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

 Wei Feng, Chicago Transit Authority
 Miguel Figliozzi, Portland State University
 Robert Bertini, Cal Poly State Univ., San Luis Obispo

(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 & Figlioizzi (2012)

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

12 SCATS signals

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

- 26th WB
- 43rd WB

Far-side:
- 33rd WB
- 39th EB
- 49th EB
- 50th EB
- 52nd EB
- 65th EB
- 69th EB
- 71st EB
- 72nd EB

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)

\[ \text{Arrival time} \]

\[ R_j^s \]

\[ \text{Departure time} \]

\[ R_j^e \]

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

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

\[ \text{Speed (mph)} \]

\[ \text{Density} \]

\[ 0.00 \ 0.10 \ 0.20 \]

\[ 0 \ 5 \ 15 \ 25 \ 35 \]
Bus Time Saving (Green Extension)

\[ t_i = R_{j+1}^{e} = t_r \]

\[ GE_{j}^{e} = R_{j+1}^{s} = t_r \]

\[ v_{\text{max}} \]

\[ GE_{j}^{s} \]

\[ GE_{j}^{e} \]

\[ t_l \]

\[ d_1 \]

\[ d_2 \]

\[ d_{t_i} \]

\[ \text{Arrival time} \]

\[ \text{Departure time} \]
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
When A TSP Request Will Benefit from GE/EG

- Benefit from Green Extension
- Benefit from Early Green

Cycle

- Red-GE
- GE
- Green

Cycle

- Red-EG
- EG
- Green
Potential Results of A TSP Request

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

<table>
<thead>
<tr>
<th>Location</th>
<th>EG</th>
<th>GE</th>
</tr>
</thead>
<tbody>
<tr>
<td>39th</td>
<td>50%</td>
<td>0%</td>
</tr>
<tr>
<td>42nd</td>
<td>50%</td>
<td>0%</td>
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<tr>
<td>50th</td>
<td>50%</td>
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<td>69th</td>
<td>50%</td>
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<tr>
<td>71st</td>
<td>50%</td>
<td>0%</td>
</tr>
<tr>
<td>72nd</td>
<td>50%</td>
<td>0%</td>
</tr>
</tbody>
</table>

near

Portland State University
Actual Outcomes of TSP Requests

- TSP request
  - No TSP phase within the cycle
  - 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

![Bar chart showing the actual outcomes of TSP requests with percentage ranges and categories: Neither GE nor EG, EG, Both GE and EG, GE. The chart includes specific results for different years such as 39th, 42nd, 50th, 52nd, 65th, 69th, 71st, and 72nd.](chart.jpg)
TSP Effectiveness

- Bus trips that request TSP
- Green extension

![Diagram](image)

- 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>39th</th>
<th>42nd</th>
<th>50th</th>
<th>52nd</th>
<th>65th</th>
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<th>71st</th>
<th>72nd</th>
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</thead>
<tbody>
<tr>
<td>EB</td>
<td>WB</td>
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<td>WB</td>
<td>EB</td>
<td>WB</td>
<td>EB</td>
<td>WB</td>
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<tr>
<td>near</td>
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<td>near</td>
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</tr>
</tbody>
</table>

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

[Graph showing TSP Request Outcomes for GE]
TSP Request Outcomes for EG

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

<table>
<thead>
<tr>
<th></th>
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<th>42nd</th>
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<td>WB</td>
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</tbody>
</table>

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

Nearness:
- d
- a
- b
- c
Ideal TSP Effectiveness

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

<table>
<thead>
<tr>
<th>39th near</th>
<th>42nd near</th>
<th>50th</th>
<th>52nd</th>
<th>65th</th>
<th>69th</th>
<th>71st near</th>
<th>72nd near</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB</td>
<td>WB</td>
<td>EB</td>
<td>WB</td>
<td>EB</td>
<td>WB</td>
<td>EB</td>
<td>WB</td>
</tr>
</tbody>
</table>

- EB: EB
- WB: WB
- on-time EG = Red/Cycle
- on-time GE = GE/Cycle
Passenger Time Saving per TSP Request

\[
\frac{\sum_{i} \text{Time saving from } GE_i}{\sum_{i} \text{TSP request}_i}
\]

\[
\frac{\sum_{i} \text{Time saving from } EG_i}{\sum_{i} \text{TSP request}_i}
\]

![Bar chart showing time saving for different TSP requests from GE and EG](chart.png)
TSP Phase Triggered by TSP Requests

- **TSP phase**
  - GE or EG

- **TSP request within the cycle**
  - No TSP request within the cycle
  - TSP request within the cycle

- **EB**
  - Neither EB or WB

- **WB**
  - Both EB and WB
% of GEs Associated to TSP Requests From
% of EGs Associated to TSP Requests From

- Neither EB nor WB
- EB
- EB and WB
- WB

Percentages for years:

- 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

The diagram illustrates the efficiency of green extension for various cycle points from 39th to 72nd, categorized as follows:

- **Out of Cycle**
- **Early (c)**
- **On-time (b)**
- **Late (a)**

Each cycle point is represented with bars indicating the percentage of each category. The diagram shows a breakdown of efficiency with a focus on how early, on-time, and late extensions are distributed across the cycles.
Actual Early Green Efficiency

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

30
TSP Efficiency (Time Saving vs. Delay)

TSP phase
GE or EG

If on-time

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

\[ \sum_{j} Time\ saving\ of\ GE_{j} \]

\[ \sum_{j} GE_{j} \]
Vehicle Time Savings and Delay

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

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

Assume single occupancy vehicles

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

seconds

39th | 42nd | 50th | 52nd | 65th | 69th | 71st | 72nd

35
Early Green Efficiency

Assume single occupancy vehicles
Summary of Findings

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

**Early green**
- Time savings $>$ Delay

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

<table>
<thead>
<tr>
<th>TSP request</th>
<th>Actual</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-time</td>
<td><img src="on-time.png" alt="on-time" /></td>
<td><img src="on-time.png" alt="on-time" /></td>
</tr>
<tr>
<td>Within a cycle but early</td>
<td>1.5%</td>
<td>6%</td>
</tr>
<tr>
<td>Within a cycle but late</td>
<td>2.5%</td>
<td>0%</td>
</tr>
<tr>
<td>No TSP phase within a cycle</td>
<td><img src="no-tsp.png" alt="no-tsp" /></td>
<td>0%</td>
</tr>
<tr>
<td>Bus time saving</td>
<td>0.3s</td>
<td>0.3s</td>
</tr>
<tr>
<td>Passenger time saving</td>
<td>7.5s</td>
<td>0%</td>
</tr>
</tbody>
</table>

Actual:
- GE: 1.5%, 2.5%, 25%, 55%
- EG: 10%, 5%, 1%, 0%

Ideal:
- GE: 1.5%, 5%, 1%, 0%
- EG: 10%, 5%, 1%, 0%

Bus time saving: 0.3s (GE), 0.5s (EG)
Passenger time saving: 7.5s (GE), 10s (EG)
On Average

<table>
<thead>
<tr>
<th>TSP phase</th>
<th>Actual</th>
<th>Ideal</th>
<th>GE or EG</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early</td>
<td>5%</td>
<td>40%</td>
<td>100%</td>
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<tr>
<td>Late</td>
<td>3%</td>
<td>30%</td>
<td>0%</td>
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<tr>
<td>No TSP request within a cycle</td>
<td>64%</td>
<td>8%</td>
<td>0%</td>
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<td></td>
<td>28%</td>
<td>22%</td>
<td>0%</td>
</tr>
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<td></td>
<td>=100%</td>
<td>=100%</td>
<td>=100%</td>
</tr>
<tr>
<td>Duration</td>
<td>7s</td>
<td>11s</td>
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<tr>
<td>Bus passenger time savings</td>
<td>20s</td>
<td>90s</td>
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<tr>
<td>Major street vehicle time savings</td>
<td>60s</td>
<td>300s</td>
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<tr>
<td>Minor street vehicle delay</td>
<td>80s</td>
<td>200s</td>
<td></td>
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</table>

- GE or EG
  - GE: 100%
  - EG: 0%
  - Actual: 0%
  - Ideal: 0%