Type-1 freeway on-ramp
Type-2 freeway on-ramp

- Freeway Mainline
- Crossroad
- Neighboring intersections
- Ramp meter
- Target arterial area
Impacts by a local-ramp metering control

More freeway throughput

Less arterial throughput

Lower metering rate

Longer on-ramp queue

Lower green ratio for the ramp signal

Shorter cycle length to the ramp signal

Lower green ratios at the upstream intersections

Shorter cycle lengths at the upstream intersections

Less in-flows to the on-ramp

Neighboring intersections

Ramp meter

Freeway Mainline

On-ramp

Target arterial area for control
Research issues

How to balance the benefits between the freeway and its local intersections near the on-ramps?

How to prevent the on-ramp queue spillback during the peak hours?

How to avoid queue spillover at the intersection’s turning bays?

How to provide progression for vehicles within the control area, and minimize queues at the boundaries?
System structure

Traffic State Detection/Prediction

Local RM activation

Freeway Input Data
- Freeway flow rate
- Ramp flow rate
- Freeway base capacity
- On-ramp length

Arterial Input Data
- Flow rate by turning movement
- Volume to on-ramp
- Number of lanes in each approach
- Bay length
- ...

Signal Optimization:
RM and neighboring intersections

Objective
- Maximize total throughput for the freeway and the local arterials
- Minimize queueing vehicles

Constraints
- Capacity of the freeway on-ramp segment
- Ramp maximum queue length
- Intersection queue constraints

Freeway control Output
- Metering rate

Arterial control Output
- Cycle length
- Green splits
- Offsets
- Phase sequence

Traffic Conditions
- On-ramp queue length
- Freeway throughput
- Arterial throughput

Execution
**Methodology**

**Objective**

Maximize Freeway throughput

\[ + \alpha \times \text{Arterial throughput} \]

\[ - \beta \times \text{total queue vehicles} \]

- **Available capacity under the ramp metering rate**
- **Vehicles moving out of the control area** (movements by green arrows), based on
  - The demand that can enter the target area
  - Green ratios at the boundary intersections
- **Queuing vehicles not within the control area** (see red arrows)

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**Diagram:**

- Freeway Mainline
- Crossroad
- On-ramp
- Neighboring intersections
- Ramp meter
Methodology

Freeway capacity reduction due to on-ramp merging vehicles

**Rear void**
- Speed difference between Lane-1 and Lane-A
- Deceleration to accommodate merging flows
- Create a void due to one lane change
- On-ramp vehicles
- Capacity reduction due to all created voids

**Upstream lane change**
- Density on lane 2
- Density on lane 1
- On-ramp merging vehicles
- Number of lane-changing vehicles due to ramp flows
- Capacity reduction due to vehicle weavings

Assumption: the density ratio between lanes 1 and 2 remains approximately stable before and after the ramp-weavings.
Methodology

Constraints

- On the on-ramp
  - Type A: Queues caused by excessive volumes
  - Type B: Queues caused by vehicles per cycle from the upstream intersections

- On the arterial links
  - Vehicles not experiencing local progression
  - Vehicles entering a link
  - Vehicles not experiencing local progression

On-ramp queues $\leq$ On-ramp length

Bay length/link length $\leq$ Discharging capacity

Vehicles not experiencing local progression $=$ Queueing vehicles
Key control logic – providing progression for vehicles of all movements within the control area

Constraints

Local progression bands

Offsets between intersections
Phase sequence
Local progression bands
Vehicles not experiencing progression
Vehicle queues on an arterial link

These vehicles form the queue

Offsets between intersections
Phase sequence
Local progression bands
Vehicles not experiencing progression
Vehicle queues on an arterial link

Local bandwidth

$u, v$: start, and end of a green phase
For Type-2 ramps

Additional Constraints

**Dual on-ramp Control**

**Freeway Flow rate**_{upstream} - (off-ramp flow rate) + total on-ramp flow rate \leq = Freeway **Capacity**_{downstream}

**On-ramp demand** = actual volume on link x turning ratio to the ramp

*Prior to the control by signals*
Illustration of model application

I-270 @ Exit 1, EB on-ramp

Freeway mainline:
• 2 lanes (excluding HOV lane), 3000 vph

Metered on-ramp:
• 792 ft, one lane

Intersection volume input and turning ratios obtained from ITMS.

Arterial signals
• 90s<cycle<180s
• Lost time: 2 s, Minimum phase duration: 9 s

Study period: 1 hr
Model application: Max. total throughput out of the control area

Signal Cycle length = 95s
Arterial throughput = 6537 veh/hr
Freeway throughput = 3222 veh/hr
Type A on-ramp queue = 587 ft (27 veh)
Type B on-ramp queue = 205 ft (9 veh)
On-ramp inflow = 353 veh
Total restrained vehicles = 0 veh

Major throughput under Optimized results

Input Volume (total = 6890 veh)
Primary model output

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>180</td>
<td>Cycle length (s)</td>
<td>160</td>
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<tr>
<td>8436</td>
<td>Arterial throughput (veh/hr)</td>
<td>8405</td>
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<tr>
<td>3083</td>
<td>Freeway throughput (veh/hr)</td>
<td>3069</td>
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<tr>
<td>13</td>
<td>On-ramp residual queues (veh)</td>
<td>0</td>
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<tr>
<td>23</td>
<td>Ramp queues from arriving vehicles per cycle (veh)</td>
<td>20</td>
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<tr>
<td>458</td>
<td>Vehicles entering the on-ramp under the signal plan (vph)</td>
<td>458</td>
</tr>
<tr>
<td>62</td>
<td>Total restrained vehicles (veh)</td>
<td>94</td>
</tr>
<tr>
<td>90</td>
<td>Suggested RM cycle length (s)</td>
<td>80</td>
</tr>
</tbody>
</table>

• Shorter on-ramp length ➔ shorter intersection cycle length, and higher RM green ratio

1.3 * vol, ramp length = 972 ft

1.3 * vol, ramp length = 450 ft
Upgrading the system to real-time operation

Evaluation criteria:
- Arterial volume changes by 2 levels + Freeway or Ramp volume changes by 1 level
- Freeway and Ramp volume changes by 1 level
- Freeway or Ramp volume changes by 2 levels

Real-time data collection

Arterial volume
- Level 1
- Level 2
- Level 3
- Level 4
- Level ...

Freeway volume
- Level 1
- Level 2
- Level 3
- Level 4
- Level ...

Ramp volume
- Level 1
- Level 2
- Level 3
- Level 4
- Level ...

Has traffic condition changed significantly in the last interval?
- Yes
  - Implement one pre-solved optimal signal timing plan
    - Signal plan 1
    - Signal plan 2
    - Signal plan 3
    - Signal plan 4
    - Signal plan ...
    - Signal plan N
  - Next time interval
- No
  - Keep current signal timing plan

Stop ramp metering control

Has the peak hour ended?
- Yes
- No
  - Identify volume level combination
  - Next time interval

Start