Empirical evaluation of Transit Signal Priority Effectiveness and Efficiency

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Outline

• Introduction
• Objectives
• Corridor description
• TSP effectiveness analysis
• TSP efficiency evaluation
• Summary
• Next steps
Introduction

• Transit signal priority (TSP) strategies
  – Green extension
  – Early green (red truncation)

• TSP grant conditions
  – Unconditional
  – Conditional
  – Real-time optimization
Introduction

Data archive systems in SE Powell Blvd, Portland, Oregon

• **Bus stop event data**
  - Bus arrival/departure time and passenger activities at each bus stop

• **SCATS data**
  - Signal phase logs (start/end time for each phase including TSP phase) at each intersection
  - Traffic counts (15 minutes aggregation level) for each lane at each intersection
Objectives

At the intersection level, evaluate

1. **TSP effectiveness:**
   whether TSP helped reduce bus travel time crossing intersection (and by how much), controlling for traffic conditions and signal delay

2. **TSP efficiency**
   How many granted TSP phases were effective and how many were wasted
Corridor description

Traffic signals

- 12 SCATS signals implemented in November, 2011
- TSP was turned off in April, 2013
Corridor description

Bus route 9 and 66

EB: 24 bus stops, WB: 25 bus stops

Time points:

Milwaukie Ave.
39th Ave.
82nd Ave.
Corridor description

Bus stop-to-stop segments with at least one signal

- 6 near side
- 14 far side
- 3 near side and far side
TSP effectiveness analysis

• Bus stop-to-stop travel time

\[ = \text{arrive time (i)} - \text{leave time (i-1)} \]

• 2900 observations at each stop-to-stop segment

(March and May 2013, weekdays only)
- In March 2013, TSP was working at all intersections
- In May 2013, TSP was turned off
TSP effectiveness analysis

stop-to-stop travel speed boxplot (all day)  WB <= ======

- Speed (mph)
- Stop name
- Stop type
- Signal name
- Distance (mi)
- Red time (sec)

- No TSP
- TSP
TSP effectiveness analysis

• Method:
  – Regression model for each stop-to-stop segment crossing intersection

• Dependent variable:
  – bus stop-to-stop travel time crossing intersection

• Control variables:
  – bus pass by
  – Time of day effects
  – Traffic volume
  – Red light delay
  – TSP is working or not (a bus trip was made in March or May)
  – Bus trips that requested TSP or not
### TSP effectiveness analysis

<table>
<thead>
<tr>
<th>Eastbound</th>
<th>39th</th>
<th>50th</th>
<th>52nd</th>
<th>65th</th>
<th>69th</th>
<th>71st</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP (seconds)</td>
<td>-3.5 ***</td>
<td>-6.5 ***</td>
<td>-3.4 ***</td>
<td>-0.7 *</td>
<td>-1.1 ***</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Westbound</th>
<th>33rd</th>
<th>39th</th>
<th>50th</th>
<th>52nd</th>
<th>65th</th>
<th>72nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP (seconds)</td>
<td>-1.4 ***</td>
<td></td>
<td>-6.1 ***</td>
<td>-3.3 ***</td>
<td>-0.8 ***</td>
<td>-1.3 ***</td>
</tr>
</tbody>
</table>

***: significant at the 0.001 level  
*: significant at the 0.05 level

- 5-15% travel time reduction

- TSP effectiveness was not significantly different between buses that requested TSP and buses that did not request TSP
TSP efficiency evaluation

[    : leave time from stop i-1;
]    : arrive time at stop I;
*    : TSP phase start time at signal j

• [ * ] : a TSP phase was granted efficiently;
• [ ]*  : a TSP phase was granted too late (<3 minutes late);
• * [ ] : a TSP phase was granted too early (<1 minute early);
• *    : a TSP phase was granted incorrectly.
TSP efficiency evaluation

green extension

- % of TSP phases that cannot find any bus 3 minutes ago or 1 minute after: ~~~ * ~~~
- % of TSP phases that were within the bus travel time interval: ~~~ [*]~
- % of TSP phases that started < 3 minute after the end of interval: ~~~ [ ] ~
- % of TSP phases that started <= 1 minute before the beginning of interval: ~~~ * [ ]~
TSP efficiency evaluation

% of TSP phases that cannot find any bus 3 minutes ago or 1 minute after: ~~~ * ~~~
% of TSP phases that were within the bus travel time interval: ~~~ [*]~~~
% of TSP phases that started < 3 minute after the end of interval: ~~[ ]* ~~~
% of TSP phases that started <= 1 minute before the beginning of interval: ~~~ * [ ]~

early green

# of granted TSP per day
Summary

• On average, TSP significantly reduced bus stop-to-stop travel time crossing intersections (for far-side stop segments)

• The benefits of the conditional TSP implementation are not significantly different between buses that requested TSP and buses that did not request

• A large proportion of granted TSP phases were wasted (green extension worse than early green)
Next steps

• Study bus stop location effects (near-side / far-side)

• Study TSP effects on:
  – bus travel time variability
  – headway variability
  – on-time performance

controlling for traffic conditions variability and passenger activities variability.
Acknowledgements

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Questions?

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Additional slides
Introduction

- TSP performance measures
  - Intersection level: passenger delay
    (analytical or simulation approach)
  - Corridor level: bus running time, service reliability
    (simulation or empirical analysis)
Corridor description

Traffic signals

median cycle length and green split

seconds

cycle length
EB through green
WB through green
EB through red
WB through red

Mke  21st  26th  33rd  39th  42nd  50th  52nd  65th  69th  71st  72nd  82nd
TSP effectiveness analysis

March 2013:
(TSP was working)

May 2013:
(TSP was not working)
TSP effectiveness analysis

stop-to-stop travel speed boxplot (all day)  EB =====>>

- speed (mph)
- stop name
- stop type
- signal name
- distance (mi)
- red time (sec)

- Stop names: 9th, 9th, Mke, 21st, 21st, 24th, 24th, 26th, 26th, 28th, 28th, 31st, 31st, 33rd, 33rd, 34th, 34th, 36th, 36th, 39th, 39th, 42nd, 42nd, 47th, 47th, 50th, 50th, 52nd, 52nd, 57th, 57th, 60th, 60th, 62nd, 62nd, 65th, 65th, 67th, 67th, 69th, 69th, 72nd, 72nd, 75th, 75th, 79th, 79th, 82nd, 82nd, 86th, 86th

- Signal names: Mke_21st, Mke_21st, 26th, 26th, 33rd, 33rd, 39th, 39th, 42nd, 42nd, 50th, 50th, 52nd, 52nd, 65th, 65th, 69th, 69th, 71st, 71st, 72nd, 72nd, 82nd, 82nd, 86th, 86th

- Distance (mi): 0.9, 0.9, 0.14, 0.14, 0.51, 0.51, 0.13, 0.13, 0.1, 0.1, 0.18, 0.18, 0.13, 0.13, 0.09, 0.09, 0.12, 0.12, 0.16, 0.16, 0.16, 0.16, 0.15, 0.15, 0.24, 0.24, 0.16, 0.16, 0.12, 0.12, 0.14, 0.14, 0.09, 0.09, 0.11, 0.11, 0.13, 0.13, 0.18, 0.18, 0.2, 0.2

- Red time (sec): 55_26, 55_26, 35, 35, 17, 17, 66, 66, 72, 72, 46, 46, 43, 43, 13, 13, 11, 11, 16, 16, 17
TSP effectiveness analysis

- Control variables:

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass by</td>
<td>Dummy</td>
<td>=1, If a bus skipped departure stop</td>
</tr>
<tr>
<td>Am</td>
<td>Dummy</td>
<td>=1, if a bus trip was made in 6-8 am</td>
</tr>
<tr>
<td>Pm</td>
<td>Dummy</td>
<td>=1, if a bus trip was made in 3-5:30 pm</td>
</tr>
<tr>
<td>Mid</td>
<td>Dummy</td>
<td>=1, if a bus trip was made in 8 am – 3 pm</td>
</tr>
<tr>
<td>Red</td>
<td>Dummy</td>
<td>=1, if there was a red phase within the bus trip</td>
</tr>
<tr>
<td>Volume (vph)</td>
<td>Continuous</td>
<td>Vehicles per hour in the bus traveling direction</td>
</tr>
<tr>
<td>TSP</td>
<td>Dummy</td>
<td>=1, if a bus trip was made in March 2013 (when TSP was working)</td>
</tr>
<tr>
<td>Request</td>
<td>Dummy</td>
<td>=1, if a bus was more than 30 seconds late from departure stop (met the TSP request condition)</td>
</tr>
</tbody>
</table>
### Bus travel time regression analysis

<table>
<thead>
<tr>
<th></th>
<th>39th EB</th>
<th>50th EB</th>
<th>52nd EB</th>
<th>65th EB</th>
<th>69th EB</th>
<th>71st EB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coeff.</strong></td>
<td><strong>Sig.</strong></td>
<td><strong>Coeff.</strong></td>
<td><strong>Sig.</strong></td>
<td><strong>Coeff.</strong></td>
<td><strong>Sig.</strong></td>
<td><strong>Coeff.</strong></td>
</tr>
<tr>
<td>Travel time (seconds)</td>
<td>51.4 [*******]</td>
<td>41.1 [*******]</td>
<td>32.7 [*******]</td>
<td>22.4 [*******]</td>
<td>18.6 [*******]</td>
<td>23.3 [*******]</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>35.4 [*******]</td>
<td>30.5 [*******]</td>
<td>20.9 [*******]</td>
<td>20.5 [*******]</td>
<td>18.3 [*******]</td>
<td>21.1 [*******]</td>
</tr>
<tr>
<td>Pass by no Red (ref.)</td>
<td>-4.7 [*******]</td>
<td>-10.9 [*******]</td>
<td>-2.8 [*******]</td>
<td>-2.5 [*******]</td>
<td>-3.3 [*******]</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>53.7 [*******]</td>
<td>41.7 [*******]</td>
<td>44.2 [*******]</td>
<td>15.1 [*******]</td>
<td>17.3 [*******]</td>
<td>19.6 [*******]</td>
</tr>
<tr>
<td>volume (vph*1000)</td>
<td>19.2 [*******]</td>
<td>42.6 [*******]</td>
<td>22.2 [*******]</td>
<td>4.9 [*******]</td>
<td>2 [*******]</td>
<td>4.6 [*******]</td>
</tr>
<tr>
<td>volume (vph*1000)^2</td>
<td>-21.3 [*******]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| no TSP, no request (ref.) | -4.1 [****] | -6.2 [*******] | -6.7 [*******] | -2.6 [-*] | -0.8 [0.07 | -0.4 [0.12]
| TSP, no request | -6.4 [*******] | -3.8 [*******] | -1.3 [-*] | -1.3 [-*] | -1 [-**] | -1.5 [-**]
| R-Square | 0.34 | 0.32 | 0.34 | 0.3 | 0.3 | 0.33 |
| Adj. R-Square | 0.34 | 0.32 | 0.34 | 0.3 | 0.29 | 0.32 |
| N | 1556 | 1554 | 1545 | 1538 | 1551 | 1550 |
| Distance (miles) | 0.16 | 0.16 | 0.10 | 0.14 | 0.11 | 0.13 |
| Red time duration (sec.) | 66 | 48 | 45 | 14 | 12 | 15 |
## Bus travel time regression analysis

<table>
<thead>
<tr>
<th></th>
<th>33rd WB</th>
<th>39th WB</th>
<th>50th WB</th>
<th>52nd WB</th>
<th>65th WB</th>
<th>72nd WB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coef.</td>
<td>Sig.</td>
<td>Coef.</td>
<td>Sig.</td>
<td>Coef.</td>
<td>Sig.</td>
</tr>
<tr>
<td>Travel time (seconds)</td>
<td>25.2</td>
<td>44.5</td>
<td>50.4</td>
<td>37.4</td>
<td>18.9</td>
<td>29.5</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>26 ***</td>
<td>42.3 ***</td>
<td>35.6 ***</td>
<td>28.6 ***</td>
<td>15.6 ***</td>
<td>29.6 ***</td>
</tr>
<tr>
<td>Pass by</td>
<td>-2 ***</td>
<td>-6.7 ***</td>
<td>-7.5 ***</td>
<td>-4.8 ***</td>
<td>-2.1 ***</td>
<td>-2.6 ***</td>
</tr>
<tr>
<td>no Red (ref.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>18.7 ***</td>
<td>45.3 ***</td>
<td>44.6 ***</td>
<td>30.3 ***</td>
<td>13.3 ***</td>
<td>17.3 ***</td>
</tr>
<tr>
<td>volume (vph*1000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>volume (vph*1000)^2</td>
<td>-8.4 **</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no TSP, no request (ref.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSP, no request</td>
<td>-1.1 *</td>
<td>-4.2 ***</td>
<td>-2.4</td>
<td>-6.8 ***</td>
<td>-2.8 **</td>
<td>-0.8 **</td>
</tr>
<tr>
<td>TSP, request</td>
<td>-1.7 ***</td>
<td></td>
<td>-0.11</td>
<td>-7.6 ***</td>
<td>-4.6 ***</td>
<td>-1 **</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.11</td>
<td>0.11</td>
<td>0.19</td>
<td>0.14</td>
<td>0.16</td>
<td>0.26</td>
</tr>
<tr>
<td>Adj. R-Square</td>
<td>0.11</td>
<td>0.11</td>
<td>0.19</td>
<td>0.14</td>
<td>0.15</td>
<td>0.26</td>
</tr>
<tr>
<td>N</td>
<td>2756</td>
<td>2760</td>
<td>2762</td>
<td>2761</td>
<td>2760</td>
<td>2761</td>
</tr>
<tr>
<td>Distance (miles)</td>
<td>0.14</td>
<td>0.11</td>
<td>0.14</td>
<td>0.16</td>
<td>0.10</td>
<td>0.17</td>
</tr>
<tr>
<td>Red time duration (sec.)</td>
<td>18</td>
<td>66</td>
<td>56</td>
<td>35</td>
<td>14</td>
<td>16</td>
</tr>
</tbody>
</table>
Impacts of TSP on bus headway coefficient of variation (peak hours only)  EB

![Graph showing the impact of TSP on bus headway coefficient of variation.](image-url)
Impacts of TSP on bus headway