On-Ramp Flow Arrival Pattern Impacts on Ramp-Metering Queue

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Presentation Overview

- Background Introduction
- Queue Length Modeling
- Mesoscopic Queue Length Simulation
- Queue Storage Length Recommendations
- Major Findings
Why Ramp Metering?

- **Tactical Level – Control existing demands**
  - “Access rate reduction technique” to ensure total demands not to exceed freeway capacity
  - Break up vehicle platoons entering freeway

- **Strategic Level – Reduce potential demands**
  - Stimulate carpool use
  - Reduce peak hour demand
  - Shift certain traffic to local road
Metered On-Ramp

Freeway Mainline

Ramp Meter

Downstream Acceleration Distance

Upstream Queue Storage Space
Challenges

What’s 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
State-of-the-Art

- **Maximum Individual Delay-Based Estimation (California, Australia)**
  \[ S = \left( \frac{d_{\text{max}}}{60} \times 100\% \right) \times \mu \]

- **Average Delay-Based Estimation (Minnesota, Wisconsin)**
  \[ S = \left( \frac{d}{60} \times 100\% \right) \times \lambda \]

- **Mimic signalized intersection (Nevada)**
  \[ S = \left( \frac{C}{3600} \times 100\% \right) \times \left( \lambda \times \frac{D}{PHF} \right) \]

- **Regression equations (Texas Transportation Institute)**
  \[ S = \left( (3.28 \times 10^{-2} - 9.74 \times 10^{-6} \cdot V) \times 100\% \right) \cdot V \]

- **Real-time queue length estimation**

Queue storage as a percentage of peak hour demand ranging between 2%-10%

Issues with Existing Study

- 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.
What Is On-Ramp Flow Arrive Profile?
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
Observed On-Ramp Arrival Profiles at 15 sec Level
On-Ramp Arrival Patterns (Cont.)

On-Ramp Arrival Flow (veh)

Time (sec)

Center/I-80 Reno

SR 262/I-880 Bay Area
Modeling Queuing
Accumulate Arrival Departure Chart
(The Input-Output Model)

The “Newell Curve”

Gordon F. Newell
(1925 - 2001)

Foundation Scientist in Transportation Science

On-Ramp Flow Discharged from Upstream Signal

\[ G_i^0 = \frac{A_i \times (C - G_i)}{S_i - A_i} \]
Description of On-Ramp Arrival Profile
Queue Generations at Metered On-Ramps

Cumulative Number of Vehicle (veh)

Max queue in the phase

Queue Cleared

Max queue in the phase

$A_{TH}$

$S_{TH}$

$A_{RT}$

$S_{RT}$

$A_{LT}$

Max queue in the phase

Departure

$t_0$ $t_1$ $t_2$ $t_3$ $t_4$ $t_5$ $t_6$

Time

Cycle Length

$\phi 1$ $\phi 2$ $\phi 4$
Mesoscopic Simulation
Why 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
Mesoscopic Simulation Flow Charts

Freeway Connector

Arterial On-Ramp
User Interface – Arterial On-Ramp

<table>
<thead>
<tr>
<th>Category 1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream Phase</td>
<td>OnRampFeeding</td>
</tr>
<tr>
<td>Phase 1: (LT)</td>
<td>Y</td>
</tr>
<tr>
<td>Phase 2: (RT)</td>
<td>Y</td>
</tr>
<tr>
<td>Phase 4: (TH)</td>
<td>Y</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

Input Parameters

- Upstream Demand: 1200 vph
- Average Metering Rate: 1200 vph
- Analysis Interval: 15s

Output Results

- Maximum Queue: 70 veh
- 95th Percentile Queue: 64 veh

Display

Graph showing Queue, CummArr, and CummDep over time.
Field Data Collection

Diagram of an intersection showing:
- Freeway I-80
- Freeway On-Ramp
- Ramp Meter
- Camera 1: Upstream Demand
- Camera 3: Queue Length
- Camera 2: Metering Rate
Modeling vs. Observation – Arterial On-Ramp

![Graph showing Observed Queue and Modeling Result over time](image-url)
Modeling vs. Observation - Connector

![Graph showing the comparison between modeling and observation over time](image-url)
## Queue Length Simulation Scenarios

<table>
<thead>
<tr>
<th>Simulation Scenarios</th>
<th>Average Metering Rate (vph)</th>
<th>Ramp Demand (vph)</th>
<th>Demand-to-Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Metering Rate Scenarios</strong></td>
<td>480</td>
<td>200 to 600</td>
<td>0.42 to 1.25</td>
</tr>
<tr>
<td></td>
<td>720</td>
<td>300 to 900</td>
<td>0.42 to 1.25</td>
</tr>
<tr>
<td></td>
<td>960</td>
<td>300 to 1,200</td>
<td>0.31 to 1.25</td>
</tr>
<tr>
<td></td>
<td>1,200</td>
<td>400 to 1,500</td>
<td>0.33 to 1.25</td>
</tr>
<tr>
<td><strong>High Metering Rate Scenarios</strong></td>
<td>1,440</td>
<td>500 to 1,800</td>
<td>0.35 to 1.25</td>
</tr>
<tr>
<td></td>
<td>1,680</td>
<td>600 to 2,100</td>
<td>0.36 to 1.25</td>
</tr>
<tr>
<td></td>
<td>1,920</td>
<td>700 to 2,400</td>
<td>0.36 to 1.25</td>
</tr>
<tr>
<td></td>
<td>2,160</td>
<td>900 to 2,700</td>
<td>0.42 to 1.25</td>
</tr>
<tr>
<td></td>
<td>2,400</td>
<td>1,000 to 3,000</td>
<td>0.42 to 1.25</td>
</tr>
</tbody>
</table>

- ✔ Demand increases from the low to the high boundary in 50 vph intervals
- ✔ 20 simulation runs for each demand-to-capacity scenario
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)
## 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>Arterial On-Ramp</td>
<td>Freeway Connector</td>
<td>Arterial On-Ramp</td>
</tr>
<tr>
<td>0.4</td>
<td>0.7%</td>
<td>0.6%</td>
<td>0.3%</td>
</tr>
<tr>
<td>0.5</td>
<td>1.0%</td>
<td>0.8%</td>
<td>0.5%</td>
</tr>
<tr>
<td>0.6</td>
<td>1.4%</td>
<td>1.2%</td>
<td>0.8%</td>
</tr>
<tr>
<td>0.7</td>
<td>2.0%</td>
<td>1.6%</td>
<td>1.2%</td>
</tr>
<tr>
<td>0.8</td>
<td>2.8%</td>
<td>2.3%</td>
<td>1.7%</td>
</tr>
<tr>
<td>0.9</td>
<td>4.0%</td>
<td>3.2%</td>
<td>2.6%</td>
</tr>
<tr>
<td>1.0</td>
<td>6.2%</td>
<td>4.3%</td>
<td>4.0%</td>
</tr>
</tbody>
</table>
Major Findings

- On-ramp flow arrive pattern affects queue length; a **vehicle platoon** released from upstream signal tends to exacerbate queue length.

- When $v/c < 1$, queue length shows an **exponential** increasing trend with $v/c$ ratio; when $v/c > 1$, queue length tends to increase **linearly** with $v/c$ ratio.

- When $D < 1000$ vph, the required queue storage length is approximately **6.2 percent (4.3 percent)** of demand for arterial on-ramps (freeway connectors).

- When $1000 < D < 1800$ vph, the required queue storage length is approximately **4 percent (2.3 percent)** of demand for arterial on-ramps (freeway connectors).
Future Works

Right-Turn-On-Red Impacts on Queueing
- 1 uninterrupted direct feeding
- 2 direct feedings under a 3 stage signal timing control strategy

Platoon Dispersion/Decay Impacts on Queueing
- 3 direct feedings under a 3 stage signal timing control strategy
- 1 direct feeding under upstream signal control; traffic diverge at ramp entrance
Acknowledgements

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Questions and Suggestions

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