Outline

1. Dwell Time Theory
2. Bus Dwell Time Model¹
3. Light Rail Dwell Time Model²
4. Heavy Rail Dwell Time Model³


³ Puong, A., "Dwell Time Model and Analysis for the MBTA Red Line." Internal memo, MIT, March 2000.
Vehicle dwell time affects:
- system performance
- service quality

A critical element in vehicle bunching resulting in:
- high headway variability
- high passenger waiting times
- uneven passenger loads

Dwell time impact on performance depends on:
- stop/station spacing
- mean dwell as proportion of trip time
- mean headway
- operations control procedures

EXAMPLES:
Commuter rail ---> little impact of dwell time on performance
Long, high-frequency bus route ---> major impact
Dwell Time Theory

• Dwell time depends on many factors:
  • Human, modal, operating policies & practices, mobility, weather, etc.

• For a given system we have the following possible models:
  1. Single door, no congestion and interference:
     \[ \text{DOT} = a + b(DONS) + c(DOFFS) \]

  2. Single door with congestion and interference:
     \[ \text{DOT} = a + b(DONS) + c(DOFFS) + d(DONS+DOFFS)(DTD) \]
For a given system we have the following possible models ...

3. Single car with m doors:
   \[ DT = \max(DOT_1, \ldots, DOT_m) \]
   With balanced flows:
   \[ DT = a + b/m(\text{CONS}) + c/m(\text{COFFS}) + d/m(\text{CONS+COFFS})(\text{STD}) \]

4. n-car train:
   \[ DT = \max(DT_1, \ldots, DT_n) \]
   With balanced flows:
   \[ DT = a + b/nm(\text{TONS}) + c/nm(\text{TOFFS}) + d/nm(\text{TONS+TOFFS})(\text{STD}) \]
Bus Dwell Time: Prior Work

Manually collected data
• Limited data on infrequent events
  • Crowding
• Do not include latest fare media

Automatically collected data
• Does not include fare media information
• Poor fit of model

Transit Capacity and Quality of Service Manual
• Assumes a half-second penalty per passenger for crowding

Ref: Milkovits (2008)
Objective

• Develop a dwell time model using automatically collected data

• Dwell time factors:
  – Boarding and alighting passengers
  – Onboard passengers
  – Fare media type
  – Alighting door selection
  – Bus type

• Minimize the unexplained variation in dwell time

• Evaluate impact on dwell time of:
  – fare media type
  – bus design
  – enforcement of rear-only alightings

Ref: Milkovits (2008)
Data Set

• Automatically collected data from Chicago Transit Authority bus network

• Non-Timepoint, Far-Side, Known Stops

• Functioning APC counters on all doors
  – Verified by non-zero counts across day
  – Minimum per-passenger dwell time of .5 seconds

• Link-in AFC transactions
  – Fare transactions that take place within the dwell time

• Data from entire month of November 2006
  – 173,750 Records
  – 2,977 Operators
  – 85 Routes
  – 927 Stops

Ref: Milkovits (2008)
Model Formulation

• Predict dominant door activity
• Segment data and compare by:
  – Bus type
  – Crowding (passengers > number of seats)
• Combine the data and test for significant differences in the estimators

Ref: Milkovits (2008)
## Dwell Time Estimates – Front Door

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dummy</th>
<th>est</th>
<th>t-stat</th>
<th>Adjusted R²: 0.73</th>
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<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td>-1.22</td>
<td>-26.49</td>
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<tr>
<td>NABI</td>
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<td>0.53</td>
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<tr>
<td>FON_EX NOVA</td>
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<td>154.17</td>
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<tr>
<td></td>
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<td>-11.32</td>
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<tr>
<td>FOFF3UP</td>
<td></td>
<td>1.52</td>
<td>26.22</td>
<td></td>
</tr>
<tr>
<td>CARDS</td>
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<td>2.62</td>
<td>10.15</td>
<td></td>
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<tr>
<td>TICKET NFLYER</td>
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<td>39.55</td>
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<td></td>
<td>-0.58</td>
<td>-3.62</td>
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<tr>
<td>FOFF12 NFLYER</td>
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<td>22.54</td>
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<tr>
<td></td>
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<tr>
<td>ST2_PASS NFLYER</td>
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<td>0.0011</td>
<td>5.56</td>
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<tr>
<td></td>
<td>NFLYER</td>
<td>0.0017</td>
<td>3.53</td>
<td></td>
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</table>


**Ref:** Milkovits (2008)
## Dwell Time Estimates – Rear Door

<table>
<thead>
<tr>
<th>Variable</th>
<th>DUMMY</th>
<th>est</th>
<th>t-stat</th>
<th>Passenger Levels</th>
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<td>Intercept</td>
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<td>1.42</td>
<td>22.49</td>
<td></td>
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<tr>
<td></td>
<td>NABI</td>
<td>2.64</td>
<td>21.26</td>
<td></td>
</tr>
<tr>
<td>ROFF</td>
<td></td>
<td>1.69</td>
<td>40.86</td>
<td>All</td>
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<td></td>
<td>NOVA</td>
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<td>7.47</td>
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<tr>
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<td>-5.37</td>
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<tr>
<td>ST2_PASS</td>
<td>NOVA</td>
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<td>5.64</td>
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<td></td>
<td>NABI</td>
<td>-0.003</td>
<td>-3.36</td>
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</tr>
</tbody>
</table>


**Ref:** Milkovits (2008)
Bus Dwell Time Model: Key Findings

- Smart media loses benefit in crowded conditions
  - Drops from 2 second advantage in non-crowded conditions
- Crowding impact increases exponentially
- Bus attributes impact dwell time
  - Location of magnetic stripe reader (half second difference)
  - Double-wide doors
- Front door alightings may affect dwell time, while rear door alightings will happen in parallel

Ref: Milkovits (2008)
• Branching network of 28 miles (45 km) and 70 stations

• 52-seat ALRVs operate in 1-, 2-, and 3-car trains
  • high floor, low platform configuration
  • 3 doors per car on each side
  • single side boarding/alighting

• Trunk service in central subway:
  • 10 or 14 stations on round-trip
  • 1- to 2-minute headways
  • peak flows \( \approx 10,000 \) passengers/hour

Ref: Wilson and Lin (1993)
A. One-car trains:

\[ DT = 12.50 + 0.55 \times \text{TONS} + 0.23 \times \text{TOFFS} + 0.0078 \times \text{SUMASLS} \]

\[ (8.94) \quad (3.76) \quad (2.03) \quad (6.70) \]

\[ \text{SUMASLS} = \text{TOFFS} \times \text{AS} + \text{TONS} \times \text{LS} \]

(B) Two-car trains:

\[ DT = 13.93 + 0.27 \times \text{TONS} + 0.36 \times \text{TOFFS} + 0.0008 \times \text{SUMASLS} \]

\[ (7.43) \quad (2.92) \quad (3.79) \quad (2.03) \]

\[ (R^2 = 0.70) \]

Ref: Wilson and Lin (1993)
## Predicted Dwell Times

<table>
<thead>
<tr>
<th>ONS</th>
<th>LPL</th>
<th>1-Car DT</th>
<th>2-Car DT</th>
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<tbody>
<tr>
<td>0</td>
<td>any #</td>
<td>12.5</td>
<td>13.9</td>
</tr>
<tr>
<td>10</td>
<td>&lt; 53</td>
<td>20.3</td>
<td>20.2</td>
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<tr>
<td>10</td>
<td>150</td>
<td>35.6</td>
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<tr>
<td>20</td>
<td>&lt; 53</td>
<td>28.1</td>
<td>26.5</td>
</tr>
<tr>
<td>20</td>
<td>150</td>
<td>58.7</td>
<td>28.1</td>
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<tr>
<td>30</td>
<td>&lt; 53</td>
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</tr>
<tr>
<td>30</td>
<td>150</td>
<td>81.8</td>
<td>35.1</td>
</tr>
</tbody>
</table>

Ref: Wilson and Lin (1993)
• Dwell times for ALRVs are quite sensitive to:
  • Passenger flows
  • Passenger loads
• The crowding effect may well be non-linear.
• Dwell times for multi-car trains are different from those for one-car trains.
• The dwell time functions suggest high sensitivity of performance to perturbations
• Effective real-time operations control essential
• Running mixed train lengths dangerous
• Simulation models of high frequency, high ridership light rail lines need to include realistic dwell time functions.

Ref: Wilson and Lin (1993)
Heavy Rail Marginal Boarding Time

Ref: Puong (2000)  
Courtesy of Andre Puong. Used with permission.
Heavy Rail Dwell Time Function

\[ DT = 12.22 + 2.27 \cdot B_d + 1.82 \cdot A_d + 6.2 \cdot 10^{-4} \cdot TS_d^3 B_d \ (R^2 = 0.89) \] (9)

where

\[ A_d = \text{alighting passengers per door}; \]
\[ B_d = \text{boarding passengers per door}; \] and
\[ TS_d = \text{through standees per door}, \]
\[ \text{i.e., total through standees divided by the number of doors} \]

Ref: Puong (2000)

Courtesy of Andre Puong. Used with permission.