Improving Traffic Signal Operations with High-Resolution Data

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Active Traffic Signal Management Workshop
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Outline

- MnDOT Metro District
- MnDOT Signal Operations Practice
- MnDOT Technical Needs

- High-resolution Data Collection
- Arterial Performance Measurement
- Conclusion and Future Works
MnDOT Metro District

- 700 signals
  - 650 on comms
    - 200 on i2/TACTICS
    - 450 dial-up (Aries)
  - 200 intersections viewed via cameras
  - Staff of 23 (maintenance & operations)
MnDOT’s System
Signal Timing & Optimization

• Major Zones (Projects)
  – Retimed every 3 yrs
    • 5-7 plans per day – Time-of-day
    • Consultant develop, MnDOT implemented
  – Performance Measures
    • Before/after evaluation travel times
    • Synchro/SimTraffic outputs
      – Delays, stops, travel times
    • Air quality (CMAQ)
Signal Timing & Optimization

- Minor Zones - Retimed every 5 yrs
  - MnDOT developed & implemented
  - Minimal evaluation performed
    - Synchro/SimTraffic
# MnDOT Metro Major Expressways

## MAJOR CORRIDOR PROJECTS: retiming every 3 years

<table>
<thead>
<tr>
<th>Hwy</th>
<th>Location</th>
<th># signals</th>
<th>Last retimed</th>
</tr>
</thead>
<tbody>
<tr>
<td>5, 41</td>
<td>Chaska to Eden Prairie</td>
<td>29</td>
<td>Feb '09</td>
</tr>
<tr>
<td>7</td>
<td>Minnetrista to St. Louis Park</td>
<td>31</td>
<td>Aug '11</td>
</tr>
<tr>
<td>13</td>
<td>Prior Lake to Eagan</td>
<td>44</td>
<td>Sep '09</td>
</tr>
<tr>
<td>36, 51</td>
<td>Roseville, North St. Paul to Stillwater</td>
<td>26</td>
<td>Apr '09</td>
</tr>
<tr>
<td>55</td>
<td>Medina to Golden Valley</td>
<td>39</td>
<td>Sep '11</td>
</tr>
<tr>
<td>55, 149, 3</td>
<td>Mendota Heights to Rosemount</td>
<td>24</td>
<td>Aug '10</td>
</tr>
<tr>
<td>61</td>
<td>Maplewood to Hugo</td>
<td>23</td>
<td>Jan '09</td>
</tr>
<tr>
<td>65</td>
<td>Columbia Heights to East Bethel</td>
<td>33</td>
<td>Jun '09</td>
</tr>
<tr>
<td>169, 10, 47</td>
<td>Champlin to Ramsey</td>
<td>25</td>
<td>Jun '07</td>
</tr>
<tr>
<td>212</td>
<td>Flying Cloud Dr, Eden Prairie Ring Rd</td>
<td>30</td>
<td>Mar '10</td>
</tr>
<tr>
<td>252, 47</td>
<td>Brooklyn Park, Columbia Hts to Fridley</td>
<td>24</td>
<td>Oct '08</td>
</tr>
<tr>
<td>494, 35W</td>
<td>Amer. Blvd, 76th/77th, N/S Cross St's</td>
<td>43</td>
<td>Jun '11</td>
</tr>
</tbody>
</table>

- **12 projects**
- **371 signals**

## MINOR CORRIDOR PROJECTS: retiming every 5 years

<table>
<thead>
<tr>
<th>Hwy</th>
<th>Location</th>
<th># signals</th>
<th>Last retimed</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>CR 50 to Hwy 50 in Farmington</td>
<td>2</td>
<td>never</td>
</tr>
<tr>
<td>5</td>
<td>Granada Ave to Ideal Ave in Oakdale</td>
<td>5</td>
<td>never</td>
</tr>
<tr>
<td>5</td>
<td>58th St to Croixwood Blvd in Stillwater</td>
<td>7</td>
<td>Oct '11</td>
</tr>
<tr>
<td>5</td>
<td>Oak Ave to CR 59 in Waconia</td>
<td>7</td>
<td>Apr '11</td>
</tr>
<tr>
<td>8</td>
<td>Grewey Ave to Oak St in Chisago Cty</td>
<td>10</td>
<td>Apr '11</td>
</tr>
<tr>
<td>10</td>
<td>CR 7 N and S Ramps in Anoka</td>
<td>2</td>
<td>never</td>
</tr>
<tr>
<td>10</td>
<td>Foley NR to 99th Ave in Coon Rapids</td>
<td>3</td>
<td>never</td>
</tr>
<tr>
<td>10</td>
<td>Robinson to Northdale in Coon Rapids</td>
<td>3</td>
<td>Aug '07</td>
</tr>
</tbody>
</table>

- **97 projects**
- **338 signals**

*(actual spreadsheet continues, listing all 97 minor corridor projects)*
Mn/DOT Metro District Signals

Percent of signals retimed within target

Calendar year

PROPOSED PERFORMANCE TARGET

Percent of major corridor signals retimed ≤ 3 years ago

Percent of minor corridor signals retimed ≤ 5 years ago
How are we doing
Do we know?

- Ask staff –
- Ask public –
- Ask management -
Freeway Management System in Metro

- Ramp metering, camera surveillance
- Changeable Message Signs
  - *Travel Times*
- Incident Management
- Service Patrols
- Traveler Information/88.5 Traffic Radio/511
  - *Congestion Map*
- Lane Control Signals/Value Pricing
• Usually traveler information is available for freeways, so far NO arterial travel information is available.

• New technologies that uses smart-phone as traffic probe is promising but not mature.
Arterial Performance Measures

Public/Management
- Map (1000 words)
- Travel Times
- Something that’s easily understood
  - Stops/mile
  - Signals/red

Operations
- Quick look at health of system
- Useable
- Use available data
- Viewable over time
- View – corridor, intersection, approach
Technology Development Roadmap

High-Resolution Data Collection

Performance Measurement

Operational Improvement

Real-time Control
Technical Requirements

- **Passive** data collection from existing infrastructure
- **Compatible** with different detector, controller and cabinet settings
- **Capable** of handling congested traffic conditions
Ideally, for an Intelligent System

If you cannot tell the system performance yesterday, you cannot hope to manage your system today.
SMART-Signal: Systematic Monitoring of Arterial Road Traffic Signals

- An automatic and continuous data collection system from existing traffic signals
- A performance measurement system for intersection queue length and arterial travel time, especially under congested traffic conditions
- A performance tuning system for optimization of traffic signal parameters
1st Gen. Data Collection
2nd Gen. Data Collection

Plug-and-play Implementation:
1. Plug in SDLC Port.
2. Plug in power adapter.
3. Plug in Ethernet connection.
4. Turn on the power.

To debug in the field:
1. Connect your laptop with the device using the Serial Port.
2. Log into the field device using the Linux system.
Event-Based Data

Detector #8 on at 08:09:15.012; Vacant time is 7.902s

Green Phase #3 off at 08:09:16.761; Green duration time is 29.389s

Detector #9 off at 08:09:18.307; Occupy time is 0.687s

Yellow Phase #3 off at 08:09:20.244; Yellow duration time is 3.482s

Green Phase #1 on at 08:09:23.242; Red duration time is 172.806s
Research Implementation Sites

- 11 intersections on France Ave. in Bloomington (March 07 – June 09)
- 6 intersections on TH55 in Golden Valley (Feb. 08 – Sept. 09)
- 3 intersections on PCD in Eden Prairie (Current)
- 6 intersections in Pasadena, CA (Iteris, Current)
- 13 intersections on TH13 (Current)
- 10 intersections on TH55 (January 2012, Expected)
Performance Measurement Algorithms

- **Queue length estimation**
  - Delay, Level of Services, number of stops

- **Identification of oversaturated conditions**
  - Oversaturation Severity Index (OSI)

- **Travel time estimation**
  - Personal trip delay, number of stops, carbon footprint on travel
Queue Length Estimation

- Instead of traditional input-output approach, we estimate queue length by taking advantage of queue discharge process
- Based on LWR shockwave theory
Queue Length Estimation

- Utilize the data collected by advance detector
- Identify Critical Points: A, B, C
Break Point Identification from High-Resolution Detector Data

Detector Occupation Time

Time Gap Between Consecutive Vehicles

Pattern I: Capacity condition \((q_m, k_m)\)

Pattern II: Free flow arrival \((q^n_m, k^n_m)\)

Break Point A

Break Point B

Break Point C
Travel Time Estimation

- Track a virtual probe vehicle
  - Signal delay
  - Queuing delay
  - Acceleration/deceleration/no-speed-change

\[ d_1, d_2, \ldots, d_n \]
Maneuver Decision Tree

- Safe Space Headway?
  - Yes
  - Queue Ahead?
    - Yes
    - Desired Speed
    - Speed of Last Queued Vehicle
    - Zero Speed
  - No
  - Desired Speed
- Signal Status
  - Green
  - Yellow
  - Red
  - Able to Cross?
    - Yes
    - Desired Speed
    - No
    - Desired Speed

Self-Correction Property

The diagram illustrates the motion of two vehicles, one faster and one slower, with their respective positions marked by $x_f$ and $x_s$. The diagram shows the progression of time $t$ and the corresponding positions $T_a, T_b, T_c, T_d$. The faster vehicle's path is indicated by the red line, and the slower vehicle's path is shown by the blue line, with points marked as $a, b, c, d$. The stop-line is indicated at the far right end of the diagram.
Field Tests on TH55 in Minneapolis

- Advanced detectors
- Stopbar detectors
- Additional detectors
Independent Evaluation of Performance Measures on TH55

- By Alliant Engr. Inc
- Queue length
  - Manually count the vehicles (Two persons per approach)
  - Four peak hours (July 22\textsuperscript{nd} and 23\textsuperscript{rd}, 2009)
- Travel time
  - Floating car method with GPS
  - Four peak hours (July 22\textsuperscript{nd} and 23\textsuperscript{rd}, 2009)
  - More than 70 runs
Results – Maximum Queue Length

July 22nd for TH55WB at Rhode Island Intersection (AM)

July 23rd for TH55WB at Rhode Island Intersection (AM)
Results – Maximum Queue Length

MaxQL-Estimation vs. MaxQL-Observation (AM & PM)

Observation (ft)

Estimation (ft)

<table>
<thead>
<tr>
<th>Observation (ft)</th>
<th>Estimation (ft)</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
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<tr>
<td>200</td>
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<td>1500</td>
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<tr>
<td>1600</td>
<td>1600</td>
</tr>
</tbody>
</table>

+10% and -10% deviations from the estimated values.
Results – Travel Time

Travel Time Estimation vs. Observation (July 22 & 23)

Observation (seconds)

Estimation (seconds)

+10%

-10%
Identification of Spillover

Detector Occupancy Time for Westbound TH 55 at Rhode Island Ave.

QOD caused by red phase
QOD caused by spillover

Distance (feet)

7800
7600
7400
7200
7000
6800

17: 12: 20
17: 13: 03
17: 13: 47
17: 14: 30
17: 15: 13

Time

Stop-bar Detector
Advance Detector

Occupancy Time of Stop-bar Detector
Occupancy Time of Advance Detector
Queue Profile for Downstream Intersection

Queue Length Profile at the Intersection of Winnetka

Distance (feet) vs. Time

$L=842$ ft
Expanded Capability of SMART-SIGNAL

- Fine-tuning signal timing parameters
  - Offsets fine-tuning

- Adaptive control under oversaturated conditions
  - Integrated Corridor Management
  - Large directional flow diverted from freeway
Lessons Learned

- Although traffic is traditionally modeled as “continuous flow”, traffic, after all, is discrete.
- Measuring traffic flow parameters using the data collected at the individual vehicle level
- Don’t aggregate data before useful information being derived
- Technological advances support such data collection at affordable prices
Closing Remarks: Let’s Raise the Floor and Improve the State-of-the-Practice

- There are no reason that we can not monitor or archive traffic signal data.
- Traffic signal parameters can be automatically fine-tuned based on the archived data.
- Adaptive signal control should work for both undersaturated and oversaturated conditions and it should be the norm.
THANK YOU!

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