Near-Side, Far-Side, Uphill, Downhill: Impact of Bus Stop Location on Bus Delay

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Outline

- Background
- Incremental Delay Models
  1. Grade
  2. Signalized Intersections
- Conclusion
Background

- Part of a larger project concerned with optimizing bus stop locations (TCRP Transit-IDEA)

- Stop spacing models in literature take delay as a constant value

- Objective: Determine the incremental delay due to stopping on upgrades and near signalized intersections.
Objective

Why do we care?

- Factors may be used in a discrete location model
- To determine the impact of adding/removing/relocating a stop.
- For guidance on locating stops on hills, near-side, and far-side.
Model 1: Incremental Stopping Delay Due to Grade

- Industry practice is to specify rather weak engine performance.

![Acceleration Profile for Various Grades](image)

- For large grades, electric buses are used.
- Even small grades are a challenge for many buses, often resulting in large acceleration delays.
Incremental Stopping Delay Due to Grade

• For a stop spacing study, detailed roadway geometry is unlikely to be available.

• Therefore, 3 typical roadway profiles were examined.

1.) Constant Grade  
2.) Sag Curve  
3.) Crest Curve

• Acceleration was modeled as a function of grade and speed:
  \[ a(u, G) = a_0(u) - gG \]
Incremental Stopping Delay Due to Grade

\[ \text{Incremental Delay} = d_{6\%} - d_{0\%} \]

- - - - Bus no-stop trajectory

_____ Acceleration from stop trajectory
Incremental Stopping Delay Due to Grade

Incremental Stopping Delay Due to Grade, Constant Grade Profile

Incremental Delay (s)

Grade (%)
Incremental Stopping Delay Due to Grade, for Various Grades

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Constant Grade/Crest Curves</th>
<th>Sag Curves</th>
<th>Overall Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 - 25 (mph)</td>
<td>30 - 35 (mph)</td>
<td>20 - 25 (mph)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1 to 3</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4 to 6</td>
<td>5</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>7 to 9</td>
<td>9</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>10 to 12</td>
<td>10</td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>13 to 14</td>
<td>8</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>-1 to -3</td>
<td>0</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>-4 to -6</td>
<td>-1</td>
<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td>-7 to -9</td>
<td>-1</td>
<td>-3</td>
<td>-1</td>
</tr>
<tr>
<td>-10 to -14</td>
<td>-1</td>
<td>-3</td>
<td>-2</td>
</tr>
</tbody>
</table>

Example: relocating a stop from the middle of a hill with an 8% grade to a hill top can reduce running time by 10 seconds.
Model 2: Net Delay Due to Signalized Intersections

Near-Side vs. Far-Side: Conflicting Views
- Near-side is BETTER: bus can serve stop while waiting for red light – effectively killing two birds with one stone!
- Near-side is WORSE: can result in stopping for two red lights.

Methodology
- Microscopic deterministic simulation
- Bus arrival time varied from 0 to C (C = cycle length)
- Inputs: C, r/C, v/c, u, dwell time, stop setback distance, etc.
- Bus delay is plotted as a function of the bus’s projected arrival time in the cycle

Net Delay
- Net Delay = Total Delay – Control Delay – dnormal

Where:
- Control Delay = delay if bus did not stop and continued through the intersection.
- dnormal = bus delay at a stop away from influence of a traffic signal.
Net Delay Due to Signalized Intersections

Bus Delay vs. Arrival Time in Cycle: Base Case

- No Stop Delay
- Near-Side E(Delay)
- Near-Side E(Net)
- Far-Side E(Net)

Arrival Time in Cycle, $t_n$ (s)
Results for other Parameters

- Evaluated wide range of parameter values – averaging over bus arrival times.

- Far-Side: net delay always remains near zero,

- Near-Side: Delay varies greatly – most important parameters are those that determine:
  1. how much of the cycle the queue blocks the stop, and
  2. how costly it is to have to wait for the next green.
Net Delay Due to Signalized Intersections

Near-Side Average Net Delay vs. Stop Setback

![Graph showing net delay vs. stop setback for different cycle lengths and v/c ratios.]

a.) v/c = 0.8

b.) v/c = 0.6

- **Stop setback**: when setback extends beyond the range of the queue, the signal has no effect on delay.
- **Cycle Length**: For short cycles, queues are shorter and the penalty of missing the first green is smaller.
- **Low v/c or Bus Lane**: Optimal stop placement on the stop line, resulting in negative incremental delay.
Net Delay Due to Signalized Intersections

Near-Side Average Net Delay vs. Fraction Red (no overtaking)

- Short red ratios: (e.g., major st. intersecting a minor st.) delay is minimal since queues never become long and buses rarely miss the first green.
- Overtaking Permitted: If cars can overtake stopped bus, bus delay can be a few seconds larger.

Key parameter is the ratio \( \frac{L_s}{L_{QAve}} \), where \( L_s \) = stop setback and \( L_{QAve} = \frac{0.5vt_q^2L_{veh}}{C} \) = average reach of queue.
## Net Delay Due to Signalized Intersections

### Expected Incremental Net Delay for Near-Side Stops

<table>
<thead>
<tr>
<th>r/C</th>
<th>Bus Stop Setback Ratio</th>
<th>v/c = 0.6</th>
<th>v/c = 0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ft/s)</td>
<td>Ls:LQAve</td>
<td>C = 60s</td>
<td>C = 90s</td>
</tr>
<tr>
<td>0.9</td>
<td>0.00</td>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>8</td>
<td>-3</td>
</tr>
<tr>
<td>1.00</td>
<td>-3</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>1.50</td>
<td>-3</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>2.00</td>
<td>-3</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>3.00</td>
<td>-3</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>0.5</td>
<td>0.00</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1.50</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>2.00</td>
<td></td>
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<td>3.00</td>
<td></td>
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</tr>
<tr>
<td>0.3</td>
<td>0.00 - 3.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Blank cells = (-2 to 2 seconds)
Conclusion

- Results may be used in the context of a study of alternative stop locations.

- Where possible:
  - Stop placement should avoid steep upgrades.
  - Far-side stop placement is always a safe bet.
  - Near-side delay can be reduced by reducing queue interaction.
  - For exclusive bus lanes, placing the stop at the stop line yields the least delay.
  - It is possible to suggest an ideal location for a bus stop on an approach with frequent cycle overflows.
Thank you.