Quantifying the Effects of Modal Conflicts on Transit Reliability

Teo Wickland and Elizabeth Sall

SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY
Transportation Research Board 93rd Annual Meeting
January 13, 2014
Why is this important?

- Reliability needs to be treated as a major concern
- Trial Bus Method
  - Novel approach
  - Complements other tools
- Combined effects are greater than the sum of the component effects
- Overall effects are significant for operator and users
- Method is practice-ready!
The Reliability Problem
The Reliability Problem: Long Waits

Photo Credit: Streetsblog

Photo Credit: Muni Diaries
The Reliability Problem: Long Dwells

Photo Credit: Marc Chamot

Photo Credit: Andrew Barton
The Reliability Problem: Crowding
The Reliability Problem: Travel Time

Photo Credit: Ben Reed / Fotolia

Photo Credit: John Feehery
The Reliability Problem: Operating Cost

$ = Normal operating costs
$$ = Excessive operating costs

SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY
Background and Existing Research
Causes of Unreliability

Photo Credit: Cream.HR

Photo Credit: The Tender

Photo Credit: torbakhopper / Flickr

Photo Credit: CACashRefund / 12ozProphet

Photo Credit: The Overhead Wire

Photo Credit: Jason Winshell / SF Public Press
Existing Research

- Describing and understanding travel time reliability
  - Significant effect on individual behavior
  - Major impact on management, operating costs
  - Many ways to quantify
- Analyses based on observable travel times
  - Quantify effects of delay
  - Regression models
- Analyses based on simulation models
  - Monte Carlo or traffic assignment outputs
The Trial Bus Method
The Trial Bus Method

- Predicts delay and unreliability from specific conflicts
- Applicable for proposed transportation systems
- Complements other modeling tools
Trial Bus, Traversing Trial Areas
Risk of Encountering Conflict in Each Area

Probability(Encounter)
Duration(Delay | Encounter)
Example Application
Study Corridor: Geary Blvd., San Francisco

Photo Credit: Lui Salt / Photobucket
Study Corridor: Geary Blvd., San Francisco

Bus Route = 6.6 miles
Study Corridor: Geary Blvd., San Francisco

Study Corridor = 3.6 miles
Study Corridor: Geary Blvd., San Francisco

Photo Credit: Klaus Brink / Panoramio
Cause of Delay: Double Parking
Delay = 13.9 seconds per double-parked block (60 block-equivalents along study corridor)

Probability of Cumulative Delay (Binomial Distribution)

<table>
<thead>
<tr>
<th>Probability</th>
<th>Cumulative Delay, sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0</td>
</tr>
<tr>
<td>0.20</td>
<td>15</td>
</tr>
<tr>
<td>0.15</td>
<td>30</td>
</tr>
<tr>
<td>0.10</td>
<td>45</td>
</tr>
<tr>
<td>0.05</td>
<td>60</td>
</tr>
<tr>
<td>0.00</td>
<td>75</td>
</tr>
</tbody>
</table>

Mean: 43.3 sec  
Std. Dev.: 23.1 sec  
95th Pctile.: 78 sec  

Very Simplified
Delay \sim \ln N(13.9, 15.9) \text{ seconds per double-parked block}

Probability of Cumulative Delay (Multinomial Distribution)

- Mean: 43.8 sec
- Std. Dev.: 32.8 sec
- 95th Pctile: 108 sec
Fixed delay (binomial) vs. Variable delay (multinomial)

Probability of Cumulative Delay (Comparison)

Binomial Approximation – less realistic

Multinomial Approximation – more realistic
Sensitivity Analysis
Sensitivity Analysis

Cumulative Delay Probability Distributions

Base Case

\[ p = 0.056 \]

\[ D \sim \ln N(13.9, 15.9) \]
Sensitivity Analysis

Cumulative Delay Probability Distributions

Base Case
\[ p = 0.056 \]
\[ D \sim \ln N(13.9, 15.9) \]

More Encounters
\[ p = 0.111 \]
\[ D \sim \ln N(13.9, 15.9) \]
Sensitivity Analysis

Cumulative Delay Probability Distributions

Base Case
\[ p = 0.056 \]
\[ D \sim \ln N(13.9, 15.9) \]

More Encounters
\[ p = 0.111 \]
\[ D \sim \ln N(13.9, 15.9) \]

More Delay
\[ p = 0.056 \]
\[ D \sim \ln N(27.8, 31.8) \]
### Sensitivity Analysis

<table>
<thead>
<tr>
<th></th>
<th>Base Assumptions</th>
<th>More Encounters</th>
<th>More Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(Encounter)</td>
<td>0.056</td>
<td>0.111</td>
<td>0.056</td>
</tr>
<tr>
<td>D(Delay</td>
<td>Encounter)</td>
<td>$\sim \ln N(13.9, 15.9)$</td>
<td>$\sim \ln N(13.9, 15.9)$</td>
</tr>
<tr>
<td>Mean Delay</td>
<td>43.8</td>
<td>87.7</td>
<td>86.9</td>
</tr>
<tr>
<td>Median Delay</td>
<td>37</td>
<td>81</td>
<td>74</td>
</tr>
<tr>
<td>90\textsuperscript{th} Percentile</td>
<td>89</td>
<td>150</td>
<td>177</td>
</tr>
<tr>
<td>95\textsuperscript{th} Percentile</td>
<td>108</td>
<td>173</td>
<td>213</td>
</tr>
<tr>
<td>Semi-Standard Deviation</td>
<td>54.7</td>
<td>98.9</td>
<td>107.9</td>
</tr>
</tbody>
</table>

*All figures in seconds (except probability of encounter)*
Further Applications
Additional Sources of Unreliability

Parking Maneuvers
Photo Credit: L.A. Can’t Drive

Bicycles in Shared Lane
Photo Credit: Streetsblog

Turning Vehicles/Ped Friction
Photo Credit: New York Times

Dwell Times
Photo Credit: Jason Winshell / SF Public Press

Signal Delay
Photo Credit: Streetsblog

Unsignalized Crossings
Photo Credit: Brian R. Hannan
Cumulative Delay Probability Distributions

Double Parking

\[ n = 60 \]
\[ p = 0.056 \]
\[ D \sim \ln N(13.9, 15.9) \]
Combined Effects

Cumulative Delay Probability Distributions

Parking Maneuvers
\[ n = 372 \]
\[ p = 0.00435 \]
\[ D \sim \ln N(11.5, 4.7) \]

Double Parking
\[ n = 60 \]
\[ p = 0.056 \]
\[ D \sim \ln N(13.9, 15.9) \]
Combined Effects

Cumulative Delay Probability Distributions

- **Parking Maneuvers**
  - $n = 372$
  - $p = 0.00435$
  - $D \sim \text{ln } N(11.5, 4.7)$

- **Double Parking**
  - $n = 60$
  - $p = 0.056$
  - $D \sim \text{ln } N(13.9, 15.9)$

- **Turning Vehicles**
  - $n = 46$
  - $p \sim 0.86 \times P(\text{ped_vol} > 0)$
  - $D \sim \text{regression model}$

Probability vs. Cumulative Delay (sec)
Combined Effects

Cumulative Delay Probability Distributions

- Parking Maneuvers
  - \( n = 372 \)
  - \( p = 0.00435 \)
  - \( D \sim \ln N(11.5, 4.7) \)

- Double Parking
  - \( n = 60 \)
  - \( p = 0.056 \)
  - \( D \sim \ln N(13.9, 15.9) \)

- Turning Vehicles
  - \( n = 46 \)
  - \( p \sim 0.86 \times P(ped\_vol > 0) \)
  - \( D \sim \text{regression model} \)

- Combined Effects
  - Convolution of component distributions
## Combined Effects

<table>
<thead>
<tr>
<th></th>
<th>Double Parking</th>
<th>Parking Maneuvers</th>
<th>Turning Vehicles</th>
<th>Combined Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>No delay</td>
<td>3%</td>
<td>20%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>1-60 sec delay</td>
<td>72%</td>
<td>79%</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>60-120 sec delay</td>
<td>23%</td>
<td>2%</td>
<td>63%</td>
<td>12%</td>
</tr>
<tr>
<td>121-180 sec delay</td>
<td>3%</td>
<td>0%</td>
<td>32%</td>
<td>48%</td>
</tr>
<tr>
<td>&gt;180 sec delay</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>42%</td>
</tr>
<tr>
<td>Mean (sec)</td>
<td>43.8</td>
<td>18.5</td>
<td>86.9</td>
<td>173.6</td>
</tr>
<tr>
<td>Median</td>
<td>37</td>
<td>16</td>
<td>74</td>
<td>169</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>89</td>
<td>40</td>
<td>177</td>
<td>235</td>
</tr>
<tr>
<td>95th Percentile</td>
<td>108</td>
<td>40</td>
<td>177</td>
<td>256</td>
</tr>
<tr>
<td>Semi-Standard Dev.</td>
<td>54.7</td>
<td>24.3</td>
<td>107.9</td>
<td>222.2</td>
</tr>
</tbody>
</table>

Sum = 186.9, \( \sqrt{\text{sos}} = 123.4 \)
## Potential Savings from Eliminating Conflicts Along Study Corridor

<table>
<thead>
<tr>
<th>Operator Cost Savings</th>
<th>User Time Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modal conflict delay (avg.)</td>
<td>Modal conflict delay (avg.)</td>
</tr>
<tr>
<td>3.2 min</td>
<td>3.2 min</td>
</tr>
<tr>
<td>95&lt;sup&gt;th&lt;/sup&gt; Percentile delay</td>
<td>Avg. user ride (share of run)</td>
</tr>
<tr>
<td>4.3 min</td>
<td>45%</td>
</tr>
<tr>
<td>Slack time (avg.)</td>
<td>Savings per user per run</td>
</tr>
<tr>
<td>1.1 min</td>
<td>1.4 min</td>
</tr>
<tr>
<td>Schedule time savings</td>
<td>Average ridership per run</td>
</tr>
<tr>
<td>4.3 min</td>
<td>80 riders</td>
</tr>
<tr>
<td>Cost savings per run</td>
<td>Savings per run</td>
</tr>
<tr>
<td>$8.51</td>
<td>115 min</td>
</tr>
<tr>
<td>Cost savings per year</td>
<td>Savings per year</td>
</tr>
<tr>
<td>$1.8m</td>
<td>400k hrs</td>
</tr>
</tbody>
</table>

### Total Potential Savings

- **$9.8 million per year**

### SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY
Concluding Remarks
Limitations

- Independent trial areas
- Independent causes of delay
- Only as accurate as input assumptions
Future Work

• Non-independent trial areas
• Non-independent causes of delay
• Effects of bus bunching
• Confirm whether delays (conditional on encounter) are lognormally distributed
Key Takeaways

- Reliability needs to be treated as a major concern
- Trial Bus Method
  - Model sources of delay as simple probabilistic events
  - Express delay through Bayesian probabilities
- Combined effects are greater than the sum of the component effects
- Overall effects are significant for operator and users
- Method is practice-ready!
Thank you.

sfcta.github.io/delay_distribution
teo@berkeley.edu
elizabeth@sfcta.org