Signal System Performance Measures for Prioritizing Resources and Assessing Outcomes

Chris Day
Purdue University
cmday@purdue.edu

Active Traffic Management Workshop
December 13, 2011
Merrillville, Indiana
Question

• How should the agency program resources to improve traffic control?

• Where current control is providing the least satisfactory performance

• Impossible to know without performance measures

• Impractical to compile performance measures without automation
Traffic Signal Timing Process

I. Define Objectives, Assess and Prioritize activities by Time of Day and location

II. Assembly relevant data to support timing and documentation objectives

III. Software Modeling

IV. Timing Design and Documentation

V. Deployment

VI. Assess

Theme of workshop and talk
Floating car (existing method of “statistical analysis”)

How do we correct deficiencies?

What about side streets?

Can we scale across different times of day, days of week, locations in our system?
Aspects of signal operations

**HCM Delay Equation**

\[ d = d_1(PF) + d_2 + d_3 \]

\[ d_1 = \frac{0.5C\left(1 - \frac{g_i}{C}\right)^2}{(1 - \min(1, X_i)g_i/C)} \]

\[ X_i = \frac{v}{s} \frac{C}{g_i} \]

**Progression Factor**

\[ PF = \frac{(1 - P)f_{PA}}{1 - g / C} \]

\[ P = \text{Percent arriving on green} \]

\[ g = \text{green time (s)} \]

\[ C = \text{cycle length (s)} \]

\[ X = \text{volume to capacity ratio} \]

\[ v = \text{flow rate (veh/h)} \]

\[ s = \text{saturation flow rate (veh/h)} \]
Capacity Utilization
Low capacity utilization
High capacity utilization (Split Failures)

Cumulative Frequency of V/C Ratio

**Cumulative Frequency**

<table>
<thead>
<tr>
<th>V/C Ratio</th>
<th>Cumulative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>1.00</td>
<td>1.50</td>
</tr>
<tr>
<td>1.50</td>
<td>2.00</td>
</tr>
</tbody>
</table>

**V/C Ratio**

0 0.5 1.0 1.5 0 0.5 1.0 1.5 0 0.5 1.0 1.5

**Cumulative Frequency**

0 0.5 1.0 1.5 0 0.5 1.0 1.5 0 0.5 1.0 1.5

P1 P2 P3 P4 P5 P6 P7 P8

**Time of Day**

0:00 6:00 12:00 18:00 24:00 0:00 6:00 12:00 18:00 24:00

Volume Flow Rate

0 0.5 1.0 1.5 0 0.5 1.0 1.5

**Cumulative Frequency**

0 0.5 1.0 1.5 0 0.5 1.0 1.5 0 0.5 1.0 1.5

P1 P2 P3 P4 P5 P6 P7 P8
Can we use V/C ratio to predict split failures?

(a) Beginning of green, $v/c = 0.55$

(b) End of green, $v/c = 0.55$

(c) Beginning of green, $v/c = 1.25$

(d) End of green, $v/c = 1.25$
Can we use V/C ratio to predict split failures?

As V/C increases, split failure becomes more likely

<table>
<thead>
<tr>
<th>v/c Range</th>
<th>Observations</th>
<th>Confirmed Split Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>v/c ≥ 1.1</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>1.0 &lt; v/c ≤ 1.1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>0.9 &lt; v/c ≤ 1.0</td>
<td>13</td>
<td>5</td>
</tr>
</tbody>
</table>

**Legend:**
- x: Visually confirmed as not split failure
- •: Visually confirmed as split failure
System Level Count of Split Failures (v/c > 1)
(Northbound & southbound left turns highlighted)

Where should direct resources to target problems in the system?
Degree of Intersection Saturation

\[ X_c = \sum_i (v/s)_{ci} \left( \frac{C}{C - L} \right) \]

\((v/s)_c \rightarrow \text{Critical Ratio of Volume to Saturation}\)
\(C \rightarrow \text{Cycle Length (s)}\)
\(L \rightarrow \text{Lost Time (s)}\)
Intersection Saturation

Simplified equation for Dual-Ring, Eight-Phase Intersection:

\[
X_C = \left[ \max \left( \frac{v_5}{s} \cdot \frac{v_6}{s} \right)_{12}, \left( \frac{v_7}{s} \cdot \frac{v_8}{s} \right)_{56} \right] + \max \left( \left( \frac{v_{34}}{s} \cdot \frac{v_{78}}{s} \right) \right) \left( \frac{C}{C - L} \right)
\]
What value of \( X_C \) do we consider critical?

\[ g_{s,\text{min}} = (C - L)(1 - X_T), \quad 0 \leq X_T \leq 1 \]

\( X_T \) = Threshold value of \( X_C \) where we expect could improve operation by adjusting splits (higher number ~ more optimistic)

\( g_{s,\text{min}} \) = minimum slack green time

\( C \) = Cycle Length

\( L \) = Lost Time (clearance intervals)
$X_c$, all cycles

Unlikely to have spare capacity

Likely to have spare capacity
$X_C$, Only cycles with split failures

- $X_C = 0.75$
- $X_C = 0.85$

- Probably not correctable
- Possibly correctable
- Probably correctable
## Example system report outcomes

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Phase</th>
<th>Total split failures</th>
<th>Correctable ($X_T \leq 0.75$ criteria)</th>
<th>Correctable ($X_T \leq 0.85$ criteria)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>34</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>236</td>
<td>93</td>
<td>158</td>
</tr>
<tr>
<td>1002</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>256</td>
<td>103</td>
<td>209</td>
</tr>
<tr>
<td>1003</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>69</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td>1004</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>141</td>
<td>88</td>
<td>124</td>
</tr>
</tbody>
</table>

Where is the greatest opportunity to improve operations by rebalancing splits?
System Report: Capacity Utilization

- High Split Failures with low opportunity for re-allocating green times
- High Split Failures with moderate opportunity for re-allocating green times
- High Split Failures with substantial opportunity for re-allocating green times
Impact of Changes to Control Parameters

Quality of Progression
Why poor progression?

1. Random arrivals – no upstream coordination – no platoons
Why poor progression?

2. Poor offset (Adjusted)

P = 38%
Poor offsets or random arrivals?

\[ P_{\phi,a} = \frac{N_{g,\phi,a}}{N_{\phi,a}} \]

Pretty good

Pretty bad

Why?
Quality of Progression

Vehicle Arrival Detection

Coordinated

- Red
- Yellow
- Green

Time of day

- 12:00:00
- 12:02:00
- 12:01:10

Time in cycle

- 0 sec
- 50 sec
- 90 sec
- 120 sec
- 70 sec

Green window

Vehicle Arrival Detection

Detection

Arrival
“Purdue Coordination Diagram”

Arrivals in Green

Arrivals in Red

Primary platoon

Secondary platoon

\[
P_{\phi,a} = \frac{N_{g,\phi,a}}{N_{\phi,a}}
\]
Corridor

Random

OK

good

Opportunity for Improvement

bad

good
Corridor

Little Opportunity for Improvement

Random

good

good

good

good

Random
System Report: Progression Quality

- Red: Low opportunity for improvement
- Yellow: Moderate opportunity for improvement
- Green: High opportunity for improvement
Impact of Optimization

Before Offset Optimization  After Offset Optimization
Before
After

Random

better

good

good

good

good

SB, SR 37 / SR 32

NB, SR 37 / SR 32

OK

SB, SR 37 / Pleasant

NB, SR 37 / Pleasant

good

SB, SR 37 / Town & Country

NB, SR 37 / Town & Country

good

SB, SR 37 / Greenfield

NB, SR 37 / Greenfield

good
<table>
<thead>
<tr>
<th>Intersection</th>
<th>Movement</th>
<th>MOE</th>
<th>June 06, Actual</th>
<th>June 06, Predicted After Offset Adjustment</th>
<th>July 25, Actual</th>
<th>July 18, Actual*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR 37 &amp; SR 32</td>
<td>Northbound</td>
<td>N&lt;sub&gt;g&lt;/sub&gt;</td>
<td>1755</td>
<td>1425</td>
<td>1472</td>
<td>1810</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>59.6%</td>
<td>48.4%</td>
<td>54.9%</td>
<td>56.8%</td>
</tr>
<tr>
<td></td>
<td>Southbound</td>
<td>N&lt;sub&gt;g&lt;/sub&gt;</td>
<td>1702</td>
<td>1702</td>
<td>1544</td>
<td>1659</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>41.2%</td>
<td>41.2%</td>
<td>42.4%</td>
<td>39.0%</td>
</tr>
<tr>
<td>SR 37 &amp; Pleasant St.</td>
<td>Northbound</td>
<td>N&lt;sub&gt;g&lt;/sub&gt;</td>
<td>1628</td>
<td>2655</td>
<td>2741</td>
<td>2995*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>40.1%</td>
<td>65.5%</td>
<td>76.0%</td>
<td>76.6%*</td>
</tr>
<tr>
<td></td>
<td>Southbound</td>
<td>N&lt;sub&gt;g&lt;/sub&gt;</td>
<td>3180</td>
<td>3674</td>
<td>3371</td>
<td>3471*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>52.9%</td>
<td>61.2%</td>
<td>62.7%</td>
<td>63.0%*</td>
</tr>
<tr>
<td>SR 37 &amp; Town and Country Blvd.</td>
<td>Northbound</td>
<td>N&lt;sub&gt;g&lt;/sub&gt;</td>
<td>3114</td>
<td>2961</td>
<td>2974</td>
<td>3507</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>79.5%</td>
<td>75.9%</td>
<td>81.0%</td>
<td>78.7%</td>
</tr>
<tr>
<td></td>
<td>Southbound</td>
<td>N&lt;sub&gt;g&lt;/sub&gt;</td>
<td>3441</td>
<td>3056</td>
<td>2875</td>
<td>3007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>80.2%</td>
<td>71.1%</td>
<td>72.6%</td>
<td>73.0%</td>
</tr>
<tr>
<td>SR 37 &amp; Greenfield Ave.</td>
<td>Northbound</td>
<td>N&lt;sub&gt;g&lt;/sub&gt;</td>
<td>1678</td>
<td>2917</td>
<td>2827</td>
<td>3438</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>37.9%</td>
<td>65.6%</td>
<td>68.6%</td>
<td>69.8%</td>
</tr>
<tr>
<td></td>
<td>Southbound</td>
<td>N&lt;sub&gt;g&lt;/sub&gt;</td>
<td>2979</td>
<td>3215</td>
<td>3045</td>
<td>3221</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>58.9%</td>
<td>63.3%</td>
<td>67.5%</td>
<td>68.2%</td>
</tr>
<tr>
<td>Arterial Network</td>
<td></td>
<td>ΣN&lt;sub&gt;g&lt;/sub&gt;</td>
<td>19477</td>
<td>21605</td>
<td>20849</td>
<td>23108</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>34856</td>
<td>34856</td>
<td>31569</td>
<td>35072</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>POG</td>
<td>55.9%</td>
<td>62.0%</td>
<td>66.0%</td>
<td>65.9%</td>
</tr>
</tbody>
</table>
Summary and Closing Message

• Uses of Performance Measures
  – System Observation
  – Locating Inefficiencies
  – Validating Control Policies
  – Before/After Studies and Statistical Analysis

• Aspects of Operations
  – Capacity Utilization
  – Progression Quality

• Continuing Research Objectives
  – Make performance measures a tool for traffic engineers’ day-to-day use
    • INDOT example to follow
  – Integration into the control process
    • Optimization
    • Real-Time Control