Control of Freeway Corridors: Objectives, Performance Measures, Strategies

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Outline

- Freeway Corridor management
  - Background/Problem Statement
  - National Programs: ICM
- Signalized Intersections: Performance Measurement
- Freeway-Arterial Coordination
- Looking Ahead
Background: Corridor Management

Cooperative management of freeways and adjacent arterial networks

Los Angeles, Smart Corridor 1988
Background: Corridor Management

Corridor Traffic Management & Information Vision
Multimodal operations
Complex modeling approaches
Operational procedures/plans
Institutional constraints
Decision support systems
Limited field evaluation
Limited research
US-75 ICM Corridor, Dallas, TX
I-15 ICM Corridor, San Diego, CA

Managed Lanes
Park and-Ride
Access Road
Direct Access Ramps
BRT Station
CA CC I-210: Decision Support

State estimation

Historical data

Current ρ,v,f state

Demand prediction

Performance prediction

Demand management strategy

Supply management strategy

Predicted OD and routes

Predicted performance

Interface

Measured ρ,v,f

Data scopes

Incidents, CHP, etc.

Normalization and fusion

Heterogeneous data

Data

Strategy bank

Knowledge

Actuation
Urban Arterials/Networks: Traffic Flow Variability vs. Control

- Fixed-Time Plans
- Time of Day (TOD)
- No Detection
- May be actuated

A

B
- Fixed time plans
- Traffic responsive plan selection
- System detection

C
- Traffic responsive control
- On-line timing development
- Approach & system detection

D
- Adaptive control
- Measure & predict arrivals per cycle
- Extensive detection
Arterial Networks: Traffic Control

- Most signal systems fixed-time control
  - Limited data
  - Out-dated timing plans

- Adaptive systems
  - High cost
  - Complex to understand and operate

Source: Alek Stevanovic, NCHRP Synthesis 403
Approach: Use of HR data*

- Performance measures for operators and travelers
  - Use of existing infrastructure
  - No interference with controller operation
- Improving Signal Timing Plans
  - Performance derived signal settings
  - Robust timing plans
- On-Going/Future Work
  - Traffic volume prediction
  - Safety (red light running)
  - Multimodal (pedestrians, bicycles)

*Work with P. Varaiya & Sensys Networks
“Management of Urban Traffic with H-R Data” IEEE ITSC 2014
Data Collection System

- Stop bar detectors
- Departure lane detectors
- Advance lane detectors

Sensys SNAPS Server
Data fusion, and application deployment

NEMA/2070/170
ED-Conflict Monitor

AP

NETWORK HUB

Cellular

Modem
Selected Test Site: Beaufort, SC
Intersection Volume; daily Variation

2/28/2015, 7AM to 8PM

Peak Period, 4-7 PM

Total volume (veh/cycle)

Total volume (veh/15 minutes)
Approach Volumes & Turning Movements

Peak Period, 4-7 PM

Approach Volume (veh/15 min)

Turning Mov - Leg 2 (veh/15 min)
Seasonal Volume Variation

Median turn movement count by month - EB, Left turn lane

- Feb
- Mar
- Jul
- Aug
- Sep
- Dec

Veh per hr

Time [hr]
Signal Control Data

Green Times per Phase

MAIN STREET: Phases 1, 2, 5, 6

CROSS STREETS: Phases 4, 8
Signal Phase Operations

Wasted green time: time phase is active with no vehicle present and conflicting phase call

Vehicle arrivals: % arrivals on green
Performance: Average Delay (sec/veh)
HCM Level of Service (LOS)

Through movement, Leg 1

Through movement, Leg 2

Left turn movement, Leg 1

Right turn movement, Leg 2
Performance: V/c and LOS

(V/C): (v*C/g*s)
S: sat flow (max discharge rate)
LOS: Level of Service per HCM
HR Data and Timing Plan Development

**Traditional Approach**

1. Local adjustments based on spot observations (complaints)
2. Field data collection of turning movement counts (one day)
3. Apply signal optimization software to develop timing plan(s)
4. Field implementation—fine tuning. Before and after studies (limited)

**Availability of HR Data**

- Assess existing intersection operations
  - Progression (% arrival on green)
  - Capacity (V/c ratio)
  - Delay

- Develop and Implement Improved Settings

- Evaluate performance
  - Approach/intersection/system Over time
Improving Signal Timing Plans

- Volume clustering – best set of volumes for the three timing plans available
- New timing plans reduce intersection signal delay by 10% on average*
Summary: Use of HR data

- Performance measures for operators and travelers
  - Use of existing infrastructure
  - No interference with controller operation

- Improving Signal Timing Plans
  - Performance derived signal settings
  - Robust timing plans

- On-Going/Future Work
  - Traffic volume prediction
  - Safety (red light running)
  - Multimodal (pedestrians, bicycles)
II. Freeway – Arterial Coordination

- Important element of corridor management
- Existing coordination guidelines mostly address institutional issues (example: FHWA Handbook)
- Most approaches consist of scenarios with “flush” signal timing plans on arterials in case of freeway incidents
- Lack of Methodologies for Freeway-Arterial Interactions
- Spillbacks to- from ramps
Background: Freeway Ramp Metering

Control on-ramp flows to preserve freeway capacity

\[
\begin{align*}
\text{MAX} & \sum_{i=1}^{N} X_i \\
\sum_{i=1}^{N} a_{ij} X_i & \leq c_j
\end{align*}
\]

\(X_i\) : input flow rate at on-ramp \(i\), \(N\) : \# on-ramps

\(a_{ij}\) : proportion of traffic entering on-ramp \(i\) going through section \(j\)

\(C_j\) : capacity of freeway segment \(j\)
Freeway Ramp Metering: Impacts

- Excessive delays to on-ramp vehicles
- Spillback to local streets
- Queue override – diminishes ramp metering benefits
On-Ramp Queue Control Regulator

Queue Override

- failed to limit the queue within the limits
- large variation in queue length

Queue Estimation & Control
Application: Los Angeles I-210W

**Improvements:** 6% Travel Time/16% Delay Reduction


Proposed on-Ramp Access Control (1)

Determine the signal settings to avoid queue spillover from ramp metering and result in queue override.

**Constraints**
- Serve the traffic demand on arterial phases
- Arterial link storage (arterial spillback)
- Minimum phase green times
Proposed on-Ramp Access Control (2)

Minimize the ratio of actual and desired green times per signal phase

Desired green time: minimum green time to serve the traffic demand

\[
\sum_k \left( \frac{g_{ik}(t)}{f_{sat,ik}} \right) - 1
\]

- Sum of all intersections
- Desired green time
- Total demand
- Existing queue
- New arrivals
- Saturation flow
- Keep the ratio of actual and desired green times close to 1
Proposed on-Ramp Access Control (3)

Constraints

- Minimum green time constraint: $g_{ik}(t) \geq G_{ik,\text{min}}$
- Cycle length constraint: $\sum_i g_{ik}(t) = C$
- On-ramp storage constraint:

$$\sum_{i \in R} f_{sat,ik} \cdot g_{ik}(t) \leq RA_r$$

Phases for on-ramp access

Total flow onto freeway on-ramp

Available on-ramp storage space
Proposed on-Ramp Access Control (4)

Constraint: Arterial link storage

\[ \sum_{i \in L} q_{i,k+1}(t) \leq (s_L - \sum_{i \in L} q_{i,k+1}(t)) \]

Available queue storage space

Available queue storage space

Existing queue

\[ \sum_{i \in L} q_{i,k+1}(t) \]

Flow into downstream link

Offset

Lost time

Existing queue

\[ f_{sat,i,k} \cdot [o_{ik}(t) + l_{acc}] \]

Downstream queue length

Available queue storage space

Link length
Application: Test Site

Test Site: I-680, San Jose CA

- AIMSUN Microscopic Simulator
Application: Findings

![Bar chart showing % change for FWY Delay, FWY VMT, Arterial Delay, Arterial Delay](chart.png)
Looking Ahead: Connected Vehicles

“Here I am”
V2V and V2I

V2I Example: SPaT message
Application: Dynamic Speed Advisory (source: UC & BMW)
Field Test Results*

Uninformed Driver (Baseline Scenario): no speed recommendation

Informed Driver: follow speed recommendation

Individual Vehicle Priority & Uninformed Driver: no speed recommendation. Intersection adapts timing with individual vehicle priority

Individual Vehicle Priority & Informed Driver: follow speed recommendation. Intersection adapts timing with individual vehicle priority

<table>
<thead>
<tr>
<th></th>
<th>Uninformed Driver</th>
<th>Informed Driver</th>
<th>Uninformed Driver &amp;APIV</th>
<th>Informed Driver &amp;APIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (L/100KM)</td>
<td>10.23</td>
<td>8.84</td>
<td>8.28</td>
<td>7.33</td>
</tr>
<tr>
<td>Improvement</td>
<td>Base Scenario</td>
<td>-13.60%</td>
<td>-19.10%</td>
<td>-28.40%</td>
</tr>
</tbody>
</table>

*https://www.fhwa.dot.gov/multimedia/research/advancedresearch/index.cfm

Looking Ahead: Beyond Connected Veh
Back Up Slides
Measuring Saturation flow

Through/ Left turn shared

Left turn lane

Statistics of saturation flow rates.

[Graphs showing saturation flow rates for through/ left turn shared and left turn lane, with histograms and cumulative distribution functions (CDFs).]
Performance: Delay (Analytical solution)

Leg 2 through movement

\[ d = \frac{C(1 - \frac{g}{C})^2}{2(1 - \frac{g}{C} \times \frac{V}{c})} \]

- \( d \): Delay (sec/veh)
- \( C \): Cycle length
- \( g \): green time
- \( V/c \): Volume to capacity ratio
ALINEA Algorithm

- Local traffic-responsive strategy – closed loop

\[ r(k) = r(k-1) + K_R [O_c - O_{out}(k)] \]

- \( r(k) \) is the metering rate in time step \( k \);
- \( r(k-1) \) is the metering rate in time step \( k-1 \);
- \( K_R \) is the regulator parameter (constant);
- \( O_{out}(k) \) is the current occupancy measurement.
Non-Recrrent Congestion: Diversion Strategies

Key Issues:
- Freeway Operating conditions (congestion level)
- Incident characteristics (location, severity)
- Characteristics of freeway control & freeway surveillance
- Characteristics of traveler information system
- Characteristics of parallel arterial(s)

Incident at Bottleneck

Incident Upstream of Bottleneck
Amount of Diverted Volume?

\[ dV_i = \frac{RC_i}{X_i} \times 100 \]

where:
- \( DV_i \) : additional traffic volume on approach \( i \) (%)
- \( X_i \) : volume/capacity (degree of saturation) on approach \( i \) (%)
- \( RC_i \) : reserve capacity on approach \( i = 1 - X_i \)
Control Strategies: Non-Recurrent Congestion

- Inhibit Metering
  - maximize flow from arterial into freeway
  - In case of incidents upstream of the on-ramp
Results (2)