Coordination of Freeway Ramp Meters and Arterial Traffic Signals (FOT)

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Outlines

• Project Review – SOW
• Work Plan
• Site Selection
• Field Data Collection and Processing
• Control Strategy
• Heuristic Coordination Strategy
• Simulation Development
• Concept of Operation
• Traffic Signal Control Interface with 2070
• Next Step
Project Review: Objectives – Long Term

• Large scale system problem:
  – Freeway corridor traffic and control
  – Related arterial(s) intersections traffic and control
  – Dynamic interaction between the two

• To resolve any (or potential) inconsistency and conflict between the two traffic control systems;

• To balance the traffic flows overall system for accommodating more traffic in peak hours;

• To eventually minimize Total Travel Time (TTT) system wide and to improve mobility, reduce emission and energy consumption;
Project Review: Objectives – Short Term

• To coordinate one onramp meter and signal control at the adjacent intersection
• To identify
  – Where and when coordination is necessary
  – Where and when is feasible
  – Technical hurdles in coordination of the two subsystems
  – Conflict of interests between the two and how to resolve
• To hopefully improve the performance of the system in some aspect in some level which could be quantified;
• To set an example for overcoming any hurdle(s) caused by multiple jurisdictions;
• To laid down a good foundation for a large project involving a freeway corridor and related arterial corridor(s) if it is successful.
Work Plan

1. Literature Review
2. Coordination Strategy Development
3. Site Selection
4. Microscopic Simulation for Selected Site
5. Data Accessing
6. Interface with TMC Computer
7. Field Implementation
8. System Integration
9. System Tuning
10. Limited Time Field Test
11. Data Analysis for Evaluation
Site Selection – Location and Neighbor Ramps

San Jose Airport

Taylor

Julian

I280 Junction
Site Selection – Overall System
Site Selection – All Movements at Taylor Intersection
Site Selection – All Movements of San Pedros St
Field Data Collection and Processing

• Video Data at Taylor Intersection
  – 04/03/12 (Tuesday) ~ 75 min from 4:50pm
  – 05/14/12 (Monday) ~ 80 min from 4:40pm
  – 05/17/12 (Thursday) ~ 90 min from 4:30pm
• Video Data Processing:
  – Manually Counted the Following Traffic State Parameters
    ➢ Vehicle count for each movement of Taylor Intersection
    ➢ Onramp Time Series Data
      – Inflow count
      – Outflow count
      – Ramp Meter Timing
      – Onramp HOV Lane vehicle count
    ➢ All aggregated to 5min and used for calibration
  – Failed to get the queue length at intersection
Field Data Collection and Processing

• Apr 03, vehicle count from 5pm to 6pm
Simulation modeling

- Road Network Modeling
  - Intersection: Taylor, San Pedro.
  - Freeway: both directions, Taylor and Julian.
  - Lane Extension for Total Travel Time Estimation

- Driver Behavior Model Selection
  - Aimsun default model: Gipps model

- Demand (OD table) Modeling base PeMS Data and Video Data
  - 5 min data;
  - General vehicles and HOV vehicles;

- Parameter Selection in Modeling
  - Reaction time: 0.6/0.7 sec
  - Reaction time at stop: 1.2 sec
Model Calibration

- Freeway Section:
  - Comparison with PeMS 5min Data
- Arterial Intersection:
  - Compared with all movement video data
- Calibration Results Based on
  - 10 Replication Runs with Different Random Seeds
  - Intuitive View from Plot
  - Statistical Analysis
Model Calibration

• Flow
  – May 17 data
    ➢ Freeway percentage: 73% (70%~80%), std = 3.5%
    ➢ Intersection percentage:
      – best movement: 99.5% (95%~100%), std = 1.6%, left-turn to NB on-ramp
      – Worst movement 67% (55%~80%), std = 8.2%, left-turn to SB on-ramp
  – Apr 03 data
    ➢ Freeway percentage: 75% (67%~83%), std = 6.8%
    ➢ Intersection percentage:
      – best movement 91.7% (83.3%~100%), std = 4.3%, left-turn to NB on-ramp
      – Worst movement 35% (25%~50%), std = 9.5%, left-turn to SB on-ramp
Model Calibration

• Occupancy
  – Compute mean square root error
  – Aggregated occupancy in 5min
  – Freeway: detector at upstream of Taylor SB on-ramp, 1 lane available
  – May 17 data: 9.9% (9.3%~10.2%), std = 0.35%
  – Apr 03 data: 8.3% (7.7%~8.8%), std = 0.44%

• Speed
  – Compute mean square root error
  – Aggregated speed in 5min
  – Freeway: detector at upstream of Taylor SB on-ramp, 1 lane available
  – May 17 data: 14.1% (13.8%~14.4%), std = 0.21%
  – Apr 03 data: 10.4% (9.7%~11.0%), std = 0.44%

• Bottleneck
  – Merge area of Taylor on-ramp

• On-ramp merge behavior
  – Looks acceptable
Model Calibration

• Freeway, May 17

![Graph showing Freeway Flow, Occupancy, and Speed over time]

Legend:
- Freeway Flow (vph)
- Freeway Occupancy (%)
- Freeway Speed (vph)

Time (5min) vs. Freeway Flow (vph), Occupancy (%), Speed (vph)
Model Calibration

- **Intersection, May 17**

![Graph showing traffic flow at Taylor intersection, comparing video (blue), simulated (red), and error bound (green).](image-url)

**Legend:**
- Blue line: Video data
- Red line: Simulated data
- Green line: Error bound

**Axes:**
- Y-axis: Left Flow (vph) for EB (East to West) and WB (West to East)
- X-axis: Time (5min)
Model Calibration

- Freeway, Apr 03

![Graph showing Freeway Flow, Occupancy, and Speed over time.](image-url)
Model Calibration

- Intersection, Apr 03

Intersection@Taylor, blue--video, red--simulated, green--error bound
Control Strategy Implementation

• Intersection: Optimal Timing Strategy
  – Minimize the weighted gap between desired green and given green for each movement;
  – Consider the minimum green time constraint;
  – Consider the storage of on-ramp;
  – Use a fix cycle length during the control period;
  – Use the same order of phases as current timing plan;
  – Green duration updates every cycle.

• Freeway: ALINEA
  – Adaptive ramp metering;
  – Based on estimation of traffic occupancy in merging area;
  – Use the measurement from detector located upstream of onramp, the PeMS detector;
  – Metering rate updates every 30sec;
Control Strategy Implementation

• Onramp dynamics

\[ U_{on}(j) = U_{on}(j-1) + \sum_{i_r \in \Phi_r} f_{i_r,sat}(j) \cdot \beta_{i_r}(j) \cdot g_{i_r}(j) - C(j-1) \cdot r_j \]

• Intersection

\[ U_i(j) = U_i(j-1) + C(j) \cdot d_i(j) - f_{i,sat}(j) \cdot g_i(j) \]

\[ U \]: queue length
\[ C \]: cycle length
\[ f_{sat} \]: saturation flow
\[ g \]: designed green length
\[ r \]: metering rate
\[ d \]: demand
Control Strategy Implementation

• Constraints:

(1): \( g_i(j) \geq G_{\text{min},i}, \ i \in \phi \)

(2): \( g_i(j) \leq \frac{[U_i(j-1) + d_i(j) \cdot C(j)]}{f_{\text{sat},i}(j)}, \ i \in \phi \)

(3): \( \sum_{i_r \in \phi_r} f_{i_r}(j) \cdot \beta_{i_r}(j) \cdot g_{i_r}(j) \leq RA(j) \)

(4): \( \sum_{i \in \phi} g_i(j) = C(j) \)

(5): \( g_1(j) + g_2(j) = g_5(j) + g_6(j) \)

(6): \( U_i(j) \leq U_{i,\text{max}} \)
Control Strategy Implementation

- **Linear Programming**

\[
J(j) = \sum_{i} \mu_i \left[ \frac{U(j-1) + d_i(j) \cdot C(j)}{f_{sat,i}(j)} - g_i(j) \right]
\]

\[
\min_{\text{g}(j)} J(j)
\]

\[
g(j) = \left[ g_1(j), \ldots, g_{N_g}(j) \right]
\]

- **Quadratic Programming**

\[
J_2(j) = \sum_{i} \mu_i \left( \frac{U(j-1) + d_i(j) \cdot C(j)}{f_{sat,i}(j)} - g_i(j) \right)^2
\]

\[
\min_{\text{g}(j)} J_2(j)
\]
Performance Analysis

• Parameters used
  – TTD (Total Travel Distance)
  – TTT (Total Travel Time)
  – Accumulated average delay in hours per km
  – Accumulated average stop time in hours per km
  – Accumulated average number of stops per km

• Results for default control and optimal timing + ALINEA RM
  – Mixed up: some replications are better and some are worse
  – Depending calibration results for the calibration: better calibration results usually have better performance in optimal timing strategy + ALINEA RM
Heuristic Coordination Strategy – Freeway Priority

• Phase 1: Freeway Mainline with Low Traffic volume (freeway mainline \(\text{Occ} \leq \sigma_1\); e. g. \(\sigma_1 = 4\%\))
  – Traffic to freeway has priority.
  – Large metering rate.
  – Large weights for movements to onramp.

• Phase 2: Freeway Mainline with Medium Traffic to high traffic volume (freeway mainline - \(\sigma_1 < \text{Occ} \leq \sigma_2\); e. g. \(\sigma_2 = 9\%\) critical occupancy): Keep freeway at its capacity flow as long as possible
  – Traffic on freeway has priority.
  – Adaptive metering to keep freeway operating near capacity.
  – Fully use the onramp storage.
  – Balance the green times of all movements.
Heuristic Coordination Strategy – Freeway Priority

• Phase 3: Freeway Mainline with High Traffic Volume (\(\sigma_2 < \text{Occ} \leq \sigma_3\); e.g. \(\sigma_3 = 20\%\)) if traffic congestion back-propagate from downstream Traffic to freeway:
  – Freeway mainline has priority.
  – Adaptive metering to prevent traffic breakdown.
  – Fully use onramp storage.
  – Balance the green times of all movements.
  – Reduce weights for movements feeding to onramp.

• Phase 4: Freeway Mainline with Traffic over capacity
  – Fully use onramp storage.
  – Possible to use intersection storage.
  – Further reduce green times/weights for movements to onramp.

• Phase 5: Freeway Mainline with Saturated Traffic (\(\text{Occ} > \sigma_4\))
  – Low metering rate.
  – Possible to use the upstream intersection storage.
Simulation Result--Improve

Accumulated system performance; default (b), optimal control (r)

Blue: default
Red: proposed
System accumulated average performance per km, default (b); optimal control (i)

Blue: default
Red: proposed
Simulation Result--Worse

Accumulated system performance; default (b), optimal control (r)

Blue: default
Red: proposed
Blue: default
Red: proposed

System accumulated average performance per km, default (b); optimal control (i)
ConOps: D4 Controller Running TSCP without Master
**ConOps:** Traffic Signal Control Interface with 2070 Controller

- Uses AB3418 protocol (a subset of NTCIP) over COM1 serial port
- Uses laptop/PC104 host in place of field master
- Currently is a simple utility for sending byte strings to serial port
- Eventually will use our publish/subscribe database (db_slv©) to interface to send timing from optimal control algorithm
- Can change max and min green for a given phase
ConOps: Traffic Signal Control Interface with 2070 Controller

• AB3418: what is it?
  – Assembly Bill No. 3418 is intended to facilitate the coordination of traffic signals operated by different jurisdictions.
  – The AB 3418 standard protocol supports remote control and monitoring functions only.
  – The control function is to enable the maintenance of signal coordination with adjacent intersections.
  – The monitoring function is to allow verification of controller operation.
**ConOps:** Traffic Signal Control Interface with 2070 Controller

- CTNET Field Protocol Specification - AB3418 Extended (AB3418E)
  - Change maximum and minimum green time
  - Change offset
Next Step

- Further traffic data collection at intersection including San Pedros
- Model calibration with new data
- Fine tuning control and coordination strategies for performance improvement
- Generalization to freeway and arterial corridors with multiple onramps and intersection
Thank you!