaa.itani@mail.utoronto.ca)
Motivation

Major unexpected rail disruptions occur frequently

Often, a simplistic approach is followed for selecting shuttle buses

Can lead to extensive delays for passengers and buildup at stations

Result in degraded service and potential loss of loyal passengers
Bus Bridging Assessment Tool

Main Goals

Develop a tool to help agencies evaluate potential bus bridging plans

Provide measures of the impact on train and bus passengers

Provide measure of how well shuttle buses are used
Bus Bridging Assessment Tool

Overview of the Methodology

Shuttle bus tracking

Shuttle Buses serving rail passengers

Waiting time based on shuttle service

End of incident and return of buses

Time for dissipating passengers queue
Demo of the Bus Bridging Assessment Tool

Subway Disruption between Kipling and Keele Station (Line 2)
# Demo of the Bus Bridging Assessment Tool

**Subway Disruption between Kipling and Keele Station (Line 2)**

## Effectiveness Summary

**TOTAL DELAYS**

<table>
<thead>
<tr>
<th></th>
<th>For Subway Riders</th>
<th>For Bus Riders</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2227.5 hours</strong></td>
<td>98.3 hours</td>
<td></td>
</tr>
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</table>

## Delays per Station

<table>
<thead>
<tr>
<th>Station Name</th>
<th>No Riders Affected</th>
<th>Riders Delays (h)</th>
<th>Queue at End (p)</th>
<th>To Clear Queue (min)</th>
<th>Extra Wait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Mill Station - Westbound Platform</td>
<td>59.8</td>
<td>7.73</td>
<td>13.31</td>
<td>14.91</td>
<td>4.44</td>
</tr>
<tr>
<td>Keele Station - Westbound Platform</td>
<td>1,892.9</td>
<td>197.4</td>
<td>731.67</td>
<td>0</td>
<td>6.26</td>
</tr>
<tr>
<td>Jane Station - Westbound Platform</td>
<td>136.9</td>
<td>16.67</td>
<td>36.22</td>
<td>13.31</td>
<td>3.78</td>
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<tr>
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<td>303.2</td>
<td>11.06</td>
<td>30.59</td>
<td>9.54</td>
<td>3.6</td>
</tr>
<tr>
<td>High Park Station - Westbound Platform</td>
<td>42.8</td>
<td>3.07</td>
<td>14.76</td>
<td>1.62</td>
<td>3.74</td>
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<tr>
<td>High Park Station - Eastbound Platform</td>
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<td>153.95</td>
<td>224.88</td>
<td>15.95</td>
<td>25.18</td>
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<td>Kipling Station - Eastbound Platform</td>
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<td>403.65</td>
<td>1,318.03</td>
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<td>13.06</td>
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<tr>
<td>Jane Station - Eastbound Platform</td>
<td>507.2</td>
<td>294.64</td>
<td>485.93</td>
<td>11.25</td>
<td>24.64</td>
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<tr>
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<td>261.7</td>
<td>151.82</td>
<td>256.17</td>
<td>10.03</td>
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<td>403.72</td>
<td>706.85</td>
<td>8.6</td>
<td>24.73</td>
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<tr>
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<td>272.68</td>
<td>432.38</td>
<td>14.39</td>
<td>24.58</td>
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Demo of the Bus Bridging Assessment Tool

Subway Disruption between Kipling and Keele Station (Line 2)
Beyond the Assessment Tool

1) Determine the maximum number of shuttle buses that could be deployed to serve a disrupted segment

2) Optimization *(Work in progress)*
   - Minimize the inconvenience of transit users due to disruption
   - Ensure passenger safety by minimizing passenger build-up at stations
Maximum Allowable Number of Shuttle Buses

The following procedure is taken from Chapter 6 (Bus Transit Capacity) of the Transit Capacity and Quality of Service Manual (TCQM).

The station of least remaining capacity controls the maximum number of shuttle buses.
Bus Bridging Optimization Tool

**Main Goal**

- Develop an algorithm that generates an efficient bus bridging plan
- Minimize the impact on train and bus passengers
- Maximize the utilization of shuttle buses

**Genetic algorithms** are optimization methods that imitate the same mechanisms as those found in nature, say inheritance, mutation, selection and crossover.
Bus Bridging Optimization Tool

Objectives and Assumptions

Minimizing Transit User Inconvenience

- Minimize subway passenger delays
- Minimize bus rider delays during disruption

Ensuring Passenger Safety

- Minimize the maximum queue at disrupted stations
Comparison of Outcomes

*Current Practice vs. Optimal Plan*

**Total User Delay**

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<tr>
<th>Passenger.hr</th>
<th>Current</th>
<th>Optimal</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>3500</td>
<td>2800</td>
</tr>
<tr>
<td>500</td>
<td>3000</td>
<td>2200</td>
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<tr>
<td>1000</td>
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<td>1500</td>
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<td>2000</td>
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<td>800</td>
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<tr>
<td>2500</td>
<td>1000</td>
<td>400</td>
</tr>
<tr>
<td>3000</td>
<td>500</td>
<td>0</td>
</tr>
</tbody>
</table>

**Maximum Queue Length**

<table>
<thead>
<tr>
<th>Passenger</th>
<th>Current</th>
<th>Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1400</td>
<td>800</td>
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<tr>
<td>200</td>
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<td>600</td>
<td>100</td>
</tr>
<tr>
<td>1000</td>
<td>400</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Net Savings = 765 passenger.hr**
  *(Total reduction in waiting time for all affected passengers)*

- **Reduced the queue at Kipling station by 400 passengers***
Comparison of Outcomes (Cont.)

Current practice vs. Optimal Plan

15 mins, on average, is saved in deadhead time of each shuttle bus

Optimal plan shows a better utilization of shuttle buses along the disrupted segment.
Benefits

- Fast execution time, allowing for the evaluation of multiple plans rapidly
- Enable the assessment and refinement of bus bridging policies and guidelines
- Training tool for staff dealing with disruption management
- Determine the most efficient bus bridging plan