Queue Storage Length Design for Metered On-Ramps

Guangchuan Yang, Ph.D.
Zong Tian, Ph.D., P.E.

Center for Advanced Transportation Education and Research
University of Nevada, Reno
Reno, NV89557

June 21, 2017
Presentation Overview

- Background Introduction
- Queue Length Modeling
- Mesoscopic Simulation Model
- Queue Storage Length Recommendations
- Major Findings
Metered On-Ramp

Downstream Acceleration Distance

Upstream Queue Storage Space
Tradeoff

What is an adequate queue storage length to:

✓ Ensure the vehicle queue does not spillback to upstream
✓ Balance queue storage length and acceleration length when existing ramps are retrofitted with meters
Queue storage as a percentage of peak hour demand ranging between 2%-10%

Resource from: Wang 2013
Issues with Existing Studies

- Queuing theory based model usually provides only the average queue length.

- Real-time queue length estimation studies were mostly for developing real-time ramp metering control algorithms rather than queue storage design.

- Queue length estimation and queue storage design need to take into consideration the unique and varying on-ramp flow arrive patterns.
Two On-Ramp Types

- **Arterial to Freeway On-Ramp**
  - Onramp traffic usually controlled by upstream signal

- **Freeway to Freeway Connector**
  - No upstream signal
  - Onramp flow arrives at a more random manner
On-Ramp Arrival Patterns (Cont.)

- Center/I-80 Reno
- SR 262/I-880 Bay Area
Description of On-Ramp Arrival Profile

- $S_{TH}$
- $A_{TH}$
- $S_{RT}$
- $A_{RT}$
- $S_{LT}$
- $A_{LT}$

- $G^T_0$, $G^T_{TH}$, $G^R_0$, $G^R_{RT}$, $G^L_0$, $G^L_{LT}$

- $\phi_1$, $\phi_2$, $\phi_4$

- Cycle Length
Modeling Queuing at Metered On-Ramps
Field Data Collection
Modeling vs. Observation

Arterial to Freeway Ramp

Freeway to Freeway Connector
Mesoscopic Simulation

- **Data Availability**
  - Various combination of demand and capacity scenarios

- **Data Quality**
  - Randomness of traffic flow
  - Measurement error when queue spillovers

- **Field Measure Data**
  - Model verification and/or calibration
User Interface – Arterial Ramp

<table>
<thead>
<tr>
<th>Category 1</th>
<th>UpstreamPhase</th>
<th>OnRampFeeding</th>
<th>OnRampDemand (Veh)</th>
<th>Saturation (Veh)</th>
<th>Green (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 1: (LT)</td>
<td>Y</td>
<td>66</td>
<td>1700</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Phase 2: (RT)</td>
<td>Y</td>
<td>580</td>
<td>2400</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Phase 4: (TH)</td>
<td>Y</td>
<td>680</td>
<td>3600</td>
<td>45</td>
</tr>
</tbody>
</table>

- Upstream total on-ramp demand (vph): 1326
- Upstream signal cycle length (sec): 90
- Downstream average metering rate (vph): 1500

- Maximum queue length: 38 Veh
- 95th queue length: 32 Veh
User Interface – Freeway Connector

![Image of user interface and graph showing input parameters and output results. The input parameters include upstream demand, average metering rate, and analysis interval. The output results display maximum queue and 95th percentile queue.](image-url)
## Simulation Scenarios

<table>
<thead>
<tr>
<th>Simulation Scenarios</th>
<th>Average Metering Rate (vphpl)</th>
<th>Ramp Demand (vphpl)</th>
<th>Demand-to-Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Metering Rate Scenarios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>100 to 300</td>
<td>0.42 to 1.25</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>150 to 450</td>
<td>0.42 to 1.25</td>
</tr>
<tr>
<td></td>
<td>480</td>
<td>150 to 600</td>
<td>0.31 to 1.25</td>
</tr>
<tr>
<td><strong>High Metering Rate Scenarios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>200 to 750</td>
<td>0.33 to 1.25</td>
</tr>
<tr>
<td></td>
<td>720</td>
<td>250 to 900</td>
<td>0.35 to 1.25</td>
</tr>
<tr>
<td></td>
<td>840</td>
<td>300 to 1,150</td>
<td>0.36 to 1.25</td>
</tr>
</tbody>
</table>
Queue Length as % of Onramp Demand
(Arterial On-Ramp)

Low Demand Scenario
(D < 500 vphpl)

High Demand Scenario
(500 < D < 900 vphpl)
Queue Length as % of Onramp Demand (Freeway Connector)

Low Demand Scenario (D < 500 vphpl)

High Demand Scenario (500 < D < 900 vphpl)
Simulation vs. Field Data (Arterial On-Ramp)

Low Demand Scenario (D < 500 vphpl)

High Demand Scenario (500 < D < 900 vphpl)
Simulation vs. Field Data
(Freeway Connector)

![Graph showing simulation vs. field data for a freeway connector. The x-axis represents the demand to capacity ratio, and the y-axis represents the queue length as a percentage of ramp demand. The graph compares simulation data (D/C<1) and (D/C>1) with observational data.](image-url)
# Queue Storage Length Recommendations

<table>
<thead>
<tr>
<th>Demand to Capacity Ratio</th>
<th>Queue Length as Percentage of Ramp Demand</th>
<th>Low Demand Scenario</th>
<th>High Demand Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Arterial On-Ramp</td>
<td>Freeway Connector</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.7%</td>
<td>0.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0%</td>
<td>0.8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0%</td>
<td>1.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.8%</td>
<td>2.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0%</td>
<td>3.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.2%</td>
<td>4.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5%</td>
<td>0.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8%</td>
<td>0.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2%</td>
<td>0.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.7%</td>
<td>0.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.6%</td>
<td>1.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0%</td>
<td>2.3%</td>
</tr>
</tbody>
</table>
On-ramp flow arrive pattern affects queue length; a vehicle platoon released from upstream signal tends to exacerbate queue length.

When $D < 500$ vphpl, the required queue storage length is approximately 6.2 percent (4.3 percent) of demand for arterial on-ramps (freeway connectors).

When $500 < D < 900$ vphpl, the required queue storage length is approximately 4 percent (2.3 percent) of demand for arterial on-ramps (freeway connectors).
Acknowledgements

This study was sponsored by California Department of Transportation (Caltrans).

The presenters thank Dr. Hao Xu of UNR CATER and Dr. Zhongren Wang of Caltrans Headquarter for their discussions; and Dr. Daobin Wang of UNR CATER for help coding the queue length simulation models.
Questions and Suggestions

Guangchuan Yang
UNR CATER
Email: gyang@unr.edu