On-Ramp Queue Estimation

Md. Arafat Hossain Khan

Supervised By: Dr. Zong Tian

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

February 19, 2015
Presentation Overview

- Introduction & Challenges
- Existing On-Ramp Queue Estimation Methods
- Methodologies
  - Offline
  - Online
- Case Studies
- Major Findings
- Assumptions
- Future Works
Introduction
(Site Geometry and Problem Statement)

Geometry, Hourly Demand, Signal Timing

Problem
1. What is on-ramp cycle by cycle queue length
2. What is the maximum queue
3. What is the ‘x percentile’ queue

Actuated Upstream Signal
To the ramp

Hourly Ramp Demand

Freeway
Flow Rate
Introduction
(technical challenges)

- Actuated Upstream (Signal Timing Information Lost)
- Breaking of Platoon (Input-Output Method Doesn’t Consider this Issue)
  - Shockwave Effect
  - When Queue Spills back
  - Diversion before Ramp
- Truck and Other Heavy Vehicles Create Platoons of More than One Cycle
- Traffic Responsive Metering Rate
Introduction
(Data Extraction Challenges - Synchronization of Videos)

Upstream

Diverging movement

Queue Length

Meter Rate
Introduction
(Application - Synchronization of Videos)
Introduction
(Long Queue – Cameras Cannot Cover)
## Existing On-Ramp Queue Estimation Methods

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td></td>
</tr>
<tr>
<td>California</td>
<td>Arrival-Discharge Chart</td>
</tr>
<tr>
<td>Minnesota</td>
<td>Average Delay-Based Estimation</td>
</tr>
<tr>
<td>Texas</td>
<td>Mathematical Modeling</td>
</tr>
<tr>
<td>Ohio</td>
<td>Recommended in the state design manual</td>
</tr>
<tr>
<td>Nevada</td>
<td>Mimic Signalized Intersection</td>
</tr>
<tr>
<td>New York</td>
<td>Recommended in the state design manual</td>
</tr>
<tr>
<td>Connecticut</td>
<td>Recommended in the state design manual</td>
</tr>
<tr>
<td>Overseas</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Maximum Individual Delay-Based Estimation</td>
</tr>
</tbody>
</table>

In most of the methods and guidelines reviewed, the on-ramp storage length was recommended to be designed as a certain percentage of peak hour demand which ranged from **2% to 10%).**
Methodologies
(Offline On-Ramp Queue Estimation)

- **Governing Equation – Input/Output Method**

- **Available Data**
  - Upstream Data - Hourly Volume, Signal Timing
  - Mainline Data – Hourly Volume
  - Diversion Percentage

- **Simulation**
  - Random Upstream Data - Hourly Volume, Signal Timing
  - Random Mainline Data – Hourly Volume
  - Random Diversion Percentage

- **Output – Queue profile for \( N \) number of cycles**
Methodologies
(Offline On-Ramp Queue Estimation)
Methodologies
(Online On-Ramp Queue Estimation)

- **Governing Equation – Input/Output Method**

- **Available Data**
  - Upstream - Hourly Volume, Signal Timing
  - Mainline – Hourly Volume
  - Diversion Percentage
  - Detector Measurement of Queue (Only for Online)

- **Online Queue Tracking Algorithms**
  - Smoothing Filters
  - Kalman Filter

- **Output – Learning and Predicting Queue profile**
Case Studies
(Study Sites)

- Training Site
  - Bradshaw/50, CA (Most General Site)

- Test Site
  - E Street/99, CA
  - Hazel/50, CA
  - 12th Ave/99, CA
Site Geometry
(Bradshaw, CA)
Site Geometry
(E Street, CA)
Site Geometry
(12th Street, CA)
Site Geometry
(Hazel Avenue, CA)
Excel Interface – Offline Queue Length Estimation
(Adding Movements and Data – Upstream & Mainline)
# Excel Interface – Offline Queue Length Estimation

(Adding Movements and Data – Upstream & Mainline)

<table>
<thead>
<tr>
<th>Name of the Ramp</th>
<th>General Parameters</th>
<th>General Simulation Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller Type</td>
<td>Unsignalized</td>
<td>No of Iteration</td>
</tr>
<tr>
<td>Average Cycle Length</td>
<td>Uniform</td>
<td>No of Cycles</td>
</tr>
<tr>
<td>Mainline Flow Rate</td>
<td>Traffic Responsive</td>
<td>Plot From Cycle #</td>
</tr>
<tr>
<td>Mainline Flow Distribution</td>
<td>Traffic Responsive</td>
<td>Plot to Cycle #</td>
</tr>
<tr>
<td>Mainline PHF</td>
<td>Traffic Responsive</td>
<td></td>
</tr>
<tr>
<td>Metering Type</td>
<td>Traffic Responsive</td>
<td></td>
</tr>
<tr>
<td>Maximum Metering Rate</td>
<td>Traffic Responsive</td>
<td></td>
</tr>
<tr>
<td>Minimum Metering Rate</td>
<td>Traffic Responsive</td>
<td></td>
</tr>
<tr>
<td>Queue Flash</td>
<td>Traffic Responsive</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Direction</th>
<th>East Bound</th>
<th>West Bound</th>
<th>North Bound</th>
<th>South Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td>Left</td>
<td>Through</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Geometry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane Configuration</td>
<td>ThruConfig1</td>
<td>ThruConfig2</td>
<td>ThruConfig3</td>
<td>ThruConfig4</td>
</tr>
<tr>
<td>Turn Type</td>
<td>Right</td>
<td>Protected</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Right Turn On Field</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Saturated Flow Rate</th>
<th>Volume Data</th>
<th>Saturated Flow Rate (RTDR)</th>
<th>Average Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|---------------------------|-----------------|-------------------------|-------------------|-----------------------------|----------------------|

<table>
<thead>
<tr>
<th>Saturation Flow Rate Adjustment (for Upstream Intersection)</th>
<th>Based on HCM 2000, Pages 16-8</th>
</tr>
</thead>
</table>

|--------------------|-------------------|-------------------|-----------------|-----------------|
Excel Interface of Queue Length Estimation

(Detail Parameter List)
Queue Comparison – Observed Vs Calculated
(Bradshaw, CA)
Queue Comparison – Observed Vs Calculated
(E Street, CA)
Queue Comparison – Observed Vs Calculated
(12th Street, CA)
Queue Comparison – Observed Vs Calculated
(Hazel Avenue, CA)
# Queue Comparison – Summary
(Observed Vs Calculated)

<table>
<thead>
<tr>
<th>Site Parameters</th>
<th>Observed</th>
<th>Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>95&lt;sup&gt;th&lt;/sup&gt; Per.</td>
</tr>
<tr>
<td></td>
<td>(veh)</td>
<td>(veh)</td>
</tr>
<tr>
<td>Avg. Metering Rate, vph</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Avg. Upstream Demand, vph</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Avg. Ramp Demand, vph</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Bradshaw</td>
<td>Hazel</td>
<td>74</td>
</tr>
<tr>
<td>598</td>
<td>1226</td>
<td>74</td>
</tr>
<tr>
<td>835</td>
<td>3223</td>
<td>74</td>
</tr>
<tr>
<td>343</td>
<td>1252</td>
<td>74</td>
</tr>
<tr>
<td>E-Street</td>
<td>Hazel</td>
<td>74</td>
</tr>
<tr>
<td>836</td>
<td>1226</td>
<td>74</td>
</tr>
<tr>
<td>1717</td>
<td>3223</td>
<td>74</td>
</tr>
<tr>
<td>704</td>
<td>1252</td>
<td>74</td>
</tr>
<tr>
<td>12 Street</td>
<td>Hazel</td>
<td>74</td>
</tr>
<tr>
<td>837</td>
<td>1226</td>
<td>74</td>
</tr>
<tr>
<td>1580</td>
<td>3223</td>
<td>74</td>
</tr>
<tr>
<td>747</td>
<td>1252</td>
<td>74</td>
</tr>
<tr>
<td>Hazel</td>
<td>Hazel</td>
<td>74</td>
</tr>
<tr>
<td>1226</td>
<td>1226</td>
<td>74</td>
</tr>
<tr>
<td>3223</td>
<td>3223</td>
<td>74</td>
</tr>
<tr>
<td>1252</td>
<td>1252</td>
<td>74</td>
</tr>
</tbody>
</table>
Simulated Queue Vs Ramp Demand (Bradshaw, CA)

Bradshaw - Ramp Demand Vs 95th Percentile Queue

- Queue Data
- Fitted Curve
- Metering Rate Line
- Observed Ramp Demand

Ramp Demand (vph)

95th Percentile Queue (veh)
Simulated Queue Vs Ramp Demand
(E Street, CA)

E Street - Ramp Demand Vs 95th Percentile Queue

- Queue Data
- Fitted Curve
- Metering Rate Line
- Observed Ramp Demand

Ramp Demand (vph) vs 95th Percentile Queue (veh)

600  650  700  750  800  850  900  950  1000  1050  1100

0  50  100  150  200  250
Simulated Queue Vs Ramp Demand
(12th Street, CA)

12 Street - Ramp Demand Vs 95th Percentile Queue

- Queue Data
- Fitted Curve
- Metering Rate Line
- Observed Ramp Demand
Simulated Queue Vs Ramp Demand
(Hazel, CA)
# Queue Comparison – Summary
*(Observed Vs Simulated)*

<table>
<thead>
<tr>
<th>Site Parameters</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>95&lt;sup&gt;th&lt;/sup&gt; Per.</td>
</tr>
<tr>
<td>Avg. Metering Rate, vph</td>
<td>598</td>
<td>11</td>
</tr>
<tr>
<td>Avg. Upstream Demand, vph</td>
<td>835</td>
<td>6</td>
</tr>
<tr>
<td>Avg. Ramp Demand, vph</td>
<td>343</td>
<td>11</td>
</tr>
<tr>
<td>Bradshaw</td>
<td>836</td>
<td>19</td>
</tr>
<tr>
<td>E-Street</td>
<td>1717</td>
<td>16</td>
</tr>
<tr>
<td>12 Street</td>
<td>704</td>
<td>19</td>
</tr>
<tr>
<td>Hazel</td>
<td>837</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>1580</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>747</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>1226</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>3223</td>
<td>66</td>
</tr>
</tbody>
</table>
### Queue Comparison – Summary
(Percentage of Ramp Demand)

<table>
<thead>
<tr>
<th>Site Parameters</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum (%)</td>
<td>95th Per. (%)</td>
</tr>
<tr>
<td>Avg. Metering Rate, vph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg. Upstream Demand, vph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg. Ramp Demand, vph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bradshaw</td>
<td>3.21</td>
<td>1.75</td>
</tr>
<tr>
<td>E-Street</td>
<td>2.70</td>
<td>2.27</td>
</tr>
<tr>
<td>12 Street</td>
<td>2.70</td>
<td>2.41</td>
</tr>
<tr>
<td>Hazel</td>
<td>5.91</td>
<td>5.27</td>
</tr>
</tbody>
</table>

In most of the methods and guidelines reviewed, the on-ramp storage length was recommended to be designed as a certain percentage of peak hour demand which ranged from 2% to 10%.
Major Findings from Offline Queue Storage

- This is not possible to exactly follow the queue profile using Input-Output Method.
- Adding more site specific features will lead to a better match of actual queue profile.
- More features will lead to a very complex input parameter list which users may not know without careful site investigation.
- Including more features may lead to adding redundant features and so giving worse results in many cases.
- On-ramp storage length has been found to be within 2% to 8% of peak hour ramp demand.
Online Queue Storage
(Step 1: State Prediction)

\[^k\uparrow 0\downarrow Q \equiv \text{Residual Queue at the end of } k\text{-th phase}\]
\[^k\uparrow \downarrow Q \equiv \text{Maximum Queue in } k\text{-th phase}\]

\[V\downarrow k = ^k-1\uparrow 0\downarrow Q + ^k\uparrow 0\downarrow g \ s\downarrow k + [T\downarrow k - ^k\uparrow 0\downarrow g]v\downarrow k\]

\[^k\uparrow 0\downarrow Q \equiv ^k-1\uparrow 0\downarrow Q + ^k\uparrow 0\downarrow g [s\downarrow k - v\downarrow k] + T\downarrow k v\downarrow k - \min(\mu\downarrow k T\downarrow k, V\downarrow k)\]

\[^k\uparrow \downarrow Q \equiv ^k-1\uparrow 0\downarrow Q + ^k\uparrow 0\downarrow g \ \max(s\downarrow k - \mu\downarrow k, 0)\]

\[X\downarrow k = [█0\&1@0&1][█^k\uparrow \downarrow Q @^k\uparrow 0\downarrow Q ]+[█^k\uparrow 0\downarrow g [s\downarrow k - v\downarrow k] + T\downarrow k v\downarrow k - \min(\mu\downarrow k T\downarrow k, V\downarrow k) ] @^k\uparrow 0\downarrow g \ \max(s\downarrow k - \mu\downarrow k, 0) ][█1@1 ]+ \varepsilon\downarrow X\]
Online Queue Storage
(Step 2: Detector Prediction)

\[ Z_{\downarrow k} = C X_{\downarrow k} + \varepsilon_{\downarrow Z} \]

\[ Q_{\text{est}} \equiv [\varepsilon 1 & 0] [\varepsilon^{\uparrow k}_{\downarrow Q} @^{\uparrow k}_{\downarrow 0} Q ] + \varepsilon_{\downarrow Z} \]

\[ \varepsilon_{\downarrow X} = [\varepsilon \sigma_{\downarrow 1} \uparrow 2 & \sigma_{\downarrow 1} \sigma_{\downarrow 2} @ \sigma_{\downarrow 2} \sigma_{\downarrow 1} & \sigma_{\downarrow 2} \uparrow 2 ] \]

\[ \varepsilon_{\downarrow Z} = \sigma_{\text{measurement} \uparrow 2} \quad [\text{Define a value}] \]

\[ \sigma_{\downarrow 1} \uparrow 2 = \text{variance of}^{\uparrow k}_{\downarrow Q}, \quad \sigma_{\downarrow 1} \uparrow 2 = \text{variance of}^{\uparrow k}_{\downarrow 0} \downarrow Q \]

Plug – In these values to the Filter algorithm
Online Queue Storage
(Result Using State Prediction)
Online Queue Storage
(Noisy Result Using State Prediction)
Online Queue Storage - Bradshaw
(Moving Average Filter)
Online Queue Storage - Bradshaw
(Local Regression Filter – Order 1)
Online Queue Storage - Bradshaw (Kalman Filter)
Online Queue Storage
(Kalman Filter Algorithm)

\[ \bar{X}_k = AX_{k-1} + BU_k \]
\[ \Sigma_k = A \Sigma_{k-1} A^T + \Xi_x \]
\[ K_k = \Sigma_k C^T (C \Sigma_k C^T + \Xi_z)^{-1} \]
\[ X_k = \bar{X}_k + K_k (Z_k - C \bar{X}_k) \]
\[ \Sigma_k = (I - K_k C) \Sigma_k \]
Online Queue Storage– E Street
(Kalman Filter)
Online Queue Storage– 12th Street (Kalman Filter)
Online Queue Storage– Hazel (Kalman Filter)
Major Findings from Online Queue Storage

- Among linear first order filters discussed so far, Kalman Filter predicts the queue with most accuracy.
- Real time queue computation using Kalman Filter is very fast and can be implemented in the field.
- As long as the governing equation is the linear first order Input-Output method more complex higher order filters are unnecessary.
Assumptions

- **Offline Queue Storage Model**
  - The vehicles are entering the ramp in platoon.
  - Upstream vehicles entering the ramp and not entering the ramp are evenly distributed.
  - 1 Truck is equivalent to 2 passenger cars.

- **Online**
  - All the assumptions for offline.
  - The state prediction model is linear and first order.
  - The noise is predicted to be Gaussian.
Summary

- **Offline Queue Storage Model**
  - The maximum and 95\textsuperscript{th} percentile queue was estimated.
  - Based on the simulation the queue storage was found to be within 2\%~8\% of the upstream demand.

- **Online Queue Storage Model**
  - The queue profile was estimated by using adaptive filters.
  - The queue profile matches with the observed queue profile as expected.
Future Works

- More field data collection from Los Angeles and improving the offline queue storage model.
- Modeling metering rate from mainline flow rate using adaptive filtering method
- Creating vehicle counting system from live video feed.
- Adding online queue prediction algorithm to live vehicle counter.
Acknowledgement

- Laura Zhao - for literature review.
- Dr. Hao Xu - for valuable comments throughout the work.
- Lab members - for helping me collecting the data.
- Caltrans - for supporting us in this research.

And

Dr. Zong Tian - for helping me in every single step.
References

References


Questions and Discussions