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

<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>

**MAJOR CORRIDOR PROJECTS: retime every 3 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>Greeway 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>

**MINOR CORRIDOR PROJECTS: retime every 5 years**

<table>
<thead>
<tr>
<th>Hwy</th>
<th>Location</th>
<th># signals</th>
<th>Last retimed</th>
</tr>
</thead>
</table>

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

Percent of signals retimed within target

PROPOSED PERFORMANCE TARGET

Percent of major corridor signals retimed ≤ 3 years ago

Percent of minor corridor signals retimed ≤ 5 years ago

Calendar year
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.
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

(a) Detector Occupation Time

(b) Time Gap Between Consecutive Vehicles

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

Pattern II: Free flow arrival \((q_a', k_a')\)

Break Point C
Travel Time Estimation

- Track a virtual probe vehicle
  - Signal delay
  - Queuing delay
  - Acceleration/deceleration/no-speed-change
Maneuver Decision Tree
Self-Correction Property
Field Tests on TH55 in Minneapolis

Boone Ave.  Winnetka Ave.  Glennwood Ave.

Rhode Ave.  Douglas Dr.

TH 55  2635 ft  842 ft  1777 ft  TH 55

400 ft

Phase 2

- Advanced detectors
- Stopbar detectors
- Additional detectors

Phase 6
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 22nd and 23rd, 2009)

• Travel time
  - Floating car method with GPS
  - Four peak hours (July 22nd and 23rd, 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)
Results – Travel Time

![Travel Time Estimation vs. Observation (July 22 & 23)](image-url)
Identification of Spillover

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

Distance (feet)

7800
7600
7400
7200
7000
6800


Time

QOD caused by red phase
QOD caused by spillover

Stop-bar Detector
Advance Detector

Occupancy Time of Stop-bar Detector
Occupancy Time of Advance Detector

$\nu_2$

$\nu_2$
Queue Profile for Downstream Intersection

Queue Length Profile at the Intersection of Winnetka

Distance (feet)  Queue Length Profile at the Intersection of Winnetka

1800
1500
1200
900
600
300
0

17: 05: 17 17: 12: 29 17: 19: 41 17: 26: 53 17: 34: 05 17: 41: 17

$L=842 \text{ ft}$
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 under-saturated and oversaturated conditions and it should be the norm.
Acknowledgements
THANK YOU!

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SMART-Signal Web Site:
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