Ramp Metering: Operations and Analysis

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VASITE Annual Meeting 2017
Agenda

- Background
- Layouts / Examples
- Operational Characteristics
- Traffic Analysis
- Metering Algorithms
What is Ramp Metering?

- Strategy used to regulate entering flow to a freeway
- Controlled by traffic signal
- No direct impact to mainline operations
Ramp Meters: One-Lane Ramp

- One Vehicle Per Green
Ramp Meters: One-Lane Ramp

- "Ramp Metered When Flashing" sign
- Flashing yellow indication
- Located on both sides of ramp
- Clear Messages
- Flashing beacons dark when not in operation
Ramp Meters: One-Lane Ramp

Loop Detection
- Demand loops
- Passage loop
- Advance queue detection loop
- AQ loop impacts meter rate
- No backups onto arterial street
Ramp Meters: One-Lane Ramp

- ‘One Vehicle Per Green’ sign
- Two red/green indications
- ‘Stop Here on Red’ sign
- ‘One Vehicle Per Green’ sticker on bottom indication
- All located on left side of ramp
Ramp Meters: Two-Lane Ramp

- One Vehicle Per Green
Ramp Meters: Two-Lane Ramp

- One Vehicle Per Green

Ramp Meter Control
- Same look as single-lane ramp metering
- Equipment on both sides of ramp
Ramp Meters: Two-Lane Ramp

- One Vehicle Per Green

- Merging
  - ‘Pavement Width Transition’ sign for advance merge warning
Ramp Meters: One-Lane Ramp

- Two Vehicle Per Green
Ramp Meters: Two-Lane Ramp

- Two Vehicle Per Green
Ramp Meters: Quick note on Enforcement

- Tattle-Tale Enforcer
Traffic Signal Displays – Non-Metering Mode

- Flashing Circular Yellow
  - Recommended
  - In MN reduced knockdowns during snow events

- Steady Circular Green
  - May contradict with signs

- Dark
  - “vehicular traffic approaching a nonfunctioning traffic control signal at an intersection shall stop, yield to vehicles, remain stop until safe to enter and continue through the intersection”
  - Although these signals are not located at an intersection there could be driver confusion
Traffic Signal Displays – Metering Mode

- Green -> Red
  - Not aware of law which required yellow change interval
  - FHWA Ramp Metering Handbook states
    - Most efficient operation is from Green to Red
  - No added compliance issues by not including yellow

- Green -> Yellow -> Red
  - Uses Operational Yellow which is typically 0.7 seconds
    - Technically violates VDOT Policy
    - TE 306.1 – Minimum yellow change
Traffic Signal Displays – Transitions (Startup)

Option 1
- Flashing Yellow with HIB Dark ->
- Flashing Yellow with HIB Flashing Yellow ->
- (NORMAL METERING) Solid Green with HIB Flashing Yellow
  - Meets MUTCD 4D.31 & Typical for SHA

Option 2
- Flashing Yellow with HIB dark ->
- Flashing Yellow with HIB Flashing Yellow ->
- Solid Yellow (with a 3.0 second minimum interval) with HIB Flashing Yellow ->
- Solid Red with HIB Flashing Yellow ->
- (NORMAL METERING) Solid Green with HIB Flashing Yellow
  - Meets MUTCD 4D.31
  - Used by ODOT
Traffic Signal Displays – Transitions (Shutdown)

**Option 1**

- (NORMAL METERING) Solid Green with HIB FY ->
- (NORMAL METERING) Solid Yellow (if we do OP yellow) with HIB FY ->
- (NORMAL METERING) Solid Red with HIB FY ->
- Flashing Yellow with HIB FY (time a delay in the end of metering to the HIB going dark to clear the queue) ->
- Flashing Yellow with HIB dark.
  - Meets MUTCD 4D.29
  - SHA typical setup for intersections
  - Could do with or without HIB time delay at end of metering operations
Traffic Signal Displays – Transitions (Shutdown)

Option 2

- (NORMAL METERING) Solid Green with HIB FY ->
- Flashing Yellow with HIB FY (time a delay in the end of metering to the HIB going dark to clear the queue) ->
- Flashing Yellow with HIB dark.
  - Meets MUTCD 4D.29
  - Could do with or without HIB time delay at end of metering operations
Ramp Meters: U.S. Example Photos
Ramp Meters: U.S. Example Photos
Ramp Metering – Freeway Breakdown Phenomenon
Ramp Metering – Freeway Flow

Volume-Occupancy: All Lanes

Free-Flow Region
Congested Region

Flow, vph vs Occupancy, %

0 10 20 30 40 50 60

Volume-Occupancy: All Lanes

0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0 10 20 30 40 50 60

Congested Region
Free-Flow Region
Ramp Metering – Volume Rates / Thresholds

- Allowable metering rate:
  - Maximum: 720 to 900 vph
  - Minimum: 180 to 240 vph

- Volume Balance: \[ 5\% < \frac{\text{Volume}_{\text{Ramp}}}{\text{Volume}_{\text{Freeway(Downstream)}}} < 50\% \]
  - Ideal, between 10% and 30%
Ramp Metering – Quality of Service

The diagram illustrates the relationship between metering availability and ramp demand volume for different conditions. The y-axis represents metering availability (%) and the x-axis represents ramp demand volume (vph). The lines indicate the quality of service for different metering rates:

- Good
- Fair
- Fail

The graph shows how metering availability decreases as the ramp demand volume increases, with varying degrees of quality depending on the metering rate.
Ramp Metering – Queuing

- 95\textsuperscript{th} Percentile Queue
  - \( L = 3.2808 \times (0.250V - 0.00007422V^2) \)
Ramp Metering – Queuing

![Diagram showing Arrival Rate and Discharge Rate over time with a queue]

- Arrival Rate
- Discharge Rate
- Time
- Vehicle Per Hour (VPH)
Ramp Metering – Impact on Arterials
## Ramp Metering Analysis – HCS

### Adjust Capacity

<table>
<thead>
<tr>
<th>Freeway Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of analysis</td>
<td>Merge</td>
</tr>
<tr>
<td>Number of lanes in freeway</td>
<td>3</td>
</tr>
<tr>
<td>Free-flow speed on freeway</td>
<td>70.0 mph</td>
</tr>
<tr>
<td>Volume on freeway</td>
<td>5881 vph</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>On Ramp Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Side of freeway</td>
<td>Right</td>
</tr>
<tr>
<td>Number of lanes in ramp</td>
<td>1</td>
</tr>
<tr>
<td>Free-flow speed on ramp</td>
<td>45.0 mph</td>
</tr>
<tr>
<td>Volume on ramp</td>
<td>1429 vph</td>
</tr>
<tr>
<td>Length of first accel/decel lane</td>
<td>1500 ft</td>
</tr>
<tr>
<td>Length of second accel/decel lane</td>
<td>ft</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Adjacent Ramp Data (if one exists)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Does adjacent ramp exist?</td>
<td>No</td>
</tr>
<tr>
<td>Volume on adjacent Ramp</td>
<td>vph</td>
</tr>
<tr>
<td>Position of adjacent Ramp</td>
<td></td>
</tr>
<tr>
<td>Type of adjacent Ramp</td>
<td></td>
</tr>
<tr>
<td>Distance to adjacent Ramp</td>
<td>ft</td>
</tr>
</tbody>
</table>

### Conversion to pc/h Under Base Conditions

<table>
<thead>
<tr>
<th>Junction Components</th>
<th>Freeway</th>
<th>Ramp</th>
<th>Adjacent Ramp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume, V (vph)</td>
<td>5881</td>
<td>1429</td>
<td>vph</td>
</tr>
<tr>
<td>Peak-hour factor, PHF</td>
<td>0.97</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Peak 15-min volume, v15</td>
<td>1516</td>
<td>401</td>
<td>v</td>
</tr>
<tr>
<td>Trucks and Buses</td>
<td>3</td>
<td>2</td>
<td>%</td>
</tr>
<tr>
<td>Recreational vehicles</td>
<td>0</td>
<td>0</td>
<td>%</td>
</tr>
<tr>
<td>Terrain type:</td>
<td>Level</td>
<td>Level</td>
<td>Level</td>
</tr>
<tr>
<td>Grade</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Length</td>
<td>mi</td>
<td>mi</td>
<td>mi</td>
</tr>
<tr>
<td>Trucks and buses PCE, ET</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Recreational vehicle PCE, BR</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>
Ramp Metering Analysis - VISSIM

- VAP Controller
- If/Then VAP Script
- Detector Setup
Ramp Metering Analysis - CORSIM

- Run Time Extension
- FRESIM Ramp
- Node Structure
Ramp Metering – Objectives and Types

- Local or Coordinated
- Platoon-breakup
- Gap-acceptance
- Demand-capacity
Ramp Metering – Platoon Metering

Interval Times (sec)

<table>
<thead>
<tr>
<th>Interval</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>2.00</td>
<td>2.00</td>
<td>2.32</td>
<td>2.61</td>
<td>2.86</td>
<td>3.08</td>
</tr>
<tr>
<td>Yellow</td>
<td>1.00</td>
<td>1.70</td>
<td>2.00</td>
<td>2.22</td>
<td>2.41</td>
<td>2.58</td>
</tr>
<tr>
<td>Green</td>
<td>1.00</td>
<td>3.37</td>
<td>5.47</td>
<td>7.35</td>
<td>9.13</td>
<td>10.83</td>
</tr>
<tr>
<td>Cycle Length</td>
<td>4.00</td>
<td>7.08</td>
<td>9.78</td>
<td>12.19</td>
<td>14.40</td>
<td>16.49</td>
</tr>
<tr>
<td>Meter Capacity</td>
<td>900</td>
<td>1017</td>
<td>1104</td>
<td>1181</td>
<td>1250</td>
<td>1310</td>
</tr>
</tbody>
</table>
Ramp Metering – Gap Acceptance

upstream gap detector

detected gap

vehicle released for gap
Local Ramp Metering – Demand-Capacity

- Mainline detector used to determine metering rate
  - Detected volume = 4800 vph

- Design capacity = 5400 vph

- Metered ramp upstream of potential bottleneck
  - Allowed volume = 600 vph
  - Meter rate of 600 vph or 6.0 seconds per vehicle.
Ramp Metering – Control Methods

Ramp Metering Algorithms

Isolated
- ALINEA
  - Local Metering using Neural Networks

Coordinated
- Coordinated ALINEA
  - ALINEA
- ZONE
- COOPERATIVE
  - HELPER Algorithm
  - LINKED Algorithm
- COMPETITIVE
  - BOTTLENECK Algorithm
  - SWARM Algorithm
- INTEGRATED
  - FUZZY LOGIC Algorithm
  - METALINE Algorithm
  - FHWA/BALL Space Algorithm
  - DYNAMIC Metering Control
Ramp Metering – ALINEA Algorithm

- Local traffic responsive algorithm in which the control logic is based on the feedback structure from the mainline loop detectors.
- The feedback control logic dynamically maintains the mainline occupancy level below the target occupancy level by restricting the inflow from on-ramps.
- Easy to calibrate and implement in field.
- Queue override feature can be incorporated in the algorithm if required.

$$r(t) = r(t-1) + K_R \cdot (O_{\text{desired}} - O_{\text{downstream}}(t))$$

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r(t)$</td>
<td>Metering rate at timer interval 't' (veh/hr)</td>
</tr>
<tr>
<td>$O_{\text{desired}}$</td>
<td>Desired occupancy rate of the downstream detector station (%)</td>
</tr>
<tr>
<td>$O_{\text{downstream}}(t)$</td>
<td>Measured occupancy rate at the downstream detector station (%)</td>
</tr>
<tr>
<td>$r(t-1)$</td>
<td>Measured on-ramp volume for time interval t-1 (veh/hr).</td>
</tr>
<tr>
<td>$K_R$</td>
<td>Regulator parameter (veh/hr), typically set at 70 veh/hr.</td>
</tr>
</tbody>
</table>
Ramp Metering – Zone Algorithm

- First implemented by Minnesota Department of Transportation (MnDOT) in the St. Pauls area of Minneapolis.
- A type of coordinated algorithm which is based on the control logic of equating the input into a zone to the output from the zone and thus operate the mainline at capacity.

Pseudo code of the ZONE algorithm:
- Divide the corridor into multiple zones based on location of critical bottlenecks in the corridor - u/s end of the zone is a free flow and the d/s is the critical bottleneck.
- Regulate the inflow from the on-ramps so as to smooth out the congestion and then allow the traffic on the mainline to move at capacity.

$$A + U + M + F = X + B + S$$
Ramp Metering – Bottleneck Algorithm

- Implemented by the Washington Department of Transportation in the Seattle region.
- A type of coordinated algorithm in which the network is divided into sections based on bottleneck locations.
- The control logic has a two tier structure:
  - Local
    - Real-time upstream demand is compared to the downstream capacity and the difference is the local metering rate for the ramp.
  - Global
    - Coordinate control strategy identifies bottlenecks and computes the volume reduction required at the bottleneck based on flow conservation.
    - Algorithm distributes volume reduction according to predetermined weights based on the criticality of the ramp.
- Once the two rates are computed, the more restrictive of the two is the metering rate for the ramp.
Ramp Metering – SWARM Algorithm

- Implemented in the Orange County region of California.
- A coordinated algorithm that maintains the real-time mainline density below the defined saturation density.
- Like the bottleneck algorithm has a two tier control logic:
  - Local metering rate
    - Based on local density near the ramp merge.
  - Global metering rate
    - Base volume reduction on ramps upstream of a PREDICTED bottleneck, instead of measured conditions.

- The more restrictive of the two rates is implemented. The pro and the con of the algorithm being:
  - Pro – SWARM predicts the location of bottlenecks in the network based on predicted traffic volume and flow patterns thus making it a more preventive measure rather than a reactive one.
  - If prediction is poor, the algorithm can produce worse failure than bottleneck which is more based on measured volumes.