Use of Probe and Bluetooth data for arterial performance measures in the I-95 Corridor Coalition

February 12, 2015
MWCOG Vehicle Probe Data Users Group Meeting

University of Maryland
Center for Advanced Transportation Technology
CATT Works
Stanley Young
Outline

• Background on I-95 Vehicle Probe Project
• Results of first multi-vendor validation (freeways)
• Fundamental Challenges with Arterials
• Traditional & Distribution Based Methods
• “A tale of three arterials” …
• Recommendations/Conclusions
• Next Steps -
  – Maryland Supplemental Coverage
  – Validation on Route 1 in VA
Probe & Re-identification

GPS Probe

- Vehicles self-report positions and speed based on GPS equipment
- Individual vehicle data is aggregated to overall traffic
  - Speed samples & point-pair processing
- Third party (INRIX, HERE, TomTom) reports traffic data
  - 24/7/365, in real-time
  - Every minute using TMC codes
- Scales to large networks
- No roadside equipment, and therefore less costly

Re-Identification

- Directly samples travel time of the traffic stream – Sensor Based
- Road-side detectors record vehicle ID such as license plates, toll tags, Bluetooth, WiFi, etc.
- Detector network determines traffic travel time
- Costs and sample (penetration rate) vary by technology
- Data only available when trip is complete, vehicle must be re-observed for trip to be recorded
Vehicle Probe Project in 2008

Core Coverage
• 1500 Freeway miles
• 1000 Arterial miles
• New Jersey to North Carolina

Roadways
• I-95/Parallel Freeways
• Beltways & Cross-linking Freeways
• Alternate Route Arterials
VPP as of 2013

<table>
<thead>
<tr>
<th>State</th>
<th>Freeway Miles</th>
<th>Other Miles</th>
<th>Total Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maine</td>
<td>66</td>
<td>0</td>
<td>66</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>16</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>96</td>
<td>0</td>
<td>96</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>162</td>
<td>597</td>
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</tr>
<tr>
<td>Connecticut</td>
<td>111</td>
<td>0</td>
<td>111</td>
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<td>New Jersey</td>
<td>895</td>
<td>63</td>
<td>958</td>
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<tr>
<td>Pennsylvania</td>
<td>637</td>
<td>118</td>
<td>755</td>
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<tr>
<td>Maryland</td>
<td>781</td>
<td>3779</td>
<td>4,560</td>
</tr>
<tr>
<td>Washington DC</td>
<td>31</td>
<td>233</td>
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<tr>
<td>Virginia</td>
<td>1,411</td>
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<td>North Carolina</td>
<td>1,553</td>
<td>12,996</td>
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<tr>
<td>South Carolina</td>
<td>934</td>
<td>7,187</td>
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<td>Georgia</td>
<td>398</td>
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<td>Florida</td>
<td>718</td>
<td>0</td>
<td>718</td>
</tr>
<tr>
<td>Total</td>
<td>7,809</td>
<td>32,186</td>
<td>39,995</td>
</tr>
</tbody>
</table>
VPPII – starting Aug 2015

• Three Vendors
  – INRIX
  – HERE,
  – TomTom
• Emphasis on latency & arterial roadways
• Multi-vendor validations
  – (as well as NPMRDS)
Traditional Validation

• Compares Vendors Data to Bluetooth Reference Data:
  – Average Absolute Speed Error: Measures deviation from ground truth (10 MPH spec)
  – Speed Error Bias: Measures any consistent over or under estimation of reported speed (+/- 5 MPH Max)

• Accuracy is assessed in four flow regimes
  0 - 30 MPH  30-45 MPH
  45-60 MPH  > 60 MPH

• Specs are applied against Standard Error of the Mean (SEM) band when flow exceeds 500 vph
Freeway Validation Ex. – Jan 2010

Bluetooth Data in Blue
Narrow SEM Band
Wide SEM Band
VPP Data in Red
Outliers marked with Black

TMC:PA01-0001
I-95 SOUTHBOUND ending at I-476/EXIT 7 (1.1215648651123 miles)
PA-08 I-83 & I-81 Harrisburg
October 9-22, 2014

• PA-08
  – 14 Segments
  – 31.3 miles
• Data collection
  – 2300 to 2555 total hrs
  – 71 to 80 hrs [0-30]
  – 53 to 66 hrs [30-45]
• AASE
  – 2.1 to 4.1 mph [0-30]
  – 3.1 to 5.8 mph [30-45]

www.I95Coalition.org
PA-08  PM Peak Hour (Oct 15-16, 2014)
PA-08 Summary

• All vendors were within spec
• More similarities than differences
• All individual reports, graphs and data available for review
• Challenges
  • Maintain ‘Apples-to-Apples’ comparison
  • Timestamp consistency for Latency
# Freeways vs. Arterials

<table>
<thead>
<tr>
<th></th>
<th>Freeways</th>
<th>Arterials</th>
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</thead>
<tbody>
<tr>
<td>Volume</td>
<td>2200 vphpl</td>
<td>1400 vphpl on green</td>
</tr>
<tr>
<td>Speed Range</td>
<td>20-70 mph</td>
<td>10-45 mph</td>
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<tr>
<td>Freeflow</td>
<td>65 mph</td>
<td>Unknown</td>
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<tr>
<td>Congestion Types</td>
<td>Recurring / Non-recurring</td>
<td>Cycle Failure / Mid-Block Friction</td>
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<tr>
<td>Congestion Signature / Incident</td>
<td>Slowdowns &lt; 55 mph</td>
<td>Difficult to recognize</td>
</tr>
<tr>
<td>Flow characteristic</td>
<td>Uniform</td>
<td>Higher Variance, Frequently Bi-Modal</td>
</tr>
</tbody>
</table>
Arterial Data Example

TMC: DE04-0004
DE-7 NORTHBOUND ending at I-95/JFK MEMORIAL HAVY/EXIT 101B/EXIT 165 (1.16543567180634 miles)

Large Variance or Envelope of Speeds

Much less data – lower volumes
Sample Arterial Plot – VA

VPP reports faster of two speeds

No one travels average speed

Two Speed Bands – Due to signal delay
TMC Issues on Arterials

- Segments often too long
- TMCs slow to update for new alignments/roads
- May not be available on roads that warrant coverage
- TMCs designed primarily for freeways, may not work for all arterials
- **Alternatives are propriety**
Summary of Issues - 2011

• Validation of arterials complicated by …
  – Broad definition of Arterials (No prevailing objective standard)
  – Freeway methodology/specifications inappropriate
  – Arterial congestion patterns more complex
  – Travel time often not uniform, frequently bi-modal
  – TMC codes problematic
Shift in Thought 2012-2014

• Requirements for performance measurement differ than that needed for operations
  – Resulted in alternate ways of observing/contrasting travel time of probe data using **weekday overlays** to show trends

• Validation shifted from comparing means to comparing the distributions of travel times
  – Resulted in comparing **Cumulative Frequency Diagrams (CFDs)** rather than means

• Travel time and reliability are best characterized by the distributions, not a single measure.
  – Reliability literature now reflects travel time distribution concepts, rather than simple measures.
Analysis Method

Sampled Distribution Method

• Analyze VPP and BTM based on recurrent traffic patterns
  – 24-hour overlay plots reveal impacts of signal timing and cycle failures
  – Travel Time distributions (in the form of CFDs) provide direct comparisons of performance.

• Traditional performance measures can be directly calculated from the distribution:
  – TTI, PTI, BTI, Percentiles, IQR, etc.

• **Strengths**
  – Captures complex flow dynamics (that are repeatable)
  – Can characterize the ‘nature’ of variation
Sample of 24 Hour Overlay Plot

Segment: NJ11-05  Q-I  Weekdays Only from 09/10-09/26 2013  Length: 1.16 miles

24 Hour Overlay Plot

Travel Time (min)

Hour of Day

BlueTooth

VPP
Sample of CFD Plot and 24 Hour Overlay Plot

Segment: NJ11-05 Q-I  Weekdays Only from 09/10-09/26 2013  Length: 1.16 miles
# Case Study Locations

## Validation of Arterials

<table>
<thead>
<tr>
<th>State / Set ID</th>
<th>State</th>
<th>Road Number</th>
<th>Road Name</th>
<th>Validation Date Span</th>
<th># of Segments</th>
<th># of Through Lanes</th>
<th>AADT Range (in 1000s)</th>
<th>Length* (mile)</th>
<th># Signals / Density</th>
<th># of Access Points</th>
<th>Median Barrier</th>
<th>Speed Limit (mph)</th>
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<tbody>
<tr>
<td>NJ-11</td>
<td>NJ</td>
<td>US-1</td>
<td>Trenton Fwy, Brunswick Pike</td>
<td>Sep 10 - 24, 2013</td>
<td>10</td>
<td>2-4</td>
<td>33 - 90</td>
<td>14.2</td>
<td>10 / 0.7</td>
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<td>Black Horse Pike</td>
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<td>2</td>
<td>25-54</td>
<td>12.5</td>
<td>23 / 1.8</td>
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<td>US-130</td>
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<td>Burlington Pike</td>
<td></td>
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<td>10</td>
<td>3</td>
<td>42</td>
<td>14.3</td>
<td>28 / 2.0</td>
<td>229</td>
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<td>NJ-12</td>
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<td>NJ-38 Kaighn Ave.</td>
<td>Nov 5-19, 2013</td>
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<td>35 - 45</td>
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<td>PA-611 Easton Rd</td>
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<td>10</td>
<td>2-4</td>
<td>18-31</td>
<td>6.7</td>
<td>21 / 3.13</td>
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<td>NO</td>
<td>40-45</td>
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<td>PA-611</td>
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<td>Old York Rd</td>
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<td>1-2</td>
<td>21-30</td>
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<td>26/ 3.56</td>
<td>105</td>
<td>Partial</td>
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<td>PA-611</td>
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<td>N Broad St</td>
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<td>VA-07</td>
<td>VA</td>
<td>VA-7 Leesburg Pike and Harry Byrd Hwy</td>
<td>April 5-16, 2014</td>
<td>30</td>
<td>2-4</td>
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<td>US-29</td>
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<td>Lee Hwy (S Washington St)</td>
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<tr>
<td>VA-08</td>
<td>VA</td>
<td>US-29 Lee Hwy</td>
<td>May 8-19, 2014</td>
<td>26</td>
<td>2-4</td>
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<td>US-29 Lee Hwy</td>
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<td>MD-140</td>
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<td>Baltimore Blvd</td>
<td>June 5-14, 2014</td>
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</tbody>
</table>

- 9 Case Studies from 2013-14
- Spans NJ through NC
- Test extent of probe data >20K AADT & 2+ lanes
- Range of signal density and access
- Objective: Reference case studies
A tale of three arterials ...

• Segments where VPP performed well:
  – NJ11_US-1

• ... mixed performance:
  – NJ11_NJ42

• … poor performance:
  – VA07_VA-7
## Sample of Well Performed VPP NJ11_US-1

<table>
<thead>
<tr>
<th>Data Set Name</th>
<th>Road Number</th>
<th>Road Name</th>
<th>Validation Date Span</th>
<th># of Segments</th>
<th># of Through Lanes</th>
<th>AADT Range (in 1000s)</th>
<th>Length (mile)</th>
<th># Signals / Density</th>
<th># of Access Points</th>
<th>Median Barrier</th>
<th>Speed Limit (mph)</th>
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</thead>
<tbody>
<tr>
<td>NJ-11</td>
<td>US-1</td>
<td>Trenton Fwy, Brunswick Pike</td>
<td>Sep 10 - 24, 2013</td>
<td>10</td>
<td>2-4</td>
<td>33 - 90</td>
<td>14.2</td>
<td>10 / 0.7</td>
<td>112</td>
<td>Yes</td>
<td>55</td>
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</table>
# Traditional Analysis_ AASE and SEB (NJ11_US-1 Corridor)

<table>
<thead>
<tr>
<th>Speed Bin</th>
<th>Absolute Speed Error (&lt;10mph)</th>
<th>Speed Error Bias (&lt;5mph)</th>
<th>Number of 5 Minute Samples</th>
<th>Hours of Data Collection</th>
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<tr>
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<td>Comparison with SEM Band</td>
<td>Comparison with Mean</td>
<td>Comparison with SEM Band</td>
<td>Comparison with Mean</td>
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<tr>
<td>0-15 MPH</td>
<td>2.9</td>
<td>4.4</td>
<td>2.8</td>
<td>3.8</td>
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<tr>
<td>15-25 MPH</td>
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<td>7.3</td>
<td>5.2</td>
<td>6.9</td>
</tr>
<tr>
<td>25-35 MPH</td>
<td>5.4</td>
<td>9.6</td>
<td>5.2</td>
<td>8.8</td>
</tr>
<tr>
<td>&gt;35 MPH</td>
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<td>6.5</td>
<td>-1.3</td>
<td>-2.9</td>
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<tr>
<td>All Speeds</td>
<td>2.9</td>
<td>6.9</td>
<td>-0.1</td>
<td>-0.8</td>
</tr>
</tbody>
</table>
US-1 (NJ11-06) 9/12/2013

TMC: NJ11-0006
US-1 NORTHBOUND ending at Washington Rd (2.98470854759216 miles)

195-Corridor Coalition Vehicle Probe Project
Copyright University of Maryland © 2008

Date and Time (EST)

x Bluetooth • Filtered bluetooth ——— Average bluetooth • Inrix ———— Band low ———— Band high

Speed (mph)
NJ11-03, 8AM – 9AM

Segment: NJ11-03  C-D   Weekdays Only from 09/10-09/26 2013   Length: 0.749 miles

24 Hour Overlay Plot

CDF – Focus Hour: 8AM to 9AM

Percentile

Travel Time (min)

Hour of Day

Travel Time (min)

Travel Time (minutes)

VPP

BT

TTI 1.51 1.83
PTI 2.40 2.87
6TI 1.59 1.46
25th 2.47 3.08
50th 3.27 4.42
75th 4.01 5.22
95th 6.21 6.46
IQR 1.64 2.14
US-1 (NJ11-07) 9/13/2013

Optimistic tendency of Probe Data
## Sample of Mixed Performed VPP_NJ11_NJ-42

<table>
<thead>
<tr>
<th>Data Set Name</th>
<th>Road Number</th>
<th>Road Name</th>
<th>Validation Date Span</th>
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<th># of Through Lanes</th>
<th>AADT Range (in 1000s)</th>
<th>Length (mile)</th>
<th># Signals / Density</th>
<th># of Access Points</th>
<th>Median Barrier</th>
<th>Speed Limit (mph)</th>
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<tbody>
<tr>
<td>NJ-11</td>
<td>NJ-42</td>
<td>Black Horse Pike</td>
<td>Sep 10 - 24, 2013</td>
<td>8</td>
<td>2</td>
<td>25-54</td>
<td>12.5</td>
<td>23 / 1.8</td>
<td>260</td>
<td>Yes</td>
<td>45-50</td>
</tr>
</tbody>
</table>
Mixed Performance: Identifies slow down, but inaccurate magnitude
Sampled Distribution Method
(NJ11-19, 4PM – 5PM)

Segment: NJ11-19 F-L  Weekdays Only from 09/10-09/26 2013  Length: 1.37 miles

24 Hour Overlay Plot

CDF - Focus Hour: 4PM to 5PM

<table>
<thead>
<tr>
<th>Statistic</th>
<th>VPP</th>
<th>BT</th>
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</thead>
<tbody>
<tr>
<td>TTI</td>
<td>1.15</td>
<td>1.25</td>
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<tr>
<td>PTI</td>
<td>1.59</td>
<td>1.70</td>
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<tr>
<td>OTI</td>
<td>1.30</td>
<td>1.36</td>
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<tr>
<td>25th</td>
<td>3.78</td>
<td>4.75</td>
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<td>50th</td>
<td>4.07</td>
<td>5.47</td>
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<tr>
<td>75th</td>
<td>4.58</td>
<td>6.16</td>
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<tr>
<td>90th</td>
<td>5.03</td>
<td>7.43</td>
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<tr>
<td>IQR</td>
<td>0.80</td>
<td>1.41</td>
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</table>
NJ11-18, 5PM – 6PM

Signal Timing Change at 3pm

Segment: NJ11-18 L-F  Weekdays Only from 09/10-09/26 2013  Length: 1.33 miles

24 Hour Overlay Plot

CDF – Focus Hour: 5PM to 6PM

<table>
<thead>
<tr>
<th>25th</th>
<th>50th</th>
<th>75th</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.22</td>
<td>2.47</td>
<td>2.55</td>
</tr>
<tr>
<td>3.05</td>
<td>3.65</td>
<td>4.03</td>
</tr>
<tr>
<td>4.65</td>
<td>0.23</td>
<td>0.98</td>
</tr>
</tbody>
</table>

VPP  BT

TTI   1.08  1.29
FITI  1.55  1.64
BTI   1.43  1.27
25th  2.22  3.05
50th  2.47  3.65
75th  2.55  4.03
95th  3.54  4.65
IQR   0.23  0.98
NJ11-21, 5PM – 6PM

Bimodal Distribution, VPP favors faster flow
# Sample of Poorly Performed VPP_-_VA07_VA-7

## Data Set Name: VA07_VA-7

<table>
<thead>
<tr>
<th>Data Set Name</th>
<th>Road Number</th>
<th>Road Name</th>
<th>Validation Date Span</th>
<th># of Segments</th>
<th># of Through Lanes</th>
<th>AADT Range (in 1000s)</th>
<th>Length (mile)</th>
<th># Signals / Density</th>
<th># of Access Points</th>
<th>Median Barrier</th>
<th>Speed Limit (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA-07</td>
<td>VA-7</td>
<td>Leesburg Pike and Harry Byrd Hwy</td>
<td>April 5-16, 2014</td>
<td>30</td>
<td>2-4</td>
<td>45-60</td>
<td>30.5</td>
<td>57 / 1.9</td>
<td>203</td>
<td>Yes</td>
<td>35-55</td>
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</tbody>
</table>
Major construction on VA-7 impacted traffic patterns
VA-7 (VA07-13) 4/11/2014

Bimodal Distribution

VA-7 WESTBOUND ending at Cascades Pkwy (0.90668475627892 miles)
VA07-02, 5PM – 6PM

Segment: VA07-02 B to C  Weekdays Only from 04/05-04/13 2013  Length: 1.1 miles
VA07-26, 7AM – 8AM

Segment: VA07-26  F to E   Weekdays Only from 04/05-04/13 2014   Length: 0.883 miles

24 Hour Overlay Plot

CDF -- Focus Hour : 7AM to 8AM

<table>
<thead>
<tr>
<th>VPP</th>
<th>BT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTI</td>
<td>1.08</td>
</tr>
<tr>
<td>PTT</td>
<td>1.23</td>
</tr>
<tr>
<td>BTI</td>
<td>1.13</td>
</tr>
<tr>
<td>25th</td>
<td>1.33</td>
</tr>
<tr>
<td>50th</td>
<td>1.40</td>
</tr>
<tr>
<td>75th</td>
<td>1.48</td>
</tr>
<tr>
<td>90th</td>
<td>1.59</td>
</tr>
<tr>
<td>IQR</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Travel Time (minutes)

Hour of Day

Travel Time (minutes)

Percentile

Percentile
Arterial Probe Data Rec’s

<table>
<thead>
<tr>
<th>Likely to have usable probe data</th>
<th>Possibly usable probe data</th>
<th>Unlikely probe data is usable</th>
</tr>
</thead>
<tbody>
<tr>
<td>• AADT &gt;40000</td>
<td>• AADT 20K to 40K</td>
<td>• Low volume, &lt; 20K AADT</td>
</tr>
<tr>
<td>• 2+ lanes</td>
<td>• 2+ lanes</td>
<td>• &gt;=2 signals per mile</td>
</tr>
<tr>
<td>• &lt;= 1 signals per mile</td>
<td>• &lt;= 2 signals per mile</td>
<td>• Major Collectors (HPMS)</td>
</tr>
<tr>
<td>• Principal Arterials (HPMS)</td>
<td>• Minor Arterials (HPMS)</td>
<td>• Not recommended</td>
</tr>
<tr>
<td>• Limited Curb cuts</td>
<td>• Should be tested</td>
<td></td>
</tr>
</tbody>
</table>

- Probe data is anticipated to improve in time
  - Increased probe density and better processing
- As Probe data degrades, delay is underestimated
  - As probe technology matures, measured delay may increase
  - Challenged by queuing or cycle failure
  - Not sensitive to / confused by bi-modal traffic patterns
Parting Thoughts

• Expectations are running ahead of reality
  – Probe data works on highest class arterials
  – Use with caution on mid class and below

• Arterial Performance
  – Travel time is the measure of choice
  – CDF’s tell a concise story
    • Facilitates before/after, degradation in time, compare difference facilities, different signal timings

• Need reviewers / Arterial Focus Group
Future Validations

- US-1 in VA
  - DC to Fredericksburg
  - 50 miles
  - Currently being processed
- Spring 2015
  - Maryland Supplemental Coverage (120 miles all three vendors)
  - Freeway & Arterial

www.I95Coalition.org  
I-95 Corridor Coalition Vehicle Probe Project  
January 29, 2015
Maryland Supplemental Coverage
Questions?

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