Analyzing Bay Bridge Westbound Traffic

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B.S. Civil Engineering, expected 2018
6/21/17
Research Team

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Research Motivation

• San Francisco—Oakland Bay Bridge (SFOBB) is arguably the most important bridge in the Bay Area, but traffic congestion is severe.

• Replacement of the Eastern Span cost $6.5 Billion, so adding additional capacity is highly unlikely.

• With tolling and more complicated roadway geometry in the Westbound direction, it is important to study Westbound traffic.
Defining the Problem

• Understand the severity and causes of Westbound AM-peak congestion

• Determine general relationship between metering rate and traffic conditions

• Suggest solutions to improve the operation of the bridge

• Compare traffic conditions in 2016 to those found in 2015 study
Outline

• Bridge Statistics
• Understanding Bridge Geometry
• Research Methodology & Data Sources
• 2015 Study

• Tollbooth Area
  – M/D/1 Queue
• Metering Area
• Merging Area
• Congestion Patterns
Bridge Statistics

- San Francisco—Oakland Bay Bridge (SFOBB) serves an average of 132,000 vehicles westbound each day.

- Demand will only increase, as Bay Area population is expected to increase by 30% between 2010 and 2040\(^1\).

- 2\(^{nd}\) most congested segment in Bay Area and 16\(^{th}\) most in nation\(^2\).

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1. According to Metropolitan Transportation Commission (MTC).
2. According to MTC and American Highway Users Alliance, respectively.
Geometry of Westbound Entrance
Geometry of Westbound Entrance

- 16 tollbooths (3-18)
- 4 HOV lanes (1-2 & 19-20)
- Red numbers denote volume in vehicles per hour per lane
Research Methodology & Data Sources

• Analyze 3 phases of bridge
  – Tollbooth Area
  – Metering Area
  – Merging Area

• Compare congestion patterns to those found in 2015

• Data Sources
  – PeMS
  – Independent Tollbooth Counts
  – Metering Logs
  – Video Recordings
SFOBB 2015 Study


- Before metering is activated, there is early congestion at the merging area due to high volumes in the middle lanes
- Little correlation between the metering rate and number of vehicles that pass the tollbooths
- Around 8-9 AM, congestion begins West of Yerba Buena Island and propagates upstream all the way to the merging area
- HOV lanes generally have lower flows and are underutilized after 9 AM
Tollbooth Area: Overview

• Fastrak vehicles can access 8 metering gates, whereas cash vehicles can only access 4

• On average, 582 vph for Fastrak lanes and 177 vph for Cash/Fastrak lanes

• HOV lanes pay a smaller toll and are FasTrak only
Tollbooth Area: M/D/1 Queue

- $\lambda = \text{demand per hour}$
- $\mu = \text{service rate per hour}$
- $Q = \text{average length of queue}$
- $W = \text{average waiting time}$

$$\rho = \frac{\lambda}{\mu}$$

$$Q = \frac{1}{2} \left( \frac{\rho^2}{1 - \rho} \right)$$

$$W = \frac{\rho}{2\rho(1 - \rho)}$$
# Tollbooth Area: M/D/1 Queue

<table>
<thead>
<tr>
<th></th>
<th>Q</th>
<th>( \rho )</th>
<th>( \lambda )</th>
<th>( \mu )</th>
<th>( W )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastrak</td>
<td>20, 40</td>
<td>0.975, 0.99</td>
<td>582</td>
<td>597, 588</td>
<td>124, 248</td>
</tr>
<tr>
<td>Cash</td>
<td>20, 40</td>
<td>0.975, 0.99</td>
<td>177</td>
<td>181, 179</td>
<td>406, 812</td>
</tr>
</tbody>
</table>

\[
\rho = \frac{\lambda}{\mu}
\]

\[
Q = \frac{1}{2} \left( \frac{\rho^2}{1 - \rho} \right)
\]

\[
W = \frac{\rho}{2\rho(1 - \rho)}
\]
Metering Area

<table>
<thead>
<tr>
<th>Bridge lanes</th>
<th>Metering gates</th>
<th>Toll booths</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>12</td>
<td>19-20</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>17-18</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>12-16</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>7-11</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3-6</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>582</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>582</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>582</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>582</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>582</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3-6</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>177</td>
</tr>
</tbody>
</table>

Merge area (1600') Metering area (1000') Toll plaza
Metering Area Overview

• At the time of study, operator manually adjusted metering rates based on congestion they saw at the metering area

• Metering logs indicate the metering rate in vehicle per minute and the time that it changes at

• In addition, metering logs provide the table that the operator selected, which indicates the ratio of Fastrak to Cash lane greens

<table>
<thead>
<tr>
<th>TIME</th>
<th>TYPE OF METERING</th>
<th>METERING RATE</th>
<th>REASON FOR RATE CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:31</td>
<td>fixed</td>
<td>60</td>
<td>Congested @ Merge</td>
</tr>
<tr>
<td>5:34</td>
<td></td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>6:00</td>
<td></td>
<td>160</td>
<td>Congested @ merge</td>
</tr>
</tbody>
</table>
Metering Rates and Tollbooth Counts

- Tollbooth counts (proxy for demand) and metering rates roughly mirror each other, which makes sense given operating regime

- PeMs data provides more evidence that metering rates are dictated by traffic conditions
May 17, 2016

Tollbooth Counts and Metering Rates on May 17th, 2016

Flow [veh/5min] on May 17th, 2016

Occupancy [%] on May 17th, 2016

Speed [mph] on May 17th, 2016

Berkeley
UNIVERSITY OF CALIFORNIA
May 19, 2016

Tollbooth Counts and Metering Rates on May 19th, 2016

Flow [veh/min] on May 19th, 2016

Occupancy [%] on May 19th, 2016

Speed [mph] on May 19th, 2016
# Merging Area

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<td>19-20</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>17-18</td>
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<tr>
<td>4</td>
<td>10</td>
<td>12-16</td>
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<td>9</td>
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<td>3</td>
<td>7</td>
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<td>4</td>
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<tr>
<td>1</td>
<td>2</td>
<td></td>
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<tr>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Merge area (1600')

Metering area (1000')

Toll plaza
Merging Area Flow

- HOV lanes feed into lanes 1 and 5, whereas Fastrak/Cash lanes feed into lanes 2-4

- HOV lanes are under-utilized during 5-6AM and 9-10AM

- PeMS data confirms trends implied by the Tollbooth Counts
# Merging Area Flow

<table>
<thead>
<tr>
<th>Time</th>
<th>Lane 1</th>
<th>50</th>
<th>1403</th>
<th>1874</th>
<th>1888</th>
<th>1345</th>
<th>742</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-5AM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td>0</td>
<td>895</td>
<td>1381</td>
<td>1701</td>
<td>1611</td>
<td>816</td>
<td></td>
</tr>
<tr>
<td>5-6AM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lanes 2-4 (avg)</td>
<td>1595</td>
<td>2400</td>
<td>2016</td>
<td>1640</td>
<td>1910</td>
<td>1909</td>
<td></td>
</tr>
<tr>
<td>6-7AM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-8AM</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>8-9AM</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>9-10AM</td>
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<td></td>
</tr>
</tbody>
</table>

![Graphs showing flow, occupancy, and speed over time](image-url)
Congestion Patterns
Congestion Patterns in 2016
Congestion Patterns in 2015
2016: 10am Congestion

- Congestion increases at 10am
- At 10am, toll price is reduced and HOV lane restriction is lifted
2015 vs 2016 Congestion

Traffic Flow in March, 2015 by Hour

Traffic Flow in March, 2016 by Hour
Conclusions

• HOV lanes are under-utilized from 5-6 AM and 9-10 AM

• Travelers in 2016 arrived at the bridge earlier than in 2015

• Congestion waves propagate upstream from West of Yerba Buena Island

• At the time, no detectors on West Span of bridge, making it difficult to determine the causes of these congestion patterns