Ubiquitous Volume Estimation - A Machine Learning Approach: Results from the Denver Metropolitan Area

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June 13, 2018
Outline

1. Motivation and Background
2. Standard Error Measures in Prediction
3. Volume Estimation on Freeways
4. Volume Estimation on Non-Freeways
5. Summary and Future Work
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

Ubiquitous network observability
- Ideal but expensive to achieve with sensors

Best alternative
- 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

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

Calibration Network

Estimator
Machine Learning Techniques

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

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

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

- **Coefficient of Determination:** \( R^2 = 1 - \frac{(\bar{V}_i - V_i)^2}{(V_i - \bar{V})^2} \)
  - Depicts 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

<table>
<thead>
<tr>
<th>AADT Range</th>
<th>Decreasing (−)</th>
<th>Increasing (+)</th>
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</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>

MNDOT Example
Volume Estimation on Freeways
Volume Estimation on Freeways

- 14 Continuous Count Station (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

• 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 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>
## Contribution of Probe Vehicle Data

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Overall MAPE</th>
<th>Overall ETCR</th>
<th>Median R²</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>

Probe vehicle data has significant impact on volume estimation accuracy!!!
Estimation vs. Observation

Traffic Crash - Serious Injuries

Denver Police Dept. 🚑
@dDenverPolice

#Traffic: Delays possible in area of 6th Ave/Steele St due to a 2-vehicle crash with serious injuries. #Denver
5:37 PM - Feb 23, 2017

DC Sheriff 🚗
@dcsheriff

It's treacherous out! Douglas county is on accident alert. PLEASE slow down and drive carefully! #headsup #dcsotraffic
5:19 PM - Feb 23, 2017

Road Name: US

ON CHANNEL 2

February 24, 2017

Date
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)

~1% of hourly volumes are between 0 to 100 vehs/hr

More than 25% of hourly volumes are between 0 to 50 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
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 has significant impact on volume estimation accuracy

• Can be applied for both historical and real-time
On-going / 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 / AADT

Seeking Operational Partners:
• Taking it from the Laboratory to the Streets ....
  If interested please contact us
Thank You!