Empirical Evaluation of Transit Signal Priority through Fusion of Heterogeneous Transit and Traffic Signal Data and Novel Performance Measures

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Empirical Evaluation of Transit Signal Priority

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(Doug Beghtel/The Oregonian)
Background—Transit Signal Priority

Kamila Widulinski and Matthew Lapointe (2013)
Background—Transit Signal Priority

Evaluation methods

- **Analytic:** Lin (2002); Abdy & Hellinga (2011)
- **Simulation:** Furth & Muller (2000); Dion et al. (2004)
- **Empirical:** Kimpel et al. (2005); Albright & Figliozzi (2012)

Pre-install

Before / after

Performance measures

- Bus travel time
- Schedule adherence
- Headway variability
- Delay for other vehicles
- **Lack of effectiveness and efficiency measures/evaluation**
Motivation

Unique set of complementary data sources

- **TriMet**
  - Bus AVL/APC data
    - **AVL**: Automatic Vehicle Location
    - **APC**: Automatic Passenger Count

- **City of Portland**
  - SCATS signal phase log data
  - Intersection vehicle count data
  - **SCATS**: Sydney Coordinated Adaptive Traffic System
Research Questions

Current TSP system in Portland:
– Effectiveness and efficiency?
– Time savings for buses vs. delay to cross street vehicles
– Green extension vs. early green phases?
– Near-side vs. far-side bus stops?
– Any problems and improvement opportunities?
Study Corridor

Bus Route 9
Bus Route 66
SE Powell Blvd.

Milwaukie 21st 26th 33rd 39th 42nd 50th 52nd 65th 69th 71st, 72nd 82nd

Near-side: 26th EB 33rd EB 42nd EB 72nd EB
26th WB 43rd WB

Far-side: 33rd WB 39th EB 50th EB 52nd EB 65th EB 69th EB 71st EB 72nd WB
39th WB 50th WB 52nd WB 65th WB

12 SCATS signals

Stop-to-stop segment
Near-side (6)
Far-side (12)
Bus stop-to-stop segments

6 near-side segments

12 far-side segments
SCATS Signals

Median Cycle Length, Green phase and red phase duration

Seconds

Intersections / Directions

- Red
- Green
Data Integration

- Bus ALV/APC Database
- SCATS Vehicle Count Database
- SCATS Signal Phase Log Database
- Bus Stop-to-Stop Trip Database
- TSP Performance Evaluation
Bus Stop-to-Stop Trip Attributes

**Input data**
- Bus departure/arrival time
- Passenger activities
- Signal phase start/end time
- Priority request
- Upstream/downstream distance

**Output variables**
- Probability of arriving at intersection in:
  - Green
  - Red
  - Green extension
  - Early green
- Signal delay
- Time savings
Bus Time Saving (Early Green)

\[
R_j^e = EG_j^s
\]

Arrival time

Departure time

\[
dt_i
\]

\[
d_1
\]

\[
d_2
\]

\[
v_{max}
\]

\[
t_l
\]

\[
t_r
\]

\[
R_j^s
\]

\[
R_j^e
\]

\[
R_{j+1}^s
\]

\[
R_{j+1}^e
\]

Density

0.00 0.10 0.20

0 5 10 15 20 25 30 35

speed (mph)

EB 39th

am
Bus Time Saving (Green Extension)

\[
E_j = R_{j+1}
\]

Arrival time

Departure time

\[
d_{t_i} = R_{j+1} - R_j
\]

\[
\alpha
\]

\[
\gamma
\]

\[
\beta
\]
Key Performance Measures

– TSP Frequency

– TSP Effectiveness (for each TSP request)
  - Probability of benefiting from a TSP phase
  - Expected time saving

– TSP Efficiency (for each TSP phase)
  - Probability of being beneficial to a TSP request
  - Expected time saving per second of TSP phase duration
TSP Frequency

Average number of TSP phases per day

- Green Extension (GE)
- Early Green (EG)

Average number of bus trips per day

- Requested TSP
- Did not request TSP
When A TSP Request Will Benefit from GE/EG

Benefit from Green Extension

Benefit from Early Green

Red-GE

Green

GE

Red-EG

Green

EG
Potential Results of A TSP Request

- on-time EG = Red/Cycle
- on-time GE = GE/Cycle
Actual Outcomes of TSP Requests

TSP request

- No TSP phase within the cycle
  - NEither GE or EG
  - GE
  - EG
  - Both GE and EG

GE: Green Extension
EG: Early Green
Actual Outcomes of TSP Requests
TSP Effectiveness

1. Bus trips that request TSP
2. Green extension

No TSP phase within the cycle

TSP phase within the cycle

Effectiveness

- Early
- On-time
- Late

Benefit

Time saving
TSP Request Outcomes for GE

- d: no GE
- a: late GE
- b: on time GE
- c: early GE

<table>
<thead>
<tr>
<th>Year</th>
<th>GE Status</th>
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<tr>
<td>39th</td>
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<td>42nd</td>
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<tr>
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TSP Request Outcomes for EG

- d: no EG
- a: late EG
- b: on time EG
- c: early EG

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</table>

- d: no EG
- a: late EG
- b: on time EG
- c: early EG
Actual TSP Effectiveness

- On-time EG
- On-time GE

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<thead>
<tr>
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Ideal TSP Effectiveness

- on-time EG = Red/Cycle
- on-time GE = GE/Cycle

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</table>
Passenger Time Saving per TSP Request

\[
\sum_i \text{Time saving from } GE_i \quad \sum_i \text{Time saving from } EG_i
\]

\[
\frac{\sum_i TSP \text{ request}_i}{\sum_i TSP \text{ request}_i}
\]
TSP Phase Triggered by TSP Requests

- TSP phase
  - GE or EG

- No TSP request within the cycle
  - Neither EB or WB

- TSP request within the cycle
  - EB
  - WB
  - Both EB and WB
% of GEs Associated to TSP Requests From...
% of EGs Associated to TSP Requests From

- 0%
- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%
- 80%
- 90%
- 100%

Neither EB nor WB

EB

EB and WB

WB

39th  42nd  50th  52nd  65th  69th  71st  72nd
TSP Efficiency

- Bus trips that request TSP
- Green extension

TSP phase
- GE or EG

No TSP request within the cycle

TSP request within the cycle

Efficiency
- Early
- On-time
- Late

Benefit
- Time saving
Actual Green Extension Efficiency

- Out of cycle
- c: early
- b: on-time
- a: late

39th: 29% out of cycle, 71% on-time, 0% early, 0% late
42nd: 25% out of cycle, 75% on-time, 0% early, 0% late
50th: 15% out of cycle, 85% on-time, 0% early, 0% late
52nd: 20% out of cycle, 80% on-time, 0% early, 0% late
65th: 40% out of cycle, 60% on-time, 0% early, 0% late
69th: 30% out of cycle, 70% on-time, 0% early, 0% late
71st: 35% out of cycle, 65% on-time, 0% early, 0% late
72nd: 20% out of cycle, 80% on-time, 0% early, 0% late
Actual Early Green Efficiency

[Bar chart showing percentage breakdown for different cycles, with categories labeled as out of cycle, early, on-time, and late.]
TSP Efficiency (Time Saving vs. Delay)

If on-time

TSP phase
GE or EG

- Major street bus and other vehicles time saving
- Major street other vehicles time saving
- Minor street other vehicles delay
Bus Passenger Time Saving per EG

\[ \frac{\sum_j \text{Time saving of } EG_j}{\sum_j EG_j} \]
Bus Passenger Time Saving per GE

\[ \frac{\sum_j \text{Time saving of } GE_j}{\sum_j GE_j} \]
Vehicle Time Savings and Delay

\[ TD = \frac{q_1 \cdot q_2}{2(q_2 - q_1)} \left( 2 \cdot Red \cdot GE + GE^2 \right) \]

\[ TTS = \frac{q_1 \cdot q_2}{2(q_2 - q_1)} \left( 2 \cdot Red \cdot EG - EG^2 \right) \]
Green Extension Efficiency

Assume single occupancy vehicles
Early Green Efficiency

Assume single occupancy vehicles

- Minor street vehicle delay
- Major street vehicle time saving
- Major street passenger time saving

Seconds:

<table>
<thead>
<tr>
<th>Street</th>
<th>39th</th>
<th>42nd</th>
<th>50th</th>
<th>52nd</th>
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<td>Savings</td>
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</table>
Summary of Findings

**TSP performance**
- Vary significantly across intersections
- Big gap between actual and ideal performance

**Green extension**
- Too many late green extension phases
- Time savings $\approx$ Delay

**Early green**
- Time savings $>\,\text{Delay}$
Conclusions

• Proposed TSP performance measures can help identify problems/improvement opportunities and support planning decisions

• Findings from this study may be site-specific, but the methodologies are transferable to other corridors/cities

• TSP effectiveness and efficiency can be greatly affected by control logic, parameter calibration and signal detection/communication reliability
Future Work

• Consider vehicle queuing effect when estimating bus arrival time probabilities at intersections

• Utilize new and higher resolution data such as:
  – 5-second bus AVL data (finer bus trajectory between bus stops)
  – TSP Optical detector log data (priority log in/out records)
Acknowledgements

Steve Callas
David Crout

Peter Koonce
Willie Rotich
Questions?
On Average

TSP request

- On-time
- Within a cycle but early
- Within a cycle but late
- No TSP phase within a cycle

<table>
<thead>
<tr>
<th>Actual</th>
<th>Ideal</th>
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<tbody>
<tr>
<td>GE</td>
<td>EG</td>
</tr>
<tr>
<td>1.5%</td>
<td>10%</td>
</tr>
<tr>
<td>2.5%</td>
<td>5%</td>
</tr>
<tr>
<td>25%</td>
<td>1%</td>
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<tr>
<td>55%</td>
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Bus time saving: 0.3s GE, 0.5s EG
Passenger time saving: 7.5s GE, 10s EG

= 100% = 100%
On Average

<table>
<thead>
<tr>
<th>TSP phase</th>
<th>Actual</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GE</td>
<td>EG</td>
</tr>
<tr>
<td>On-time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>5%</td>
<td>40%</td>
</tr>
<tr>
<td>Late</td>
<td>3%</td>
<td>30%</td>
</tr>
<tr>
<td>No TSP request within a cycle</td>
<td>64%</td>
<td>8%</td>
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<td></td>
<td>22%</td>
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<td>=100%</td>
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<tr>
<td>Duration</td>
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<td>11s</td>
</tr>
<tr>
<td>Bus passenger time savings</td>
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<td>200s</td>
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<td>GE or EG</td>
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