Corridor Ranking with Automated Traffic Signal Performance Measures

Chris Day, P.E., Ph.D.
Tuesday, March 6, 2018
Research Motivation

- Automated Traffic Signal Performance Measures (ATSPMs)
Research Motivation … at the ITE Annual Meeting in Toronto, last August
ATSPM background

• Existing Data Sets
  – Volume/occupancy
  – Real-time status
  – Some performance measures in some adaptive systems

• High-Resolution Data
  – State changes (phases, detectors) at nearest 0.1 seconds
  – Pattern changes, etc.

• Travel Time Data
  – Individual vehicles
  – Average speeds

• Integration into a system
Research Motivation

• NCHRP 3-122
  – Production of Guidance for Implementation of ATSPMs

• Interviews with Early Adopters
Some Comments Received (Paraphrased)

- “The metrics need to be higher level…”
- “We need higher level reports for managers…”
- “We need something more digestible…”
- “Data Overload”
- “It’s not feasible to go through [###] signals one-by-one…”
Getting Started

• What should we measure to know that traffic signal systems are working?

• What does “working” mean?
Hierarchical Approach

- Fine Tuning
  - Adaptive Control
  - Traffic Responsive Pattern Selection

- System Timing
  - Coordination
  - Pattern Consistency

- Local Timing
  - Safe Right-of-Way Transfer
  - Efficient Capacity Allocation
  - Preemption and Priority

- Detection
  - Actuation
  - Data Collection

- Communications
  - Clock Synchronization
  - Data Transfer

Operations

Maintenance
Study Background

• We have a huge amount of ATSPM data

• How can we roll this up into something that is…
  – **Digestible**
    • Not much time needed
  – **Easy to Understand**
    • “Letter Grade” rather than numerical value
  – **“Contextual”**
    • The same quantitative result may be “good” in some circumstances, but “bad” in others
ATSPM Data in Indiana
Indiana Study Corridors

- US 231 Greater Lafayette
- SR 37 Noblesville
- US 421 Zionsville
- SR 37 Indianapolis South
- US 36 Pendleton Pike
- SR 37 Martinsville
- US 31 Greenwood
- US 31 Columbus
Focus Areas of Individual Metrics

• Maintenance
  – Communication Systems
  – Detection Systems

• Operations
  – Safety
  – Capacity Allocation
  – Progression
1. Communication Concept

• Communication systems should work

• How to measure it?
  – Failure to “ping” the controller
  – Data missing in the database
1. Communication Details

Percentage of Intersections Online by Corridor

- Pendleton Pike
- SR 37
- Indianapolis South
- SR 37
- Martinsville
- SR 37
- Noblesville
- US 231
- Greater Lafayette
- US 31
- Greenwood
- US 31
- Columbus
- US 421
- Zionsville

Study Week
“Current”
1. Communication Thresholds

- Relatively “strict” thresholds
- Without comm, we have no data

- “A” = 100% of intersections online
- “B” = More than 90% of intersections online
- “C” = More than 80% of intersections online
- “D” = More than 70% of intersections online
- “F” = Less than 70% of intersections online
# 1. Communication Outcomes

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Number of Intersections</th>
<th>Number Online</th>
<th>Percent Online</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendleton Pike</td>
<td>15</td>
<td>14</td>
<td>93%</td>
<td>B</td>
</tr>
<tr>
<td>SR 37 Indianapolis South</td>
<td>12</td>
<td>10</td>
<td>83%</td>
<td>C</td>
</tr>
<tr>
<td>SR 37 Martinsville</td>
<td>5</td>
<td>5</td>
<td>100%</td>
<td>A</td>
</tr>
<tr>
<td>SR 37 Noblesville</td>
<td>9</td>
<td>5</td>
<td>56%</td>
<td>F</td>
</tr>
<tr>
<td>US 231 Greater Lafayette</td>
<td>10</td>
<td>10</td>
<td>100%</td>
<td>A</td>
</tr>
<tr>
<td>US 31 Columbus</td>
<td>13</td>
<td>11</td>
<td>85%</td>
<td>C</td>
</tr>
<tr>
<td>US 31 Greenwood</td>
<td>8</td>
<td>7</td>
<td>88%</td>
<td>C</td>
</tr>
<tr>
<td>US 421 Zionsville</td>
<td>7</td>
<td>7</td>
<td>100%</td>
<td>A</td>
</tr>
</tbody>
</table>
2. Detection Concept

• Detection systems should work

• How do detection systems fail? (Four Heuristics)
  – Detection channels stop reporting data
    • Missing data – H1
  – Detection channels overcount
    • Too many detections – H2
  – Phases effectively are in max recall when detectors fail
    • Unintended late night max recall – H3
  – Ped buttons become stuck
    • Unintended ped recall – H4
Number of failed detectors over time…

Phases in Recall

- US 52
- US 421
- US 41
- US 40
- US 36
- US 31
- US 30
- US 24
- US 231
- SR 60
- SR 53
- SR 37
- SR 334
- SR 32
- SR 311
- SR 261
- SR 252
- SR 25
- SR 14
- SR 135
- SR 111
- I-70
- I-69
- I-465

Phases in Recall

- 10/1/2014
- 10/8/2014
- 10/15/2014
- 10/22/2014
- 10/29/2014
- 11/5/2014
- 11/12/2014
- 11/19/2014
- 11/26/2014
- 12/3/2014
- 12/10/2014
- 12/17/2014
- 12/24/2014
- 12/31/2014
- 1/7/2015
- 1/14/2015
- 1/21/2015
- 1/28/2015
- 2/4/2015
- 2/11/2015
## 2. Detection Details

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Number of Detectors</th>
<th>H1 Detectors</th>
<th>H2 Detectors</th>
<th>Number of Phases</th>
<th>H3 Phases</th>
<th>H4 Ped Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendleton Pike</td>
<td>185</td>
<td>19</td>
<td>1</td>
<td>382</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>SR-37 Indianapolis South</td>
<td>138</td>
<td>11</td>
<td>0</td>
<td>242</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>SR-37 Martinsville</td>
<td>75</td>
<td>42</td>
<td>0</td>
<td>129</td>
<td>123</td>
<td>0</td>
</tr>
<tr>
<td>SR-37 Noblesville</td>
<td>85</td>
<td>9</td>
<td>0</td>
<td>183</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>US-231 Greater Lafayette</td>
<td>142</td>
<td>4</td>
<td>4</td>
<td>199</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>US-31 Columbus</td>
<td>133</td>
<td>3</td>
<td>0</td>
<td>253</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>US-31 Greenwood</td>
<td>100</td>
<td>6</td>
<td>0</td>
<td>209</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>US-421 Zionsville</td>
<td>97</td>
<td>8</td>
<td>6</td>
<td>148</td>
<td>42</td>
<td>0</td>
</tr>
</tbody>
</table>
2. Detection Thresholds

- Metric = number of detectors/phases/ped phases in the corridor affected by each heuristic

- “A” = Less than 5% affected
- “B” = Less than 15% affected
- “C” = Less than 35% affected
- “D” = Less than 50% affected
- “F” = More than 50% affected
# 2. Detection Outcomes

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Rates</th>
<th>Subscores</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H1</td>
<td>H2</td>
<td>H3</td>
</tr>
<tr>
<td>Pendleton Pike</td>
<td>10%</td>
<td>1%</td>
<td>11%</td>
</tr>
<tr>
<td>SR-37 Indianapolis South</td>
<td>8%</td>
<td>0%</td>
<td>13%</td>
</tr>
<tr>
<td>SR-37 Martinsville</td>
<td>56%</td>
<td>0%</td>
<td>95%</td>
</tr>
<tr>
<td>SR-37 Noblesville</td>
<td>11%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>US-231 Greater Lafayette</td>
<td>3%</td>
<td>3%</td>
<td>6%</td>
</tr>
<tr>
<td>US-31 Columbus</td>
<td>2%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>US-31 Greenwood</td>
<td>6%</td>
<td>0%</td>
<td>15%</td>
</tr>
<tr>
<td>US-421 Zionsville</td>
<td>8%</td>
<td>6%</td>
<td>28%</td>
</tr>
</tbody>
</table>
3. Safety Concept

- Signal timing should be safe
- In this study, we looked at red light running
- Method of detection
3. Safety Details

![Graph showing relationship between average daily red light violations and average daily intersection volume. The graph includes various classifications (A, B, C, D, F) based on the data points.](image)
3. Safety
Thresholds

- These are what seemed to make sense based on possible ranges in our data and in other studies

- Number of red light violations per 1000 vehicles (at the intersection)

- “A” = less than 5
- “B” = less than 10
- “C” = less than 20
- “D” = less than 40
- “F” = more than 40
## 3. Safety Outcomes

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Worst Intersection Rate (violations/1000 vehicles)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendleton Pike</td>
<td>15.2</td>
<td>C</td>
</tr>
<tr>
<td>SR-37 Indianapolis South</td>
<td>8.6</td>
<td>B</td>
</tr>
<tr>
<td>SR-37 Martinsville</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SR-37 Noblesville</td>
<td>12.8</td>
<td>C</td>
</tr>
<tr>
<td>US-231 Greater Lafayette</td>
<td>17.3</td>
<td>C</td>
</tr>
<tr>
<td>US-31 Columbus</td>
<td>23.1</td>
<td>D</td>
</tr>
<tr>
<td>US-31 Greenwood</td>
<td>8.8</td>
<td>B</td>
</tr>
<tr>
<td>US-421 Zionsville</td>
<td>16.4</td>
<td>C</td>
</tr>
</tbody>
</table>
4. Capacity Allocation
Concept

• It is desirable to avoid split failures
• It is harder to avoid or correct split failures when the overall intersection utilization is reduced

• Measurement:
  – Split failure detection using red and green occupancy ratios
  – Intersection saturation measured using volumes for each movement
Detecting Split Failures

Right Lane
GOR = 100%
ROR = 100%

Left Lane
GOR = 90%
ROR = 96%

Split Failure
4. Capacity Allocation Details

![Graph showing the relationship between Degree of Intersection Saturation and Worst Percentage Split Failure on any Movement at Intersection.]
4. Capacity Allocation
Thresholds

\[ X_C = 20F - 1 \]
\[ X_C = 5F - 0.5 \]
\[ X_C = 2.9F - 0.43 \]
\[ X_C = 1.25F - 0.25 \]
## 4. Capacity Allocation
### Outcomes

<table>
<thead>
<tr>
<th>Corridor</th>
<th>AM</th>
<th>Midday</th>
<th>PM</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendleton Pike</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>SR-37 Indianapolis South</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>SR-37 Martinsville</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SR-37 Noblesville</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>US-231 Greater Lafayette</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>US-31 Columbus</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>US-31 Greenwood</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>US-421 Zionsville</td>
<td>C</td>
<td>C</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>
5. Progression Concept

• It is desirable to avoid stopping traffic, whenever possible

• Arrivals on Green is a useful metric to tell if vehicles are being stopped

• Platoon Ratio accounts for the fact that long green times lead to increased arrivals on green
5. Progression Details

The diagram shows a scatter plot with data points representing the relationship between Volume-to-Capacity Ratio and Platoon Ratio. The plot is divided into different zones labeled F, D, C, and B. The zone B is marked as "Oversaturated."
5. Progression
Thresholds

\[ \frac{v}{c} = -6R_p + 6.0 \]

\[ \frac{v}{c} = -6R_p + 6.1 \]

\[ \frac{v}{c} = -6R_p + 6.9 \]

\[ \frac{v}{c} = -6R_p + 7.8 \]
## 5. Progression
### Outcomes

<table>
<thead>
<tr>
<th>Corridor</th>
<th>AM</th>
<th>Midday</th>
<th>PM</th>
<th>Overall Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendleton Pike</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>SR 37 Indianapolis South</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>SR 37 Martinsville</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SR 37 Noblesville</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>US 231 Greater Lafayette</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>US 31 Columbus</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>US 31 Greenwood</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>US 421 Zionsville</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>
### Performance Information

<table>
<thead>
<tr>
<th>Corridor Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Intersections Total</strong></td>
<td>15</td>
<td>12</td>
<td>5</td>
<td>9</td>
<td>10</td>
<td>13</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td><strong>Number of Intersections Online</strong></td>
<td>14</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>11</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td><strong>Percent Online</strong></td>
<td>93%</td>
<td>83%</td>
<td>100%</td>
<td>56%</td>
<td>100%</td>
<td>85%</td>
<td>88%</td>
<td>100%</td>
</tr>
</tbody>
</table>

| **Communication Subscore** | B | C | A | F | A | C | C | A |

| **Number of Detectors** | 185 | 138 | 75 | 85 | 142 | 133 | 100 | 97 |
| **H1 Detectors** | 19 | 11 | 42 | 9 | 4 | 3 | 6 | 8 |
| **H1 Rate (% of detectors affected)** | 10 | 8 | 56 | 11 | 3 | 2 | 6 | 8 |
| **H1 Subscore** | B | B | F | B | A | A | B | B |

| **Number of Phases** | 382 | 242 | 129 | 183 | 199 | 253 | 209 | 148 |
| **H3 Phases** | 42 | 31 | 123 | 2 | 12 | 3 | 31 | 42 |
| **H3 Rate (% of phases affected)** | 11 | 13 | 95 | 1 | 6 | 1 | 15 | 28 |
| **H3 Subscore** | B | B | F | A | B | A | B | C |
| **H4 Ped Phases** | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 6 |
| **H4 Rate (% of pedestrian phases affected)** | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 6 |
| **H4 Subscore** | A | A | A | A | A | A | A | A |

| **Detection Subscore** | B | B | F | B | A | B | B | C |

| **Highest red light violation rate per 1000 vehicles** | 15.2 | 8.6 | (a) | 12.8 | 17.3 | 23.1 | 8.8 | 16.4 |

| **Safety Subscore** | C | B | (a) | C | C | D | B | C |

| **AM Peak capacity subscore** | B | B | (a) | C | A | B | C | C |
| **Midday capacity subscore** | B | B | (a) | C | A | C | C | C |
| **PM capacity subscore** | C | B | (a) | C | B | C | C | D |

| **Capacity Allocation Category Subscore** | C | B | (a) | C | B | C | C | D |

| **AM Peak progression subscore** | C | B | (a) | C | C | (b) | B | C |
| **Midday progression subscore** | B | B | (a) | B | C | (b) | A | C |
| **PM Peak progression subscore** | B | B | (a) | B | C | (b) | A | C |

| **Progression Category Subscore** | C | B | (a) | C | C | (b) | B | C |

| **Overall Corridor Score** | C | C | F | F | C | D | C | D |
## Overall Results

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Maintenance</th>
<th>Operation</th>
<th>Overall Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comm</td>
<td>Detection</td>
<td>Safety</td>
</tr>
<tr>
<td>Pendleton Pike</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>SR 37 Indianapolis South</td>
<td>C</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>SR 37 Martinsville</td>
<td>A</td>
<td>F</td>
<td>-</td>
</tr>
<tr>
<td>SR 37 Noblesville</td>
<td>F</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>US 231 Greater Lafayette</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>US 31 Columbus</td>
<td>C</td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>US 31 Greenwood</td>
<td>C</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>US 421 Zionsville</td>
<td>A</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>
Summary

• A method of aggregating ATSPMs to deliver a score for corridors was demonstrated for eight arterials in Indiana

• A hierarchical system of scoring was developed for five areas
  – Communication
  – Detection
  – Safety
  – Capacity Allocation
  – Progression

• “Strawman” thresholds were used to convert individual metrics for these areas into a letter-grade score

• Values for each corridor were given using the lowest area score
Questions

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Howell Li, Purdue  
Darcy Bullock, Purdue

Jim Sturdevant, Indiana DOT