Ubiquitous Traffic Volume Estimation through Machine Learning Procedures

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DOE Vehicle Technologies Program
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Project ID # eems063

Overview

Timeline

- Project award date: 09/01/2018
- Project start date: 03/15/2019 (following execution of agreement with commercial partner)
- Project end date: 03/15/2021
- Percent complete: 5% (FY19)

Barriers

- The spatial variance of probe data requires continuous calibration
- Lack of flexible and accessible traffic management data architecture

Budget

Total project funding
  - DOE share: $500K
  - Contractor share: $500K (in-kind)

Funding for FY 2019: $250K

Funding for FY 2020: $250K

Partners

- TomTom, Inc.
- Colorado Department of Transportation (DOT)
- I-95 Corridor Coalition
- Pennsylvania DOT; Tennessee DOT
- University of Maryland
- Texas Transportation Institute

RELEVANCE

- High-quality traffic (vehicle) volume data are critical for transportation planning, operations, and travel-energy calculations.
- However, such data are very sparse owing to the high capital cost and ongoing installation of traffic sensors and their ongoing maintenance.
  - The rapidly increasing availability of commercial vehicle probe data provides a more practical and affordable pathway to obtain network-wide traffic volumes.
- Developing a mature product that reduces cost and increases observability of accurate traffic volumes will benefit the transportation planning and transportation energy research communities.
- Partnering with TomTom to productize a lab-developed "volume prediction" algorithm will accelerate availability of cost-efficient, network-wide volume data.

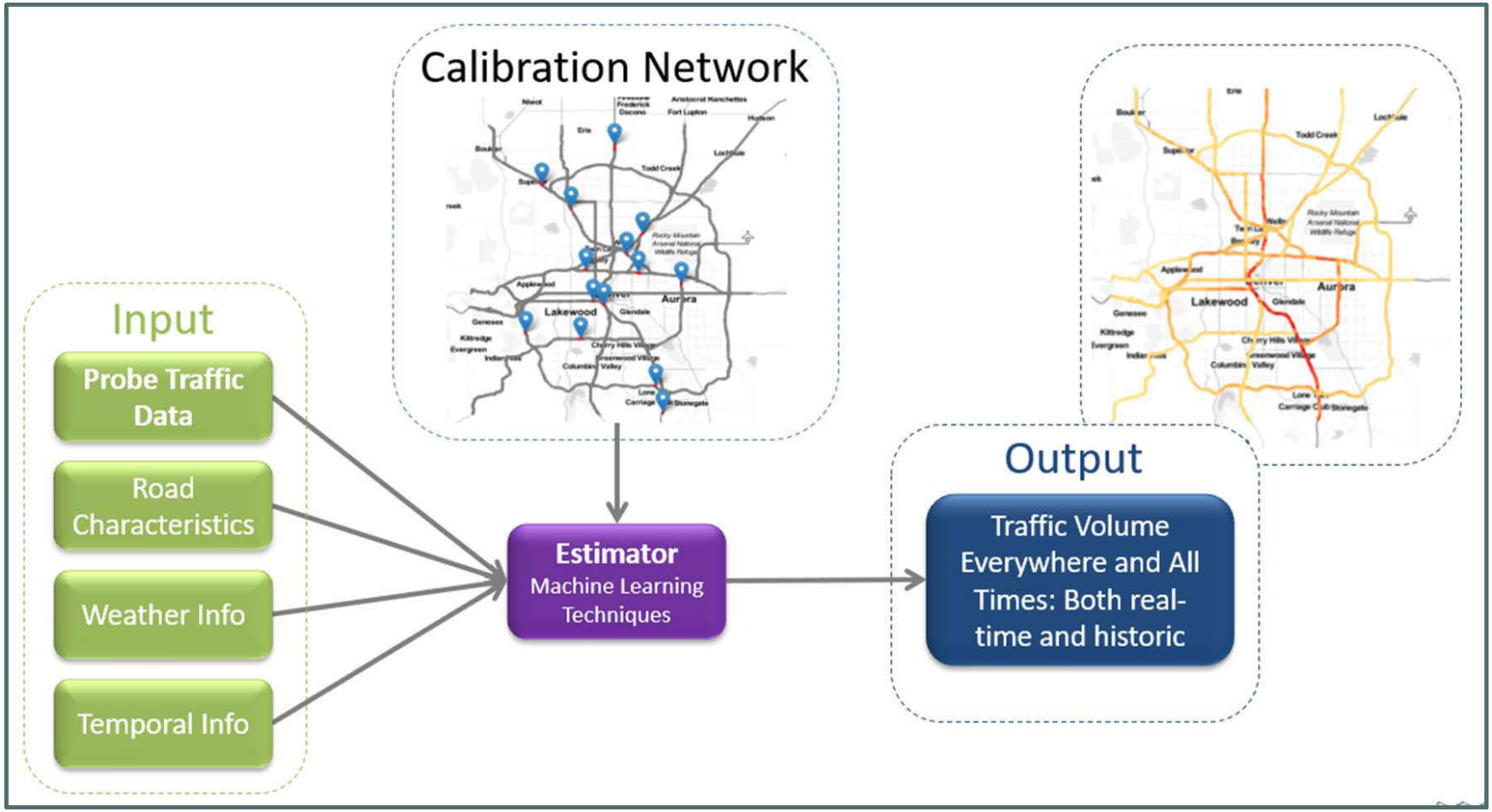
RELEVANCE:
WHY DO WE NEED MORE AND BETTER VOLUME DATA?

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

- Performance measures
  - Assess user costs
  - Utilization of existing capacity

- Economic and energy assessment
  - Estimate economic impact of congestion
  - Quantify vehicle miles travelled and energy use

APPROACH: PROPOSED SOLUTION



Probe Traffic Data

- Data derived from vehicles that self-report their position and speed as well as crowd sourced data from smartphone applications.
- Information reported can be number of probe vehicles crossing a road segment or average speed of all the probe vehicles for a given time period and location.

MILESTONES

Month/Year	Description of Milestone or Go/No-Go Decision	Status
July 2019	Agreement with DOTs to acquire volume data	On-track
October 2019	Report on spatial transferability of the volume prediction algorithm	Scheduled
December 2019	Develop a laboratory prototype of the product	Scheduled

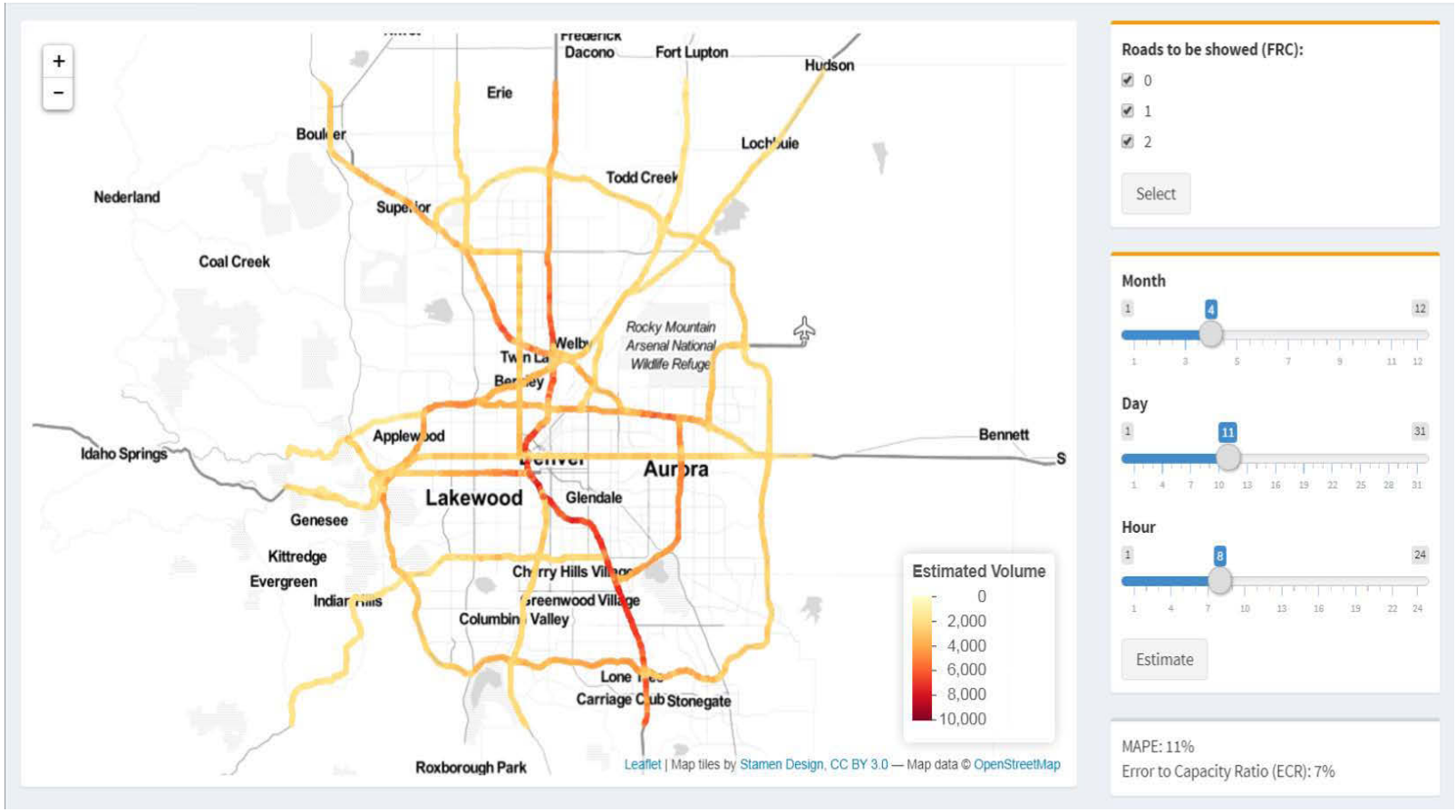
The milestone due dates are adjusted owing to the delayed start of the project.

APPROACH: ESTIMATION METHODOLOGY

- 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

APPROACH: TECHNOLOGY MATURITY

- In the proof-of-concept work, three months of data from 14 continuous counting stations within the Denver metropolitan area were used.



A web application prototype for the volume estimation product.

APPROACH: MEASURES OF EFFECTIVENESS

The following measures of effectiveness (MOE) are used to assess the performance of the proposed machine learning algorithms.

Traffic Engineer

- **Mean Absolute Percentage Error**: $\mathbf{MAPE} = \frac{1}{N}\sum_{i=1}^{N}\frac{|V_i - \widehat{V_i}|}{V_i}$
  - Reflects the absolute volume accuracy

Highway Operations

- **Error to Theoretical Capacity Ratio**: $\mathbf{ETCR} = \frac{1}{N}\sum_{i=1}^{N}\frac{|V_i - \widehat{V_i}|}{C_i}$
  - Reflects fidelity with respect to capacity

Statistician/ Planner

- **Coefficient of Determination**: $\boldsymbol{R^2} = 1 - \frac{(\widehat{V_i} - V_i)^2}{(V_i - \bar{V})^2}$
  - Explanatory power of model

APPROACH: HOW GOOD IS GOOD ENOUGH

Thresholds for various MOEs to consider volume predictions 'good enough' for traffic operations.

- 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)

- Error to Capacity (ETCR) or Max Flow (EMFR)

  < 10% becomes useful < 5% is target

- R^2 Coefficient of Determination

  >70% good >80% better >90% best

Acceptable % Change

AADT * Range	Decreasing (-)	Increasing (+)
0 - 19	-100%	400%
20 - 49	-40%	50%
50 - 99	-30%	40%
100 - 299	-25%	30%
300 - 999	-20%	25%
1000 - 4999	-15%	20%
5000 - 49999	-10%	15%
50000+	10%	10%

Source: Minnesota Department of Transportation (https://www.dot.state.mn.us/traffic/data/)

*AADT: Average Annual Daily Traffic

APPROACH: PROJECT PLAN

Phase 1: Finalizing the Estimation Methodology

- Agreement with state DOTs to acquire volume data
- Acquire probe data for identified regions
- Enhance prediction model; test spatial transferability
- Prepare the final lab prototype
- Model results and prototype demo to state DOTs

Phase 2: Productization and Market Research

- Solicit feedback on prototype from state DOTs
- Incorporate feedback from DOTs
- Scoping level of effort required for new states
- Commercialization plan and structure

Phase 3: Product Integration and Demonstration

- Integrating the product into TomTom's platform
- Beta testing in real-time
- Market the product to multiple DOTs
- Deliver the first version of the product
- Demonstration of energy estimation

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: DATA SOURCES

- Colorado Department of Transportation (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
  - Average speed and speed limit

- Temporal information
  - Month, day of week, hour of day

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: 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

1st iteration

2nd iteration

3rd iteration

...

14th iteration

- Accuracy metrics accrued from validation of 14 iterations

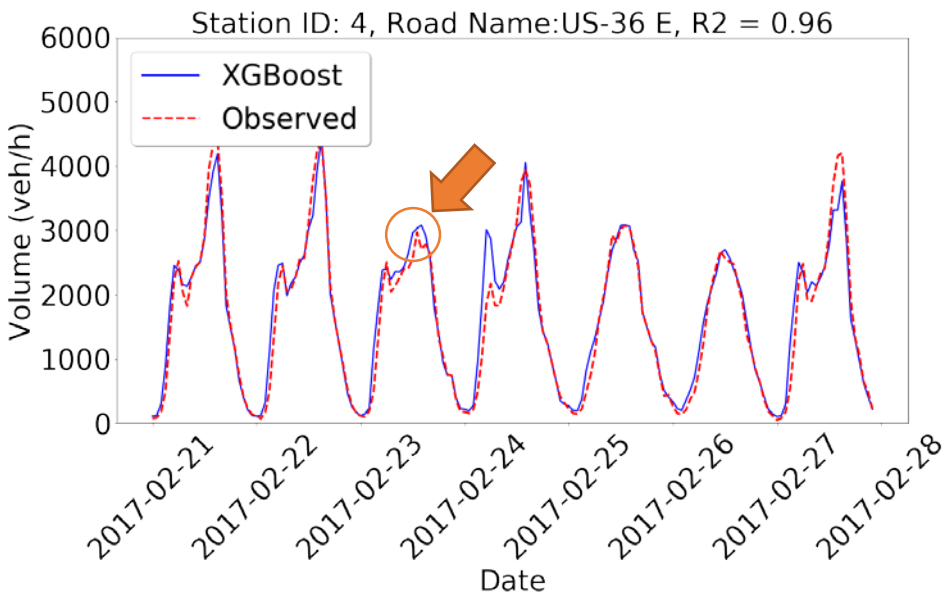
TECHNICAL ACCOMPLISHMENTS AND PROGRESS: MODEL RESULTS

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

Model	MAPE	ETCR	R^2	Training Time
RF	17.8%	5.2%	0.92	73s
GBM	18.3%	4.8%	0.93	124s
XGBoost	17.7%	5.3%	0.91	13s

ETCR: Error to Theoretical Capacity Ratio
MAPE: Mean Absolute Percentage Error

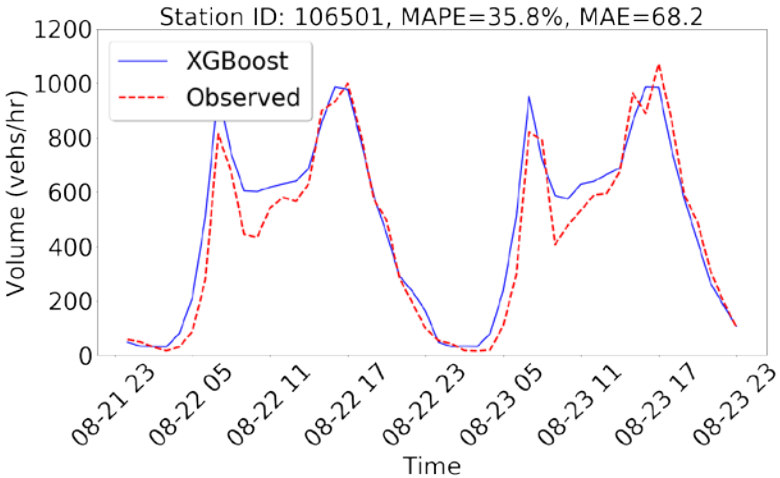
TECHNICAL ACCOMPLISHMENTS AND PROGRESS: ESTIMATION vs. Observation (Median R^2)



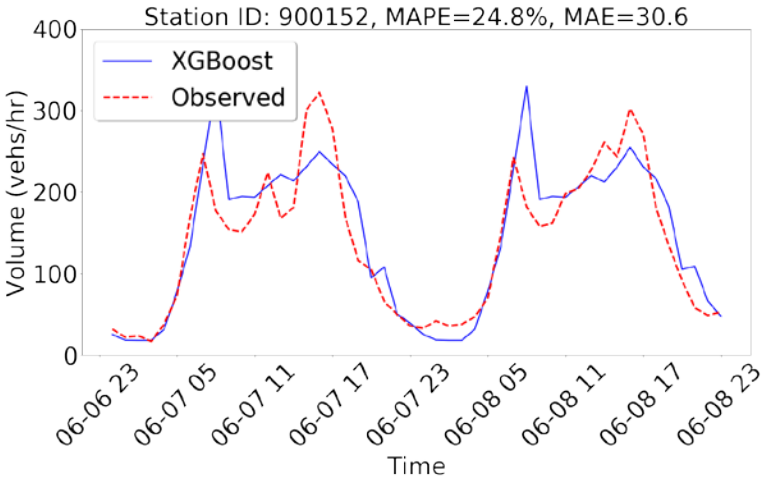
The machine learning algorithm is not only able to predict recurring traffic patterns, but also able to detect anomalies in regular patterns (in this case, due to an extreme weather event).

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: PREDICTIVE PERFOMANCE OF THE ALGORITHM

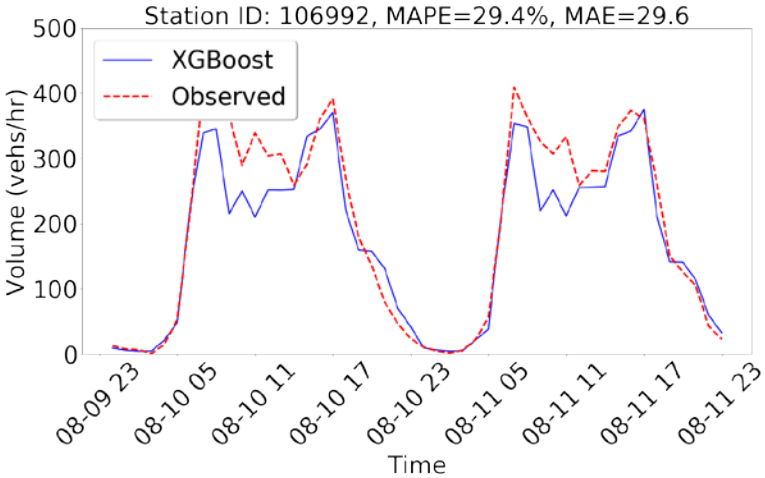
Principal Arterial



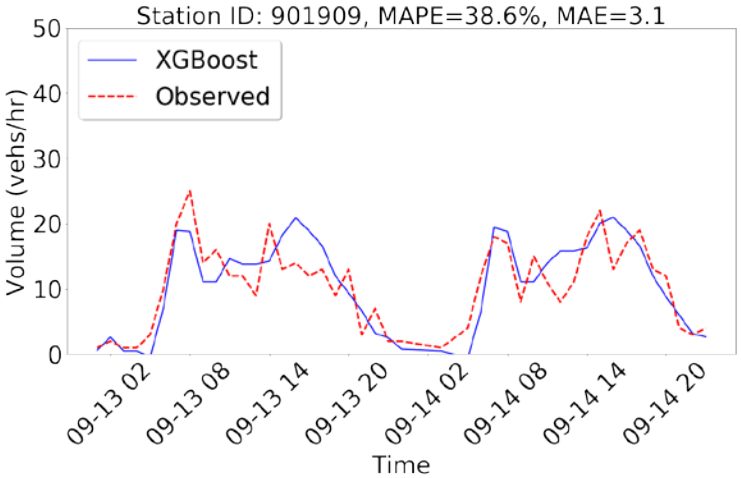
Minor Arterial



Major Collector



Local Street



RESPONSES TO PREVIOUS YEARS REVIEWERS COMMENTS

No AMR review for this project in FY 18, as it was funded in August 2018, but only began in March 2019 owing to contractual issues.

COLLABORATION AND COORDINATION

State Departments of Transportation

- Colorado
- Virginia
- I95 Corridor Coalition
- Pennsylvania
- North Carolina
- Georgia
- Maryland State Highway Administration

Private Partners

- TomTom

Universities/Research Entities

- University of Maryland
- Texas Transportation Institute

REMAINING CHALLENGES AND BARRIERS

- Availability of data, both probe vehicle data (both historic and real-time) and public sensor data, road geometry, weather, etc. for all the regions where the technology needs to be deployed.
- Rigorous validation of the estimation techniques against measured volume data from a wide variety of locations.
- A commercialization challenge/risk for this project is presented by the need for a near real-time calibration network.

PROPOSED FUTURE RESEARCH

- Incorporating vehicle fleet classification in volume predictions
  - Vehicle type detection through camera feeds
- Enhancing out of sample predictions through a mix of machine learning and traditional methods
- Better, consistent, standardize accuracy metrics
  - By number of observed probes
  - By roadway volume / Average Annual Daily Traffic
  - By time of day
- Estimating truck volumes / Average Annual Daily Traffic
- Real-time volume estimates

"Any proposed future work is subject to change based on funding levels."

SUMMARY SLIDE

Volume estimation can be supported with a combination of:

- Commercial probe data
- Other road attribute data and weather
- Ground truth sensors for calibration and validation

Machine learning provides rapid and sustainable calculation method for volume estimation

Probe data have a significant impact on volume estimation accuracy

Can be applied for both historical and real-time

Working with TomTom to productize the estimation methodology

Thank You

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Technical Backup Sides

FEDERAL HIGHWAY ADMINISTRATION (FHWA) ROAD FUNCTIONAL CLASS

- FHWA functional classification

Freeways
- Interstates
- Other Freeways

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

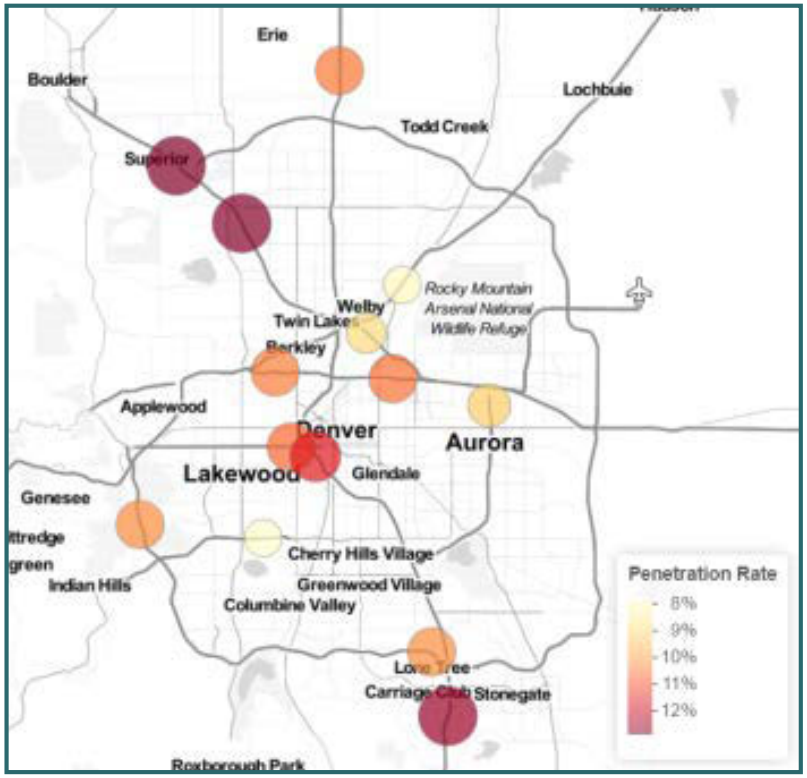
	Lower Class Roads	Freeways
Percentage of Miles	98.5%	1.5%
Percentage of Lane Miles	96.7%	3.3%
Percentage of VMT	68.5%	31.5%
Monitoring Method	Short-term counts	Continuous count stations & Short-term counts

Data source: FHWA Highway Statistics 2013

CALIBRATION / VALIDATION NETWORK

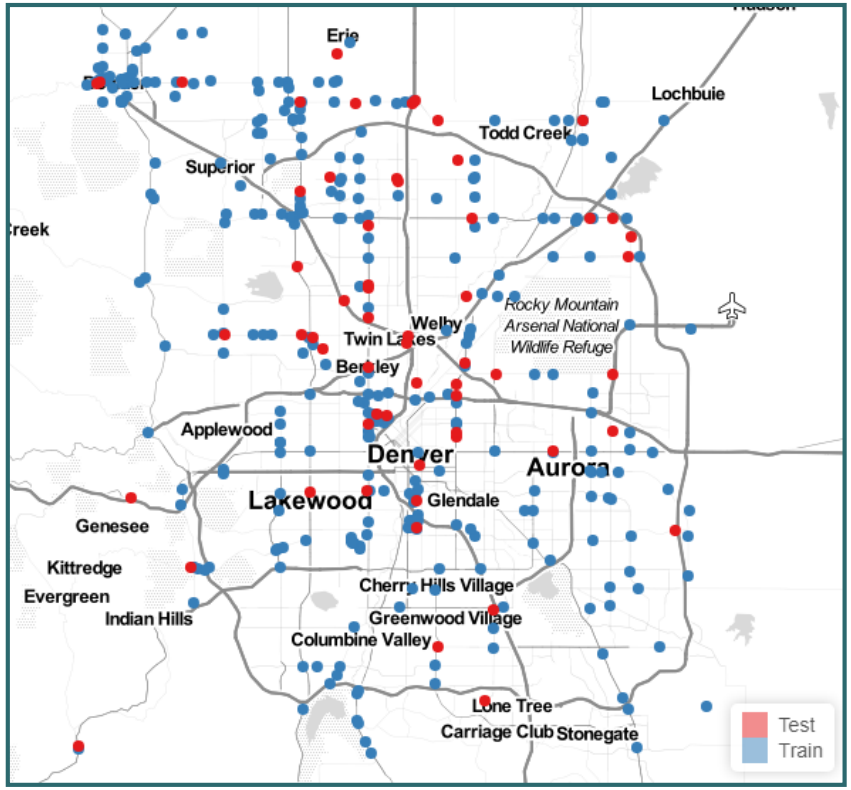
Freeway

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



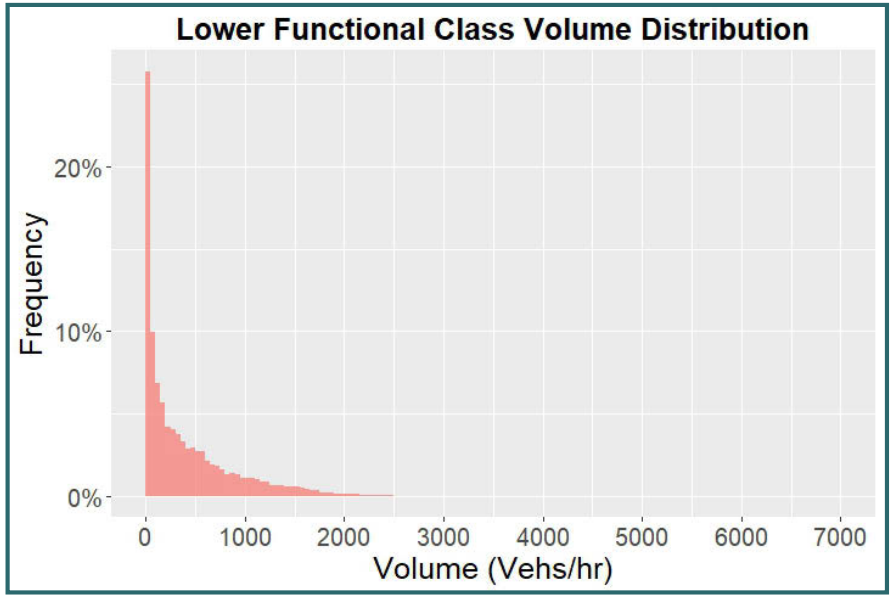
Off-Freeway

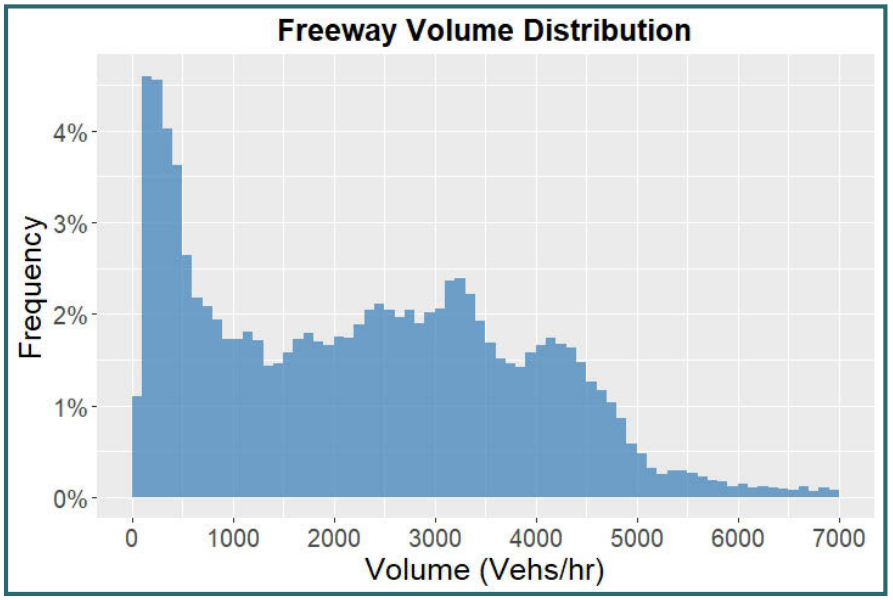
- 359 48-hour count locations
- Probe sample 3.1%-7.7% of trips (~6.4% mean)



HOURLY VOLUME DISTRIBUTION

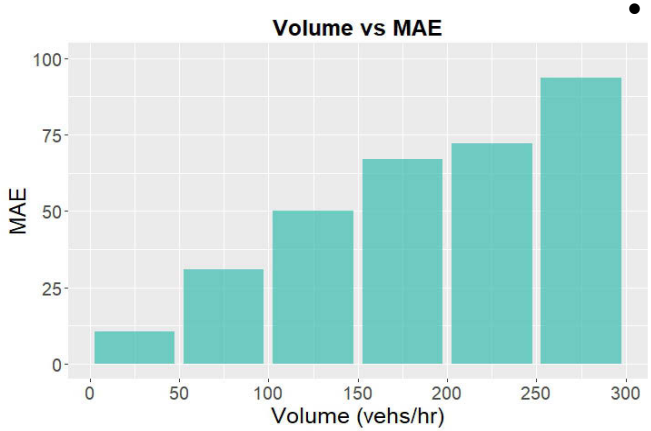
- Volume data are directional, both for volume and probe counts
- Lower functional class
  - More than 25% of hourly volumes are between 0 and 50 vehs/hr
- Freeway
  - ~1% of hourly volumes are between 0 and 100 vehs/hr

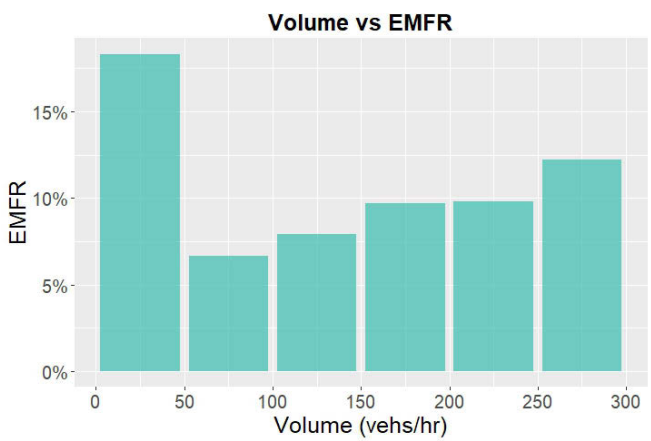


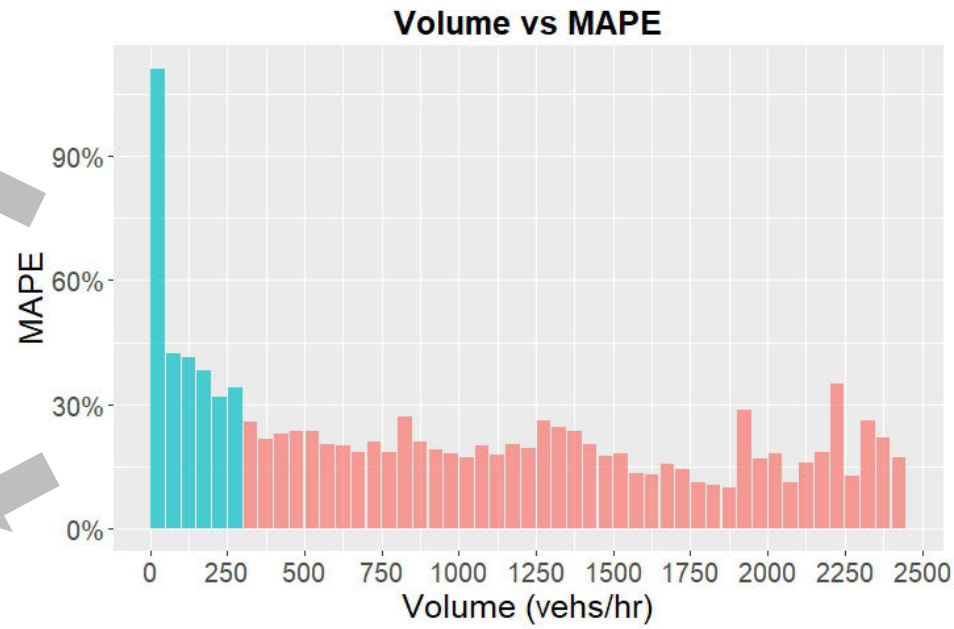


TECHNICAL ACCOMPLISHMENTS AND PROGRESS: MAPE OF DIFFERENT VOLUME RANGES

- Volume>300 vehs/hr: MAPE is low and stable
- Volume<300 vehs/hr: MAPE is high, but model is still good







EMFR: Error to Maximum Flow Ratio