Volume & Turning Movements Project

Steering Committee Meeting #5

July 27, 2017
Housekeeping Items

• Please call xxx-xxx-xxxx for difficulties with the web or audio application
• This is a virtual meeting experience
  • Please keep your phone muted until asking a question or speaking (press *6 to mute/unmute individual phone lines)
  • Please do not place call “on hold” as your hold music will be heard by the group
• Speakers will answer questions at the end of their presentation
• The audio from this meeting is being recorded
• All materials & contact information will be available to participants after the webcast
WELCOME!

Denise Markow, I-95 Corridor Coalition
Speakers

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Yi Hou, PhD
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Shawn Turner, PE
Texas A&M Transportation Institute (TTI)
shawn-turner@tamu.edu
## Attendees

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Thank you!
## Agenda

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<td>1. Welcome &amp; Project Status Update</td>
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<td>Stan Young, NREL</td>
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<td>2. Spotlight Presentation: Real-time Volume Estimation with TomTom Probe Data – Denver Area</td>
<td>Yi Hou, NREL</td>
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<td>3. Polling Questions for Steering Committee Input</td>
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Project – Year in Review

• User Survey - Completed
• Preliminary Data Analyses
  • Maryland
  • Rhode Island
  • Florida
  • Colorado
• Calibration (FHWA TMAS)
• Validation (TTI)
Project Goal

• Accelerate the timeframe to a viable volume and turning movement data feed ---
  • Anywhere/anytime on the network
  • Archive and real-time

• Ensure that initial data products meet the I-95 Corridor Coalition members’ information needs for operations, performance measurement, and planning.
Objectives - Original

• Define a practical and logistical framework for the delivery of probe-based volume and turning movement data

• Understand, document, and share data requirement needs for a variety of DOT applications requiring such data

• Create a calibration and validation testbed to assist vendors’ initial development efforts

• Provide representative data products and set appropriate expectations for data fidelity, form, granularity, and usability

• Anticipating the need for an ongoing calibration network, estimate resources needed to maintain/operate a national calibration/validation testbed
Status of Project

Calibration / Validation Testbed

- Calibration Data (TMAS)
- Validation Methods [Led by TTI]

UMD/NREL

INRIX / UMD
TomTom / NREL
HERE
Streetlight Data

- VTM products
- Validated
- Consistent formats
- Meets Coalition needs
Status

• INRIX/UMD Data – Maryland analysis complete
  • Rhode Island and Florida are the target areas for next analysis
  • Base data: Trips, Origin & Destination, and intervening waypoints

• TomTom/NREL – Archive analysis complete Colorado (presented today)
  • In discussion with TomTom and CDOT for real-time analysis
  • Base data: Probe vehicle counts on segments

• HERE – sample data sets being reviewed
  • Base data: Trips, Origin & Destination

• Streetlight Data – sample data sets being reviewed
  – Base data: AADT estimate for a roadway
Today’s Agenda

• TomTom/NREL analysis of volume estimates in CO
  • Yi Hou, NREL
  • Parallels the approach used in initial Maryland analysis

• Validation overview/thoughts –
  • Shawn Turner, TTI
Questions
Real-time Volume Estimation with TomTom Probe Data – Denver Area

Yi Hou

July 27, 2017
Problem Statement

• How to obtain accurate estimate of ubiquitous real-time traffic volume in road networks?
Proposed Solution

**Input**
- Probe Data
- Road Characteristics
- Weather Info
- Temporal Info

**Model**

**Output**
- Traffic Volume
Outline

• Data Sources
  o FHWA TMAS
  o CDOT ATR Counts
  o Weather
  o TomTom Probe Data
• Model Development
• Summary
• Web App Framework
Data Sources

- FHWA TMAS
- CDOT ATR Counts
- Weather
- TomTom Probe Data

- ATR station information and road characteristics
  - State
  - Station ID
  - Direction
  - Urban/Rural
  - Number of lanes
  - Road sign (interstate, US, state)
  - Road number
  - Latitude
  - Longitude
Data Sources

- FHWA TMAS
- CDOT ATR Counts
- Weather
- TomTom Probe Data

Temporal and volume information
  - Year
  - Month
  - Day
  - Weekday
  - Hour of day
  - Hourly volume
Data Sources

• FHWA TMAS
• CDOT ATR Counts
• Weather
• TomTom Probe Data

• Weather information
  o Average temperature
  o Visibility
  o Wind
  o Precipitation
  o Snow
  o Fog
  o Rain
  o Thunderstorm
Data Sources

• FHWA TMAS
• CDOT ATR Counts
• Weather
• TomTom Probe Data

• Probe vehicle data
  o Travel time
  o Speed
  o Probe vehicle count
  o Speed limit
  o Street name
  o Segment ID
• Match ATR locations with TomTom segments
## Snapshot of Merged data

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- Weather Probe Road Info Temporal

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<td>59</td>
<td>10</td>
<td>14</td>
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<td>59</td>
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<td>1</td>
<td>3</td>
<td>583</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Variable Correlations

• Positively correlated with volume
  o Average hourly probe counts of past 6 hours
  o Number of lanes
  o Capacity

• Negatively correlated with volume
  o Average hourly average speed of past 6 hours
  o Speed limit
Input Variables

- TomTom GPS data
  - Average speed: average hourly speed of past 6 hours
  - Probe count: average hourly probe counts of past 6 hours
- Weather
  - temperature, visibility
- Road characteristics
  - road type, speed limit, number of lanes, capacity
- Temporal information
  - month, day of week, hour of day
Data Points

- Feb 1, 2017 – April 30, 2017
- Total of 52,092 data points
- Ranges from 2800-4000
Penetration Rates

- Ranges from 8%-12%
Average Volume

- All Ranges from 1500-3500 veh/hr except station 501
- 501 is an unique case
Volume Distribution by Location

- All ATR stations have similar volume distribution except station 501
• Machine Learning Models
  o Random Forest (RF)
  o Gradient Boost Machine (GBM)
  o Extreme Gradient Boost (XGBoost)

• Advantages of these models
  o Do not require detailed mathematical forms and assumptions on variable distributions
  o Suitable for capturing the underlying relationships among different variables in an environment of uncertainty
  o Fewer parameters to tune and easy to implement
• All 14 ATR stations were used for modeling
  o At each iteration
    – 13 stations are used for training
    – 1 station is used for validation
  o Repeat this 14 times and report validation results for all 14 locations
Model Evaluation Criteria

- Coefficient of Determination: \( R^2 = 1 - \frac{(V_i - \overline{V}_i)^2}{(V_i - \overline{V})^2} \)
  - A measure of how well the model can explain data variance

- Mean Absolute Percentage Error: \( MAPE = \frac{1}{N} \sum_{i=1}^{N} \frac{|V_i - \overline{V}_i|}{V_i} \)
  - An error measure when comparing estimated volume with ground truth

- Error to Theoretical Capacity Ratio: \( ETCR = \frac{1}{N} \sum_{i=1}^{N} \frac{|V_i - \overline{V}_i|}{C_i} \)
  - An error measure when comparing estimated volume with roadway capacity
Model Results

- Results exceed the survey expectation: ETCR<10%
- When compared with linear regression:
  - Reduced MAPE by almost 60%
  - Reduced ETCR by almost 30%
  - Increased median R² by more than 10%

<table>
<thead>
<tr>
<th>Model</th>
<th>Overall MAPE</th>
<th>Overall ETCR</th>
<th>Median R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>17.8%</td>
<td>5.2%</td>
<td>0.92</td>
</tr>
<tr>
<td>GBM</td>
<td>18.3%</td>
<td>4.8%</td>
<td>0.93</td>
</tr>
<tr>
<td>XGBoost</td>
<td>17.7%</td>
<td>5.3%</td>
<td>0.91</td>
</tr>
<tr>
<td>Linear Regression</td>
<td>41.8%</td>
<td>7.2%</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Coefficient of Determination ($R^2$)

- **RF**
  - Range: 0.57-0.96
  - Median: **0.92**
- **GBM**
  - Range: 0.69-0.96
  - Median: **0.93**
- **XGBoost**
  - Range: 0.57-0.96
  - Median: **0.91**
Mean Absolute Percentage Error (MAPE)

- **RF**
  - Range: 12%-31%
  - Median: 16.1%
- **GBM**
  - Range: 13%-29%
  - Median: 16.3%
- **XGBoost**
  - Range: 13%-25%
  - Median: 16.3%
Error to Theoretical Capacity Ratio (ETCR)

- **RF**
  - Range: 2.6%-15.4%
  - Median: **4.1%**
- **GBM**
  - Range: 2.9%-13.0%
  - Median: **4.0%**
- **XGBoost**
  - Range: 3.0%-15.2%
  - Median: **4.5%**
Prediction vs. Observation (Highest $R^2$)

RF

GBM

XGBoost
Prediction vs. Observation (Median $R^2$)

**RF**

Station ID: 103, Road Name: 25 N, $R^2 = 0.91$

**GBM**

Station ID: 103, Road Name: 25 N, $R^2 = 0.91$

**XGBoost**

Station ID: 103, Road Name: 25 N, $R^2 = 0.91$
Prediction vs. Observation (Lowest $R^2$)

RF

GBM

XGBoost
Contribution of Probe Vehicle Data

- Probe vehicle data has significant impact on volume estimation accuracy

### RF

<table>
<thead>
<tr>
<th></th>
<th>Overall MAPE</th>
<th>Overall ETCR</th>
<th>Median $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data included</td>
<td>17.8%</td>
<td>5.2%</td>
<td>0.92</td>
</tr>
<tr>
<td>With only Probe Data</td>
<td>25.5%</td>
<td>6.4%</td>
<td>0.90</td>
</tr>
<tr>
<td>Without Probe Data</td>
<td>35.2%</td>
<td>10.7%</td>
<td>0.70</td>
</tr>
</tbody>
</table>

### GBM

<table>
<thead>
<tr>
<th></th>
<th>Overall MAPE</th>
<th>Overall ETCR</th>
<th>Median $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data included</td>
<td>18.3%</td>
<td>4.8%</td>
<td>0.93</td>
</tr>
<tr>
<td>With only Probe Data</td>
<td>25.7%</td>
<td>6.4%</td>
<td>0.89</td>
</tr>
<tr>
<td>Without Probe Data</td>
<td>40.5%</td>
<td>12.1%</td>
<td>0.64</td>
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</tbody>
</table>

### XGBoost

<table>
<thead>
<tr>
<th></th>
<th>Overall MAPE</th>
<th>Overall ETCR</th>
<th>Median $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data included</td>
<td>17.7%</td>
<td>5.3%</td>
<td>0.91</td>
</tr>
<tr>
<td>With only Probe Data</td>
<td>24.2%</td>
<td>6.4%</td>
<td>0.89</td>
</tr>
<tr>
<td>Without Probe Data</td>
<td>39.4%</td>
<td>12.4%</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Summary

- Results satisfy the survey expectation: ETCR<10%
- Improved MAPE by almost 60% when compared with linear regression
- Probe vehicle data has significant impact on volume estimation accuracy
- Has poor performance on unique cases or outlier
- Accuracy can be further improved with more cases or data
- Next step
  - Will scale up to state level with more data
  - Further improve accuracy by trying deep learning
Thank You!

Questions?
Poll

1. Having heard the descriptions of the error measures below, which is the most meaningful to you? (select all that apply)

- R² – Coefficient of Determination
- MAPE – Mean Absolute Percentage Error
- ETCR - Error to Theoretical Capacity Ratio, where error is calculated with respect to maximum theoretical/observed capacity
- None of the above
Poll

2. Having heard the descriptions of the error measures below, should the research team consider other error measures?

- \( R^2 \) – Coefficient of Determination
- MAPE – Mean Absolute Percentage Error
- ETCR - Error to Theoretical Capacity Ratio, where error is calculated with respect to maximum theoretical/observed capacity

- Yes
- No
Validation Framework

• Shawn Turner, Texas A&M Transportation Institute (TTI)
  – (979) 845-8829, s-turner@tti.tamu.edu

• Why TTI involvement?
  – Provide 3rd party independent validation of groups that are producing traffic volume estimates (which now include UMD & NREL)

• Smaller-scale MnDOT/TTI research project now finishing up
Validation Framework: Two-pronged approach - Trust, but Verify

• TRUST
  • Self-reported info about model calibration process and results
  • High-level description of sample scaling approach (must be non-proprietary and freely distributable)
  • Goodness-of-fit or other model calibration statistics (try to standardize)

But...

• VERIFY
  • 3rd party independent validation similar to I-95CC travel time validation
  • Use existing DOT continuous count stations for benchmark data (that is not yet publicly available)
  • Standardized accuracy measures and measure categories (bins in which error results are grouped), similar to I-95CC travel time validation
Trust: Self-Reported Information

• High-level description of sample scaling approach
  – 1-2 pages of text that explains how samples are scaled
  – Build confidence in approach to avoid “black box” perception
  – Avoid overly simplistic marketing text
  – Recognize that details are typically proprietary

• Model calibration information (if applicable)
  – Number of calibration sites
  – Duration/season of calibration data
  – Functional class and geographic representation
  – Frequency distribution of volumes used in calibration
  – Goodness-of-fit statistics (R2, others)
Verify: Benchmark Volume Data

• Similar to I-95CC travel time validation, but no extra collection of benchmark data

• DOTs provide most recent volume data that has not yet been made publicly available
  – Ideally, continuous count location from well-maintained site
  – Ideally, location not used in model calibration

• Need to identify DOTs who can provide benchmark volume data shortly after data has been collected (before it’s made public through DOT web site or TMAS)
Verify: Accuracy Measures

• Accuracy when it matters:
  – 10% error at high volume is much different than 10% error at low volume
  – For example:
    • 10% error at 200 vphpl = 20 veh
    • 10% error at 2000 vphpl = 200 veh

• Sliding scale – higher % error acceptable at lower volumes
  – MnDOT planning example

<table>
<thead>
<tr>
<th>AADT Range</th>
<th>Acceptable % Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decreasing ( - )</td>
</tr>
<tr>
<td>300 - 999</td>
<td>-20%</td>
</tr>
<tr>
<td>1,000 - 4,999</td>
<td>-15%</td>
</tr>
<tr>
<td>5,000 – 49,999</td>
<td>-10%</td>
</tr>
<tr>
<td>50,000+</td>
<td>-10%</td>
</tr>
</tbody>
</table>
Verify: Accuracy Measures

- Standardized accuracy measures and measure categories
- Comparing notes with UMD/NREL and assessing best approach
- A possibility:

<table>
<thead>
<tr>
<th>Category</th>
<th>Accuracy Measure #1</th>
<th>Accuracy Measure #2</th>
<th>Accuracy Measure #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume categories (Low, Med, High)</td>
<td>Mean Absolute Percent Error, MAPE (%)</td>
<td>Error-to-Theoretical-Capacity Ratio, ETCR (%)</td>
<td>Mean Signed Error - Bias (Number of Vehicles)</td>
</tr>
<tr>
<td>or</td>
<td></td>
<td>or</td>
<td></td>
</tr>
<tr>
<td>% of capacity categories (L, M, H)</td>
<td></td>
<td>Error-to-Maximum-Flow Ratio, EMFR (%)</td>
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</tr>
</tbody>
</table>
Next Steps

• Gather initial feedback (today)
• Identify available benchmark DOT continuous count data
  – Must be provided to TTI before being made publicly available
• Develop more detail in concept paper
• Gather feedback on concept paper from I-95CC and volume data producers in Sept/Oct
• Develop consensus on validation framework by November
Questions
Wrapping Up

Limited locations, hourly, latent

All locations, all time, historic and real-time
Take Aways – NREL/Colorado Work

• Variation in penetration rates (8% to 12%)

• Large variations in volume, can create problematic outliers

• Volume fluctuation along a roadway a concern
  • Possibly introduce a constrained model
Penetration Rates

- Ranges from 8%-12%
Average Volume

- All Ranges from 1500-3500 veh/hr except 501
- 501 is an unique case
• Volume Outlier had the highest error

• RF
  o Range: 2.6%-15.4%
  o Median: 4.1%

• GBM
  o Range: 2.9%-13.0%
  o Median: 4.0%

• XGBoost
  o Range: 3.0%-15.2%
  o Median: 4.5%
Problem Statement

• Variations along the route need to be considered.
• TMAS provides no calibration data for sequential volume/density
• May need to introduce constrained model
Final Thoughts

- Larger penetration rates helped
- Volume estimates approached ~5% Error to Capacity ratio (ETCR)
- Moving toward a formalized validation approach
Wrap Up

• Next meeting/webinar
  • Thursday, November 9, 2017
  • 10:30 a.m. - 12:00 p.m. (EST)
Final Questions
Thank You!

For Questions, please contact:

• PI – Kaveh Sadabadi (UMD-CATT) 301-405-1352 or kfarokhi@umd.edu
• Co-PI – Denise Markow (I-95 Corridor Coalition) 301-789-9088 or dmarkow@i95coalition.org
• Co-PI – Stanley Young (NREL) 301-792-8180 or Stanley.Young@nrel.gov
• UMD PM/Contracts – Kathy Frankle (UMD-CATT) 301-405-8271 or kfrankle@umd.edu
• Logistics – Joanna Reagle (KMJ Consulting, Inc.) 610.228.0760 or jreagle@kmjinc.com