Quality Volume Data Anytime & Anywhere: A Big Data Success Story

Results from NREL/UMD/I95 Corridor Coalition Research

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Oct. 31, 2018
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

Ubiquitous network observability

• 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

Best alternative
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
How Good is Good Enough?

- **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

- **Error to Capacity (ETCR) or Max Flow (EMFR)**
  - < 10% becomes useful  < 5% is target
  - {For highway operations, reflective of capacity constraint situations}
Volume Estimation on Freeways
Input Data

- 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

Calibrated to the 14 Continuous Count Stations in Denver region
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
- Percentage of traffic covered by GPS probe data (ranges from 8%-12%)
Estimation Methodology

• Machine Learning: A subfield of computer science that gives computers the ability to learn from data without being explicitly programmed
  – 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 Cross-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)
Volume Estimation Results

- Results exceed the survey expectation: ETCR<10%
- About 18% error relative to observed volume
- Representative results:

<table>
<thead>
<tr>
<th>Model</th>
<th>MAPE</th>
<th>ETCR</th>
<th>R2</th>
<th>Training Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>XGBoost</td>
<td>17.7%</td>
<td>5.3%</td>
<td>0.91</td>
<td>13s</td>
</tr>
</tbody>
</table>

• Without Probe Data

<table>
<thead>
<tr>
<th>Without Probe Data</th>
<th>MAPE</th>
<th>ETCR</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>39.4%</td>
<td>12.4%</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Estimation vs. Observation
Volume Estimation on Non-Freeways
Functional Classification of Roadways

FHWA functional classification

**Freeways**
- Interstates
- Other Freeways

**Lower Class Roads**
- Principal Arterials
- Minor Arterials
- Major Collectors
- Minor Collectors
- Local Streets

<table>
<thead>
<tr>
<th>Property</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
Calibration / Validation Network

Freeway
• 14 Continuous Count Stations
• Probe sample 8%-12% of trips

Off-Freeway
• 359 48-hour count locations
• Probe sample 3.1%-7.7% of trips (~6.4% mean)

- More than 25% of hourly volumes are between 0 to 50 vehs/hr
- ~1% of hourly volumes are between 0 to 100 vehs/hr
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
MAPE of Different Volume Ranges

- Volume > 300 vehs/hr: MAPE is low and stable
- Volume < 300 vehs/hr: MAPE is high, but model is still good
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
Aggregate Volume Measures - AADT
Florida Analysis – UMD Partner

• Overview
  • Objectives
  • Volume estimation approach

• Florida case study
  • Dataset
  • Results
    • Statewide estimates
    • AADT/AAWDT
    • Truck Volumes
    • Flagging unusual behavior

• New Hampshire case study
  • Dataset
  • Results
    • Statewide estimates
    • AADT/AAWDT
    • Model transferability

• Summary / Next Steps
• Q & A
Florida Dataset (Q4 2016)

Data needed at all TMCs

- **GPS probe data** (INRIX)
  - 75M trips, 3.4B pts
  - Penetration rate: 2.1% median
  - Snapped to base map

- **Probe speeds** (HERE)

- **Road characteristics**
  - # lanes, speed limit, facility type, etc.

- **Weather**

- **TTI hourly volume estimates**

Data needed only at continuous count stations

- **Ground truth count data** (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 Results: Summary

→ **Overall median error metrics:**
  - R2 = 0.83
  - MAPE = 25%
  - EMFR = 7%

**Summary**
Promising model performance, even over a variety of scenarios

**Observations**
- ↑ Road class = ↑ Accuracy
- ↑ Avg. hourly volume = ↑ Accuracy
- ↑ Avg. hourly GPS counts = ↑ Accuracy

<table>
<thead>
<tr>
<th>Median Error Metrics by Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Road Classification</strong></td>
</tr>
<tr>
<td>FRC 1 (Interstates)</td>
</tr>
<tr>
<td>Maryland (mostly FRC 1)</td>
</tr>
<tr>
<td>FRC 2 (Other Freeways &amp; Expressways)</td>
</tr>
<tr>
<td>FRC 3 &amp; 4 (Other principal &amp; minor arterials)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Hourly Volume (vph)</strong></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><strong>Avg probe counts / hr</strong></th>
<th>R2</th>
<th>MAPE (%)</th>
<th>EMFR (%)</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Low” [0-6]</td>
<td>0.78</td>
<td>38</td>
<td>8</td>
<td>214557</td>
</tr>
<tr>
<td>“Medium” [6-17]</td>
<td>0.84</td>
<td>24</td>
<td>7</td>
<td>249730</td>
</tr>
<tr>
<td>“High” [17-145]</td>
<td>0.85</td>
<td>22</td>
<td>6</td>
<td>230403</td>
</tr>
</tbody>
</table>
Florida: AADT & AAWDT Estimation

<table>
<thead>
<tr>
<th>Measure (VPD)</th>
<th>R²</th>
<th>MAPE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>0.86</td>
<td>15</td>
</tr>
<tr>
<td>AAWDT</td>
<td>0.87</td>
<td>15</td>
</tr>
</tbody>
</table>

AADT

AAWDT
Summary / Conclusions

• Volume estimation can be supported with a combination of:
  – Commercial Probe Data (Probe count & Speed/Travel Times)
  – Other road attribute data and weather
  – High confidence ground truth sensor for calibration and validation
• Machine learning provides rapid and sustainable calculation methods
• Probe data is key ingredient to accurately estimate traffic volumes
• Can be applied for both historical and real-time
On-going / Future Work

• **Finishing up Phase I – Proof of Concept**
  – Results in CO, MD, FL, NH
  – Established metrics and targets
  – Methods scaled from freeways to local streets

• **Phase II – Prototype – initiating in January 2019**
  – Funded through Dept. of Energy Technology Commercialization
  – Colorado DOT collaborating (lead) state – other states participating
    TomTom industry partner (possibility of other vendors)
  – Productize to standard specs – and deliver data, real-time and horizontal

• **FHWA/USDOT – Pooled Fund Study – sometime in 2019**
  – Exploring Non-Traditional Methods to Obtain Vehicle Volume and Class Data

Contact us if interested!
Thank You!

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