Webinar on Accurate Estimates of Traffic Volume - anywhere, anytime - from GPS Probe Samples

May 23, 2018
Webinar & Audio Information

- The call-in phone number is: xxx-xxx-xxxx & enter xxxxxxx# at the prompt
- Participants will be in “Listen Only” mode throughout the webinar
- Please press *0 to speak to an operator for questions regarding audio
- Please call xxx-xxx-xxxx for difficulties with the web or audio application
- This webinar will be recorded
- Presentations will be posted to the I-95 Corridor Coalition website. Participants will receive a link to the presentations after they are posted.
Asking Questions

• Please pose your questions using the **chat box**

• Questions will be monitored then answered by the speakers at the end of the webinar
Welcome
Who is the I-95 Corridor Coalition?

- 16 States and the District of Columbia
- 35% of nation’s VMT (21% of road miles)
- 565 million long-distance (>100 miles) trips annually
- Corridor = third largest economy in world

How can we better message TSMO strategies Regionally?

...a partnership of multi-state, multi-modal public agencies working together to create a seamless and efficient transportation system
I-95 Corridor Coalition Sponsored Event

320 Registered

28 States

DOTs  Turnpike Authorities  MPOs  Federal Agencies  Universities  Vendors
Introduction – Stan Young

Results from University of Maryland – Kaveh Sadabadi

Results on Colorado Roadways – Yi Hou

Summary and Discussion – Stan Young
Project Goal

Accelerate the timeframe to a viable volume and turning movement data feed ---

• Anywhere/anytime on the network
• Archive and real-time
• Freeway and Non-Freeway

Ensure that initial data products meet members’ information needs for operations, performance measurement, and planning.
Why Do We Need More and Better Volume Data?

• **Operation**
  - Detect real-time traffic volume in the network
  - Traffic volume during inclement weather and special events

• **Performance measure**
  - Assess user costs
  - Utilization of existing capacity

• **Economic and energy assessment**
  - Estimate economic impact of congestion
  - Quantify VMT and energy use
Ubiquitous Traffic Volumes

- Ideal but expensive to achieve with sensors
- Utilize and fuse existing high-quality yet sparse data with probe data to predict traffic volumes on each and every link of the road network
Proposed Solution

Calibration Network

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

Estimator
Machine Learning Techniques

Output
- Traffic Volume Everywhere and All Times: Both real-time and historic

I-95 CC Webinar
Accurate Estimates of Traffic Volume from GPS Probe Samples
May 23, 2018
Standard Error Measures

• **Mean Absolute Percentage Error:** \( \text{MAPE} = \frac{1}{N} \sum_{i=1}^{N} \frac{|V_i - \overline{V}_i|}{V_i} \)
  
  • Reflects the absolute volume accuracy

• **Error to Theoretical Capacity Ratio:** \( \text{ETCR} = \frac{1}{N} \sum_{i=1}^{N} \frac{|V_i - \overline{V}_i|}{C_i} \)
  
  • Reflects fidelity with respect to capacity

• **Coefficient of Determination:** \( R^2 = 1 - \frac{(\overline{V}_i - V_i)^2}{(V_i - \overline{V})^2} \)
  
  • Explanatory power of model
How Good is Good Enough?

- Error to Capacity (ETCR) or Max Flow (EMFR)
  - \(< 10\% \) becomes useful  \(< 5\% \) is target

- Mean Absolute Percentage Error (MAPE)
  - Volume dependent - estimate
    - 10-15\% High Volume
    - 20-25\% Mid Volume
    - 30-50\% Low Volume
      (Mean Absolute Error may be appropriate)

- \(R^2\) Coefficient of Determination
  - \(>70\% \) good  \(>80\% \) better  \(>90\% \) best

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**MNDOT Example**

<table>
<thead>
<tr>
<th>AADT Range</th>
<th>Decreasing (-)</th>
<th>Increasing (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 19</td>
<td>-100%</td>
<td>400%</td>
</tr>
<tr>
<td>20 - 49</td>
<td>-40%</td>
<td>50%</td>
</tr>
<tr>
<td>50 - 99</td>
<td>-30%</td>
<td>40%</td>
</tr>
<tr>
<td>100 - 299</td>
<td>-25%</td>
<td>30%</td>
</tr>
<tr>
<td>300 - 999</td>
<td>-20%</td>
<td>25%</td>
</tr>
<tr>
<td>1,000 - 4,999</td>
<td>-15%</td>
<td>20%</td>
</tr>
<tr>
<td>5,000 - 49,999</td>
<td>-10%</td>
<td>15%</td>
</tr>
<tr>
<td>50,000+</td>
<td>-10%</td>
<td>10%</td>
</tr>
</tbody>
</table>
Estimation vs. Observation (Median $R^2$)
Framework, Details of Analysis, Statistical Evidence

• Florida, Full Network
  • Kaveh Sadabadi, UMD

• Colorado Results
  • Yi Hou, NREL
Traffic Volume Estimation using GPS Traces

Presented by:
Kaveh Farokhi Sadabadi

Analysis Performed by:
Przemyslaw Sekula and Zachary Vander Laan

National Webinar
May 23, 2018
Presentation Outline

• Overview
  • Objectives
  • Volume estimation approach

• Florida case study
  • Dataset
  • Results
  • Statewide Estimation
  • AADT & AAWDT

• Summary & Next Steps
Objectives

• Given the following:
  – Probe volumes (processed from GPS traces of a subset of vehicles),
  – Other archived data (speeds, road geometry, weather, etc.)
  – Counts at permanent traffic monitoring stations
  – TTI volume estimates

• Can we build a model to accurately estimate statewide volumes?
Volume Estimation: General Approach

Develop and Train Model
• **Where?** TMC segments associated with permanent count stations
• **How?** Construct machine learning model to learn relation between input variables and permanent count station volumes

Apply model to state road network
• **Where?** All TMC segments on road network
• **How?** Apply trained model to input variables from any TMC segment on the network
At all TMC segments

- **GPS probe data** (INRIX)
  - 75M trips, 3.4B pts (20M trips, 1.4B pts in MD)
  - Penetration rate: 2.1% median (1.9% in MD)
  - Snapped to XD segments

- **Probe Speed data** (HERE)

- **Road characteristics**
  - NPMRDS TMC shape file features
  - Open Street Map (OSM) conflation

- **Weather data** (permanent stations)

- **TTI hourly volume estimates**

At permanent count stations

- **Traffic counts** (FDOT)
  - Used for model training / evaluation
  - Used to estimate probe penetration rate

1: cars / light-duty trucks
2: medium-duty trucks
3: heavy-duty trucks
Florida Model Evaluation

- **Model**: “Dense” Artificial Neural Network (ANN)
- **Cross validation** (repeat 173 times)
  - Train model using data from 172 of 173 permanent count stations
  - Generate model predictions using data from remaining station

- **Evaluation**: Compare estimated / observed volumes & generate metrics
Florida Results: Summary

→ Overall median error metrics:
  • $R^2 = 0.83$
  • $\text{MAPE} = 25\%$
  • $\text{EMFR} = 7\%$

• Promising model performance, over a variety of scenarios

• Better performance on higher road classes

• Better performance as average traffic volume increases

### Median Error Metrics by Scenario

<table>
<thead>
<tr>
<th>Road Classification</th>
<th>R2</th>
<th>MAPE (%)</th>
<th>EMFR (%)</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRC 1 (Interstates)</td>
<td>0.86</td>
<td>21</td>
<td>6</td>
<td>195704</td>
</tr>
<tr>
<td>FRC 2 (Other freeways &amp; Expressways)</td>
<td>0.82</td>
<td>26</td>
<td>7</td>
<td>370567</td>
</tr>
<tr>
<td>FRC 3 &amp; 4 (Other principal &amp; minor arterials)</td>
<td>0.83</td>
<td>33</td>
<td>7</td>
<td>128419</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Hourly Volume (vph)</th>
<th>R2</th>
<th>MAPE (%)</th>
<th>EMFR (%)</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1k</td>
<td>0.81</td>
<td>29</td>
<td>7</td>
<td>465591</td>
</tr>
<tr>
<td>1k-2k</td>
<td>0.86</td>
<td>22</td>
<td>6</td>
<td>164465</td>
</tr>
<tr>
<td>2k-3k</td>
<td>0.88</td>
<td>18</td>
<td>6</td>
<td>49221</td>
</tr>
<tr>
<td>3k+</td>
<td>0.87</td>
<td>19</td>
<td>6</td>
<td>15413</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time Period</th>
<th>R2</th>
<th>MAPE (%)</th>
<th>EMFR (%)</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day (6am-8pm)</td>
<td>0.49</td>
<td>20</td>
<td>9</td>
<td>405759</td>
</tr>
<tr>
<td>Night (8pm-6am)</td>
<td>0.72</td>
<td>32</td>
<td>3</td>
<td>288931</td>
</tr>
<tr>
<td>Peak (7am-9am &amp; 4pm-6pm)</td>
<td>0.51</td>
<td>22</td>
<td>10</td>
<td>116542</td>
</tr>
<tr>
<td>Off-peak</td>
<td>0.85</td>
<td>26</td>
<td>6</td>
<td>578148</td>
</tr>
</tbody>
</table>
Florida Statewide Model

- Apply trained model to entire road network
  - Requires 3 months of hourly input data at ~20k TMC segments
  - Generate hourly volume estimates at each input time/location

![Diagram showing input, model, and output with Florida map and traffic volume visualization]
Florida Statewide Model: Tampa Bay Area

ATR station selected that exhibits typical (median) model performance
Florida Results: AADT & AAWDT

<table>
<thead>
<tr>
<th>Measure (VPD)</th>
<th>AADT</th>
<th>AAWDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R^2</td>
<td>0.96</td>
<td>0.96</td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>

5/23/2018
Summary & Next Steps

• Hourly volumes:
  • Results are good and can be a useful product for both public and private sector
  • Estimation quality improves with road class and actual volumes (number of probes)
  • Estimates meet requirements for most planning and operational purposes
  • Estimates can be safely used for performance measurement and reporting

• AADT and AAWDT estimates:
  • Results are astoundingly good!
  • Consistent with expectation along major highways and urban areas

• Freight volumes
  • Generated volume estimates for light and heavy trucks
  • Results are very promising. Details will be shared in future presentations.

• Test spatial transferability of models
  • Can a model be trained with data from one location, and applied elsewhere?
  • Working with Florida, Maryland and New Hampshire datasets
Questions

Contact Information

Kaveh Farokhi Sadabadi (PI)
kfarokhi@umd.edu

Przemyslaw Sekula
psekula@umd.edu

Zachary Vander Laan
zvanderl@umd.edu
Ubiquitous Volume Estimation – Both Freeway and Off-Freeway
Results on Colorado Roadways
Freeways and Off-freeways
Volume Estimation on Freeways

- 14 CCS locations and TomTom segments
Data Sources – both Freeway and Off-Freeway

- CDOT continuous count stations (freeways) and 48-hour short-term counts (off-freeways)
  - Hourly volume, road class, number of lanes
- Weather Underground
  - Temperature, precipitation, visibility, fog, rain, snow daily (freeways) and hourly (off-freeways)
- TomTom GPS Data
  - Probe count – key ingredient, speed, speed limit
- Temporal information
  - Month, day of week, hour of day
Data Points – Freeway Analysis

- Feb 1, 2017 – April 30, 2017
- A total of 52,092 observations
- Ranges from 2800-4000 observations at each CC location
Penetration Rates – Freeway Analysis

- Percentage of traffic covered by GPS probe data
- Ranges from 8%-12%
• Machine learning
  - Random Forest (RF)
  - Gradient Boost Machine (GBM)
  - Extreme Boost Machine (XGBoost)

• Advantages
  - Do not require detailed mathematical forms and assumptions on variable distributions
  - Suitable for capturing the underlying relationships among different variables in an environment of uncertainty

• Disadvantages
  - Interpretability of input variables (“black box”)
  - Only predict within bounds of training – no extrapolation
Model Training and Validation

- In each iteration
  - 13 stations are used for training
  - 1 station is used for validation
- Repeat this 14 times and report validation results for all 14 locations

- Accuracy metrics accrued from validation of 14 iterations (similar method used for off-freeway)
Model Results

- Results exceed the survey expectation: ETCR<10%
- About 18% error relative to observed volume
- XGBoost is the most computational efficient

<table>
<thead>
<tr>
<th>Model</th>
<th>MAPE</th>
<th>ETCR</th>
<th>R2</th>
<th>Training Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>17.8%</td>
<td>5.2%</td>
<td>0.92</td>
<td>73s</td>
</tr>
<tr>
<td>GBM</td>
<td>18.3%</td>
<td>4.8%</td>
<td>0.93</td>
<td>124s</td>
</tr>
<tr>
<td>XGBoost</td>
<td>17.7%</td>
<td>5.3%</td>
<td>0.91</td>
<td>13s</td>
</tr>
</tbody>
</table>
Model Comparison

• Compare with TTI Method
  o MAPE: ~50% reduction
  o ETCR: ~30% reduction
  o $R^2$: ~10% increase

• Compare with linear regression:
  o MAPE: ~60% reduction
  o ETCR: ~30% reduction
  o $R^2$: ~10% increase
## Contribution of Probe Vehicle Data

- Probe vehicle data has significant impact on volume estimation accuracy

<table>
<thead>
<tr>
<th></th>
<th>Overall MAPE</th>
<th>Overall ETCR</th>
<th>Median $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Probe Data</td>
<td>39.4%</td>
<td>12.4%</td>
<td>0.65</td>
</tr>
<tr>
<td>With Probe Data</td>
<td>17.7%</td>
<td>5.3%</td>
<td>0.91</td>
</tr>
</tbody>
</table>
Solution to Enhancing Network Observability
Traffic for Different Time Periods

Wednesday 8:00 am

Wednesday 2:00 pm

Wednesday 1:00 am

Saturday 8:00 am
Does It Work Off Freeways?
Road Functional Class

• FHWA functional classification

Freeways
  o Interstates
  o Other Freeways

Lower Class Roads
  o Principal Arterials
  o Minor Arterials
  o Major Collectors
  o Minor Collectors
  o Local Streets

<table>
<thead>
<tr>
<th></th>
<th>Lower Class Roads</th>
<th>Freeways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of Miles</td>
<td>98.5%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Percentage of Lane Miles</td>
<td>96.7%</td>
<td>3.3%</td>
</tr>
<tr>
<td>Percentage of VMT</td>
<td>68.5%</td>
<td>31.5%</td>
</tr>
<tr>
<td>Monitoring Method</td>
<td>Short-term counts</td>
<td>Continuous count stations &amp; Short-term counts</td>
</tr>
</tbody>
</table>

Data source: FHWA Highway Statistics 2013
Volume Estimation on Lower Functional Class Roads

<table>
<thead>
<tr>
<th>Lower Class Roads</th>
<th>Freeways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume data source</td>
<td>48-hour short-term count</td>
</tr>
<tr>
<td>Number of locations / Data points</td>
<td>359 / ~35,000</td>
</tr>
<tr>
<td>Data collection period</td>
<td>Jan. – Sep., 2017 (9 months)</td>
</tr>
</tbody>
</table>

- 300 for training/calibrating
  - Total of 30,096 data points
- 59 locations for testing
  - Total of 5,118 data points
Hourly Volume Distribution

- Volume data is directional – both for volume and probe counts
- Lower functional class
  - More than 25% of hourly volumes are between 0 to 50 vehs/hr
- Freeway
  - ~1% of hourly volumes are between 0 to 100 vehs/hr
48-hour Count Data Characteristics by Functional Class

• ~80% of observations on principal and minor Arterials
• Volume on local streets are extremely low
• Few probe counts and low penetration rate on local streets

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Arterial</td>
<td>52%</td>
<td>619</td>
<td>47.1</td>
<td>7.7%</td>
</tr>
<tr>
<td>Minor Arterial</td>
<td>27%</td>
<td>257</td>
<td>16.9</td>
<td>7.7%</td>
</tr>
<tr>
<td>Major Collector</td>
<td>13%</td>
<td>129</td>
<td>5.9</td>
<td>4.1%</td>
</tr>
<tr>
<td>Local Street</td>
<td>8%</td>
<td>19</td>
<td>0.6</td>
<td>3.1%</td>
</tr>
<tr>
<td>Overall</td>
<td>100%</td>
<td>414</td>
<td>29.8</td>
<td>6.4%</td>
</tr>
</tbody>
</table>
Input Variables for Hourly Volume Estimation

• TomTom Traffic data from probes  
  o Hourly average speed and probe count

• **Hourly weather information (previously daily)**  
  o Temperature, precipitation, visibility, fog, rain, snow

• Road characteristics  
  o Road class, urban or not, speed limit  
  o **2015 AADT**  
  o **Longitude, latitude**

• Temporal information  
  o Month, day of week, hour of day

• Model training and validation used similar procedures  
  (Random assignment to 10 groups: train on 9, validate 10th)
Model Evaluation Criteria

- **Mean Absolute Percentage Error (MAPE)**
  - Reflect the absolute volume accuracy
- **Coefficient of Determination ($R^2$)**
  - Explanatory power of model

---

New Measures need for Off-Freeway Results

- **Error to Maximum Flow Ratio (EMFR)**
  - Reflect volume to capacity fidelity
- **Mean Absolute Error (MAE)**
  - Reflect the absolute error
  - Effective for low volume roads
Model Results Comparison

- Much more accurate than linear regression and AADT based methods

<table>
<thead>
<tr>
<th>Model</th>
<th>MAPE (Vol&gt;20)</th>
<th>MAE</th>
<th>EMFR</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>XGBoost</td>
<td>29.7%</td>
<td>10.8%</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>Linear</td>
<td>90.4%</td>
<td>20.5%</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>AADT Based Method</td>
<td>124.9%</td>
<td>28.1%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The results include extreme low volume

- Further examine MAPE and EMFR for volume > 20 vehs/hr

<table>
<thead>
<tr>
<th>Model</th>
<th>MAPE (Vol&gt;20)</th>
<th>EMFR (Vol&gt;20)</th>
</tr>
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<tbody>
<tr>
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<td>124.9%</td>
<td>28.1%</td>
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- Need to look at accuracy in volume ranges
MAPE of Different Volume Range

- Volume > 300 vehs/hr: MAPE is low and stable
- Volume < 300 vehs/hr: MAPE is high, but model is still good
MAPE of Different Volume Range
48-Hour Prediction on Test Locations

**Principal Arterial**

Station ID: 106501, MAPE=35.8%, MAE=68.2

**Minor Arterial**

Station ID: 900152, MAPE=24.8%, MAE=30.6

**Major Collector**

Station ID: 106992, MAPE=29.4%, MAE=29.6

**Local Street**

Station ID: 901909, MAPE=38.6%, MAE=3.1
Summary

• Machine learning provides high accuracy for hourly volume estimation on unmonitored segments
• XGBoost is promising tools for hourly volume estimation on both freeways and lower functional class roads
• GPS probe data has significant impact on volume estimation
• Next steps
  o Integrate to one single model to estimate volume on all functional class
  o Scale up to state level estimation
  o AADT estimation
Questions?

Yi Hou, PhD
National Renewable Energy Laboratory (NREL)
yi.hou@nrel.gov
Summary

• Off-Freeway volumes significantly less
Colorado Off-Freeway Results

- Stable, unbiased estimates at low volume
- Performance is volume dependent
  - Principal & Minor Arterials – GOOD
  - Major Collector – Maybe
  - Local Street – Not likely
- Need Low-Volume Filter / Flag
Florida Results

- Trained network on Freeways through Minor Arterials
- EMFR < 7%
- Performance volume dependent

<table>
<thead>
<tr>
<th>Road Classification</th>
<th>R2</th>
<th>MAPE (%)</th>
<th>EMFR (%)</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeways (FRC 1)</td>
<td>0.86</td>
<td>21</td>
<td>6</td>
<td>195704</td>
</tr>
<tr>
<td>Maryland (mostly FRC 1)</td>
<td>0.86</td>
<td>23</td>
<td>7</td>
<td>158040</td>
</tr>
<tr>
<td>Principal Arterials (FRC 2)</td>
<td>0.82</td>
<td>26</td>
<td>7</td>
<td>370567</td>
</tr>
<tr>
<td>Major/Minor Arterials (FRC 3 &amp; 4)</td>
<td>0.83</td>
<td>33</td>
<td>7</td>
<td>128419</td>
</tr>
</tbody>
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<th>Hourly Volume (vph)</th>
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I-95 CC Webinar ›
Accurate Estimates of Traffic Volume from GPS Probe Samples
May 23, 2018
Putting this to work – sample application

• Colorado – calibrate operations sensors
  • Colorado maintain nearly 3000 operations sensors related to ramp metering, signals, speed, etc.
  • Maintaining/calibrating that network is sensor is time and resource intensive. Subject to weather (wind) issues.
  • A tool to identify, prioritize and manage that sensor network could extend already scarce maintenance funds.
  • Exploring with CDOT on how to integrate volume estimation with data systems
Performance Measures for Each Roadway – for Each Hour

• Maryland – Hours of Delay
  • Initial attempt to apply hours of delay resulted in abnormally large delay estimates
  • During winter storms, prevailing methods assumed normal ‘weekday’ traffic
  • Although real-time speed estimates were available, volume data proved inadequate
  • New method allows for 24x7x365 applications of performance metrics, rather than ‘average conditions’
On-going and Future Work

• Confidence Measures
• Handling volumes outside of training data set
• Better, consistent, standardize accuracy metrics
  • By number of observed probes
  • By roadway volume / AADT
  • By time of day
• Estimating truck volumes

Seeking Operational Partners:

• Taking it from the Laboratory to the Streets ....
  If interested please contact Kaveh, Denise or Stan
Poll Question #1

1 How would you use this volume data in your agency?

___ Planning purposes
___ Operational purposes
___ Management Decisions
___ All of the above
Thank You!

For Questions, please contact:

• Kaveh Sadabadi (UMD-CATT) 301-405-1352 or kfarokhi@umd.edu

• Denise Markow (I-95 Corridor Coalition) 301-789-9088 or dmarkow@i95coalition.org

• Stanley Young (NREL) 301-792-8180 or Stanley.Young@nrel.gov
Thank You!