Ubiquitous Traffic Volume Estimation through Machine-Learning Procedure

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National Renewable Energy Laboratory
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DOE Vehicle Technologies Program
2020 Annual Merit Review and Peer Evaluation Meeting

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: 40% (FY 2020)

Barriers

- Accurately measuring transportation system-wide energy impacts
- Difficulty in sourcing empirical real-world data

Budget

- Total project funding
  DOE share: $500K
  Contractor share: $500K (in-kind)
- Funding for Year 1: $250K
- Funding for Year 2: $250K

Partners

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

RELEVANCE

Objective: Commercialize a machine learning based traffic volume estimation tool with TomTom using vehicle probe data.

EEMS STRATEGIC GOAL #2

Identify & support early stage R&D to develop innovative technologies that enable energy efficient future mobility systems.

EEMS STRATEGIC GOAL #3

Share research insights, and coordinate and collaborate with stakeholders to support energy efficient local and regional transportation systems.

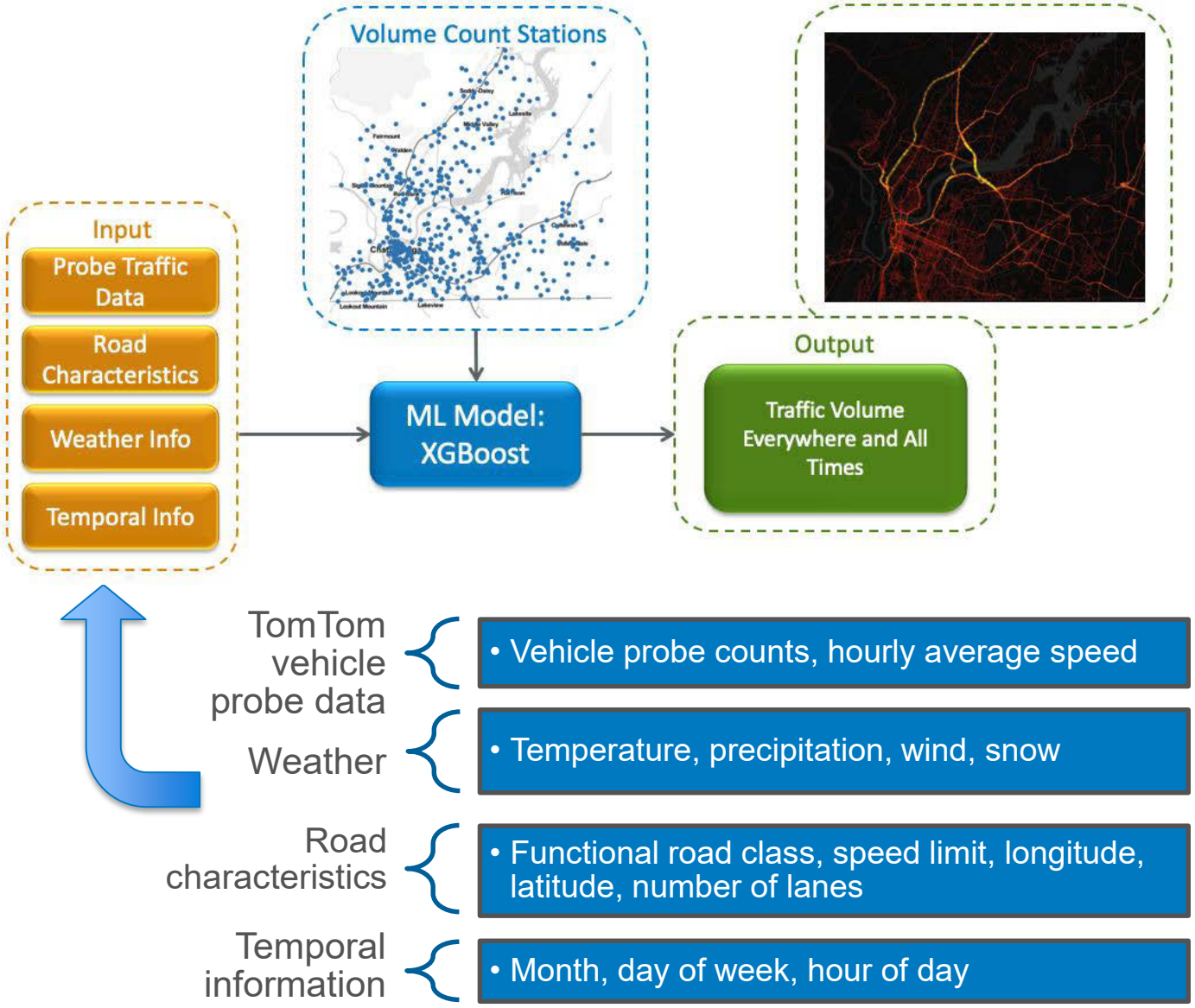
- Energy Assessment
  - Quantify vehicle miles traveled
  - Measuring transportation system-wide energy impacts
- Enhance Energy Efficiency
  - Detect real-time traffic volume in the network
  - Enable real-time traffic operation to improve mobility energy productivity
- Real-world Mobility Data
  - Good quality traffic volume data enables accurate transportation modeling and simulation

MILESTONES

Month/Year	Description of Milestone or Go/No-Go Decision	Status
June 2020	Technical report on validation results from multiple states	Completed
September 2020	Demonstration/presentation of laboratory prototype and its functionalities	On track
October 2020	Detailed commercialization plan (pricing and subscription structures)	On track
February 2021	Demonstration/presentation of the product integrated into TomTom web framework.	Scheduled
June 2021	Technical publication on validation results from real-time deployment.	Scheduled
August 2021	Deliver first version of the product	Scheduled

The milestone due dates shown here are adjusted from the original plan owing to the delayed start of the project

APPROACH: PROPOSED SOLUTION



Model Evaluation Criteria

- **Coefficient of Determination**: Explanatory power of model, between 0 and 1, higher is better

$$\boldsymbol{R^2} = 1 - \frac{(\hat{V}_i - V_i)^2}{(V_i - \bar{V})^2}$$

- **Mean Absolute Error (MAE):** Reflects simple magnitude of error, independent of the actual volume, lower is better

$$\mathbf{MAE} = \frac{1}{N}\sum_{i=1}^{N} \left|V_i - \hat{V}_i\right|$$

- **Weighted Absolute Percentage Error (WAPE)**: Reflects error relative to measured volume, lower is better

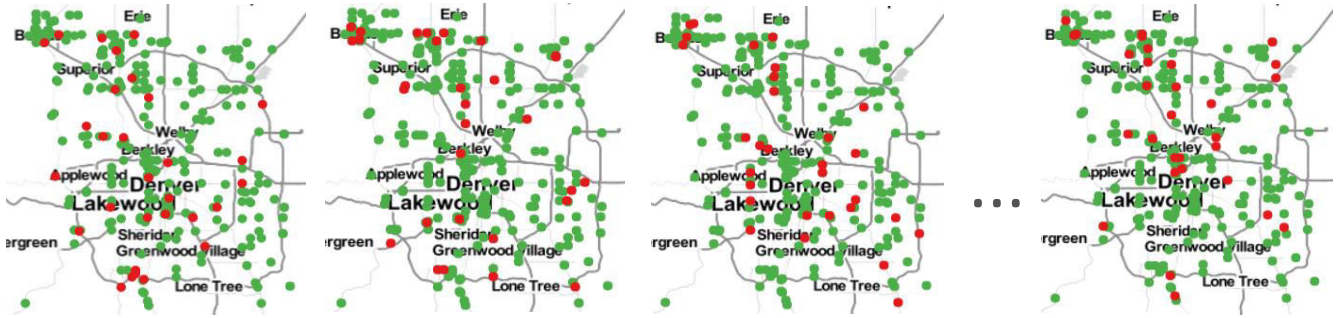
$$\mathbf{WAPE} = \frac{\sum_{i=1}^{N} \left|V_i - \hat{V}_i\right|}{\sum_{i=1}^{N} V_i}$$

- **Error to Maximum Flow Ratio (EMFR)**: Reflects error relative to the max volume observed, lower is better

$$\mathbf{EMFR} = \frac{1}{N}\sum_{i=1}^{N} \frac{\left|V_i - \hat{V}_i\right|}{V_{max}}$$

APPROACH: MODEL TRAINING AND VALIDATION

- Split fused data (vehicle probe data, weather, road characteristics, and temporal information) into training data and test data
- Training locations were randomly and evenly divided into N groups
- Repeat this for N times until all groups are used for validation
  - N-1 groups are used to train a XGBoost
  - 1 group is used to validate the XGBoost estimation results
- Find model hyperparameters that yield the best estimation results
- Train a XGBoost using all training data and test model using test data



1st iteration 2nd iteration 3rd iteration Nth iteration

Red: Validate
Green: Train

How good is good enough?

- Absolute Percentage Error
  - **High Volume (freeways): 10%–15%**
  - **Mid Volume (arterials): 20%–25%**
  - **Low Volume (local roads): 30%–50%**
- Error to Max Flow Ratio (EMFR)
  < 10% becomes useful < 5% is target
- R^2 Coefficient of Determination
  >0.7 good >0.8 better >0.9 best

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: DATA FOR MODEL TRAINING – HARRISBURG, PA

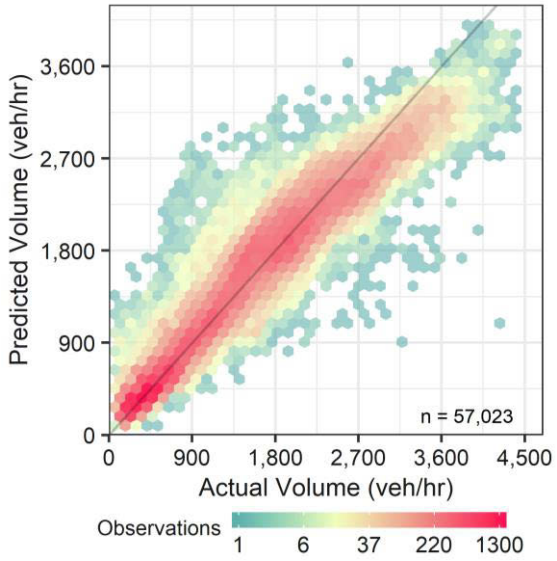
- July 1–December 31, 2018
- 8 stations
- 57,023 observations
- Average probe penetration rate: 13%

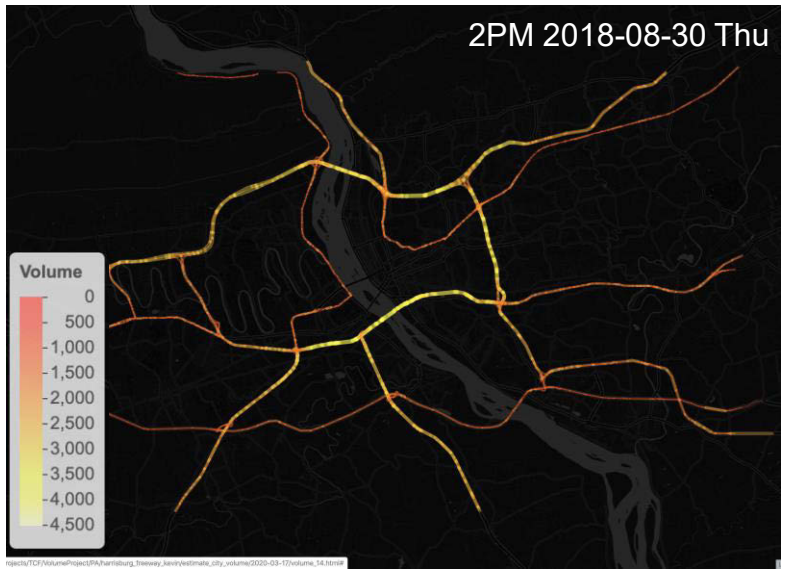
Functional Road Class	# of Continuous Count Stations
Interstate	6
Freeway / Expressway	1
Principal Arterial	1

Average Traffic Volume by Station

FRC: Functional Road Class

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: VOLUME ESTIMATION RESULTS – HARRISBURG, PA



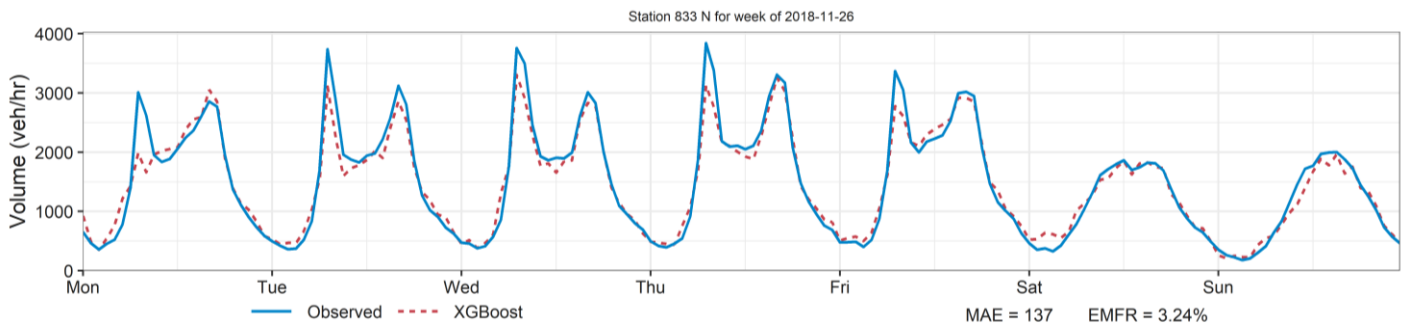


Overall model performance: **Excellent**

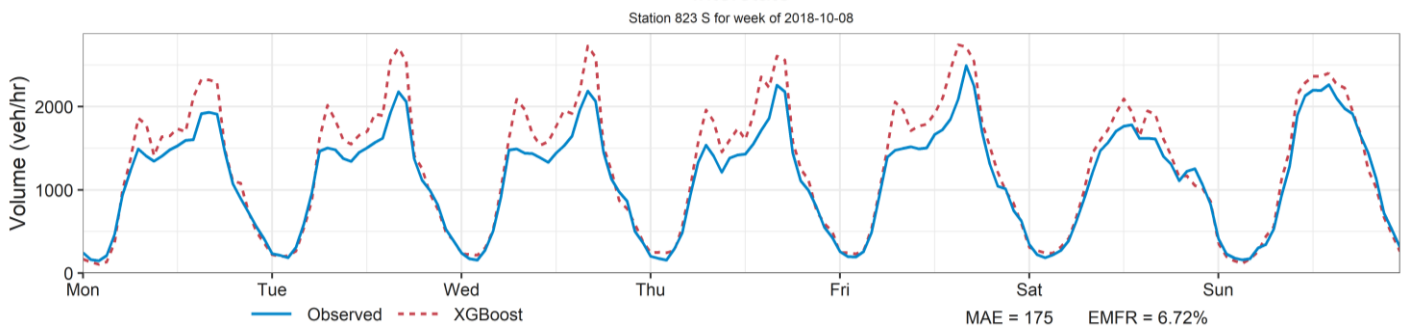
Average Error Over All Stations

R^2	MAE	WAPE	EMFR
0.91	194	13.4%	5.7%

Low Error



High Error



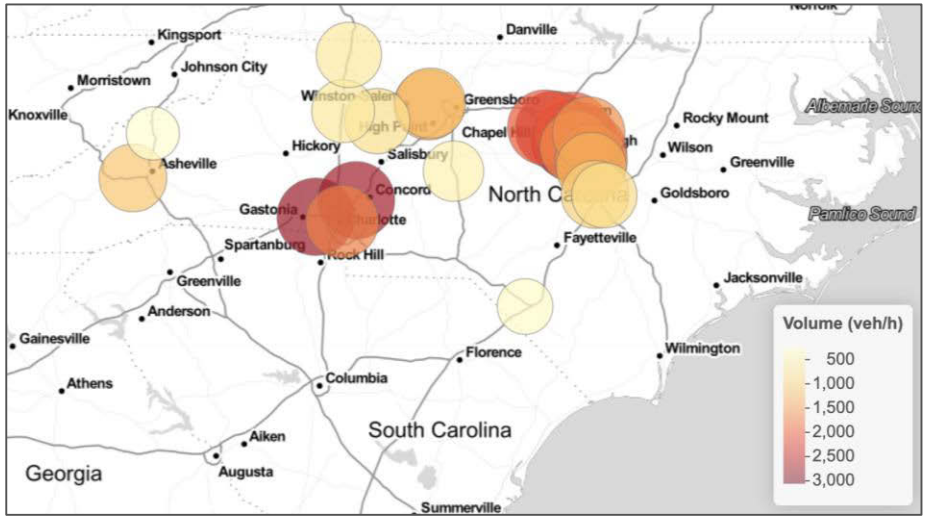
TECHNICAL ACCOMPLISHMENTS AND PROGRESS: DATA FOR MODEL TRAINING – NORTH CAROLINA

- July 1–December 31, 2018
- 52 stations
- 144,923 off-freeway observations
- 185,520 freeway observations
- Average probe penetration rate:

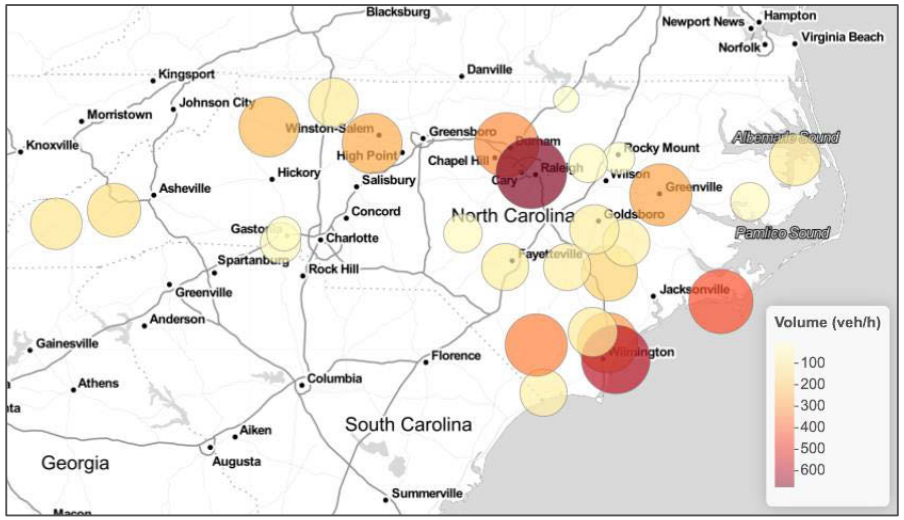
  Off-freeway: 7.5% Freeway: 16%

Federal Highway Administration (FHWA) Functional Class	# of CCSs
Interstate/Freeway	25
Principal Arterial	5
Minor Arterial	10
Minor and Major Collectors	6
Local	6

Average Traffic Volume by Station



Freeways



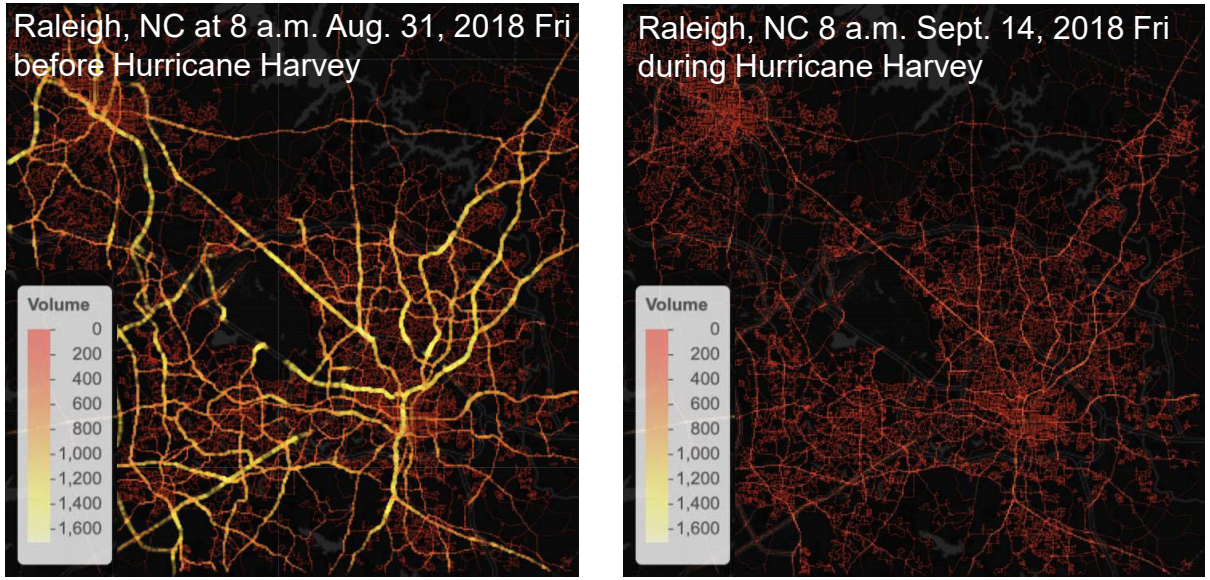
Off-freeways

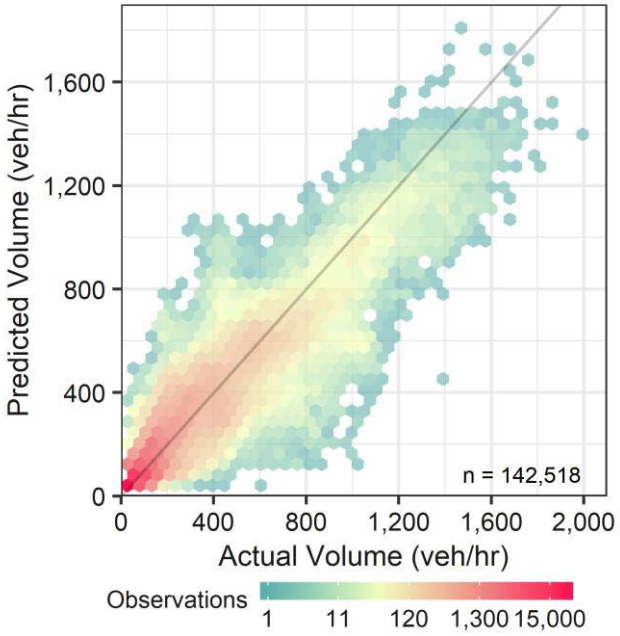
*Note: The circle sizes also scale with volume

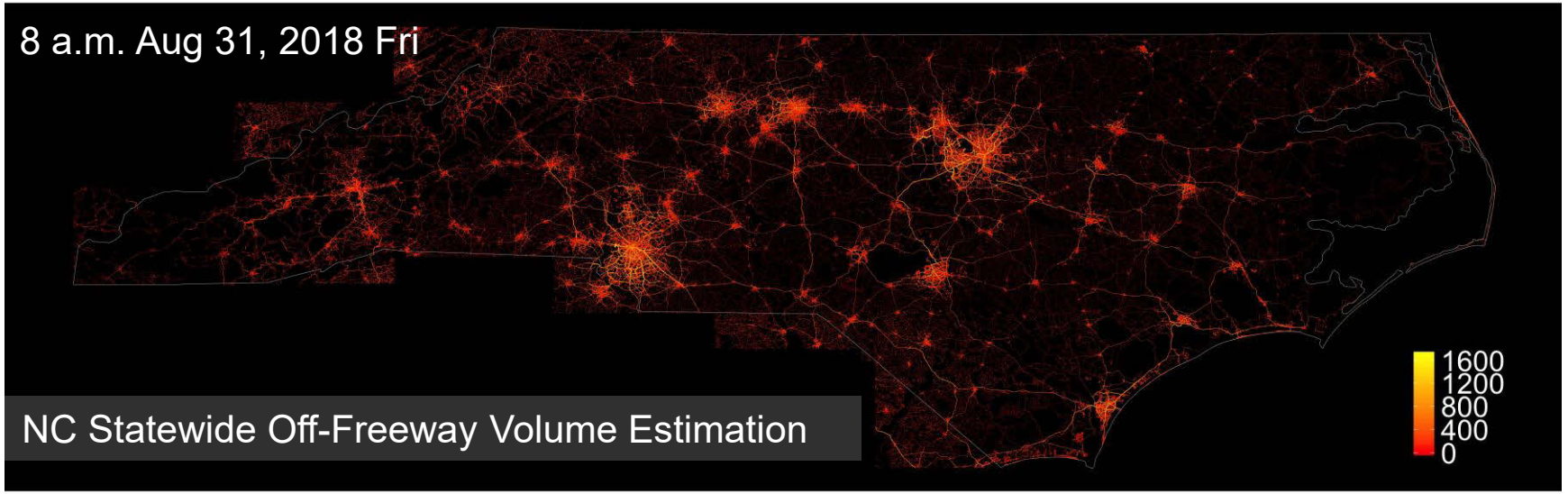
TECHNICAL ACCOMPLISHMENTS AND PROGRESS: OFF-FREEWAY VOLUME ESTIMATION RESULTS – NORTH CAROLINA

Overall model performance: **Good**

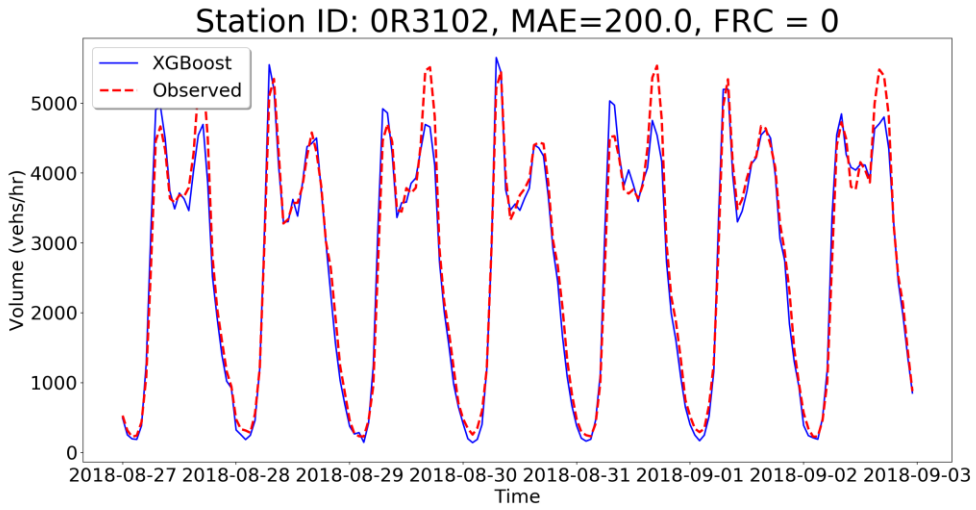
Roadway Type	R^2	MAE	WAPE	EMFR
Off-Freeway	0.87	55	31.6%	13.2%





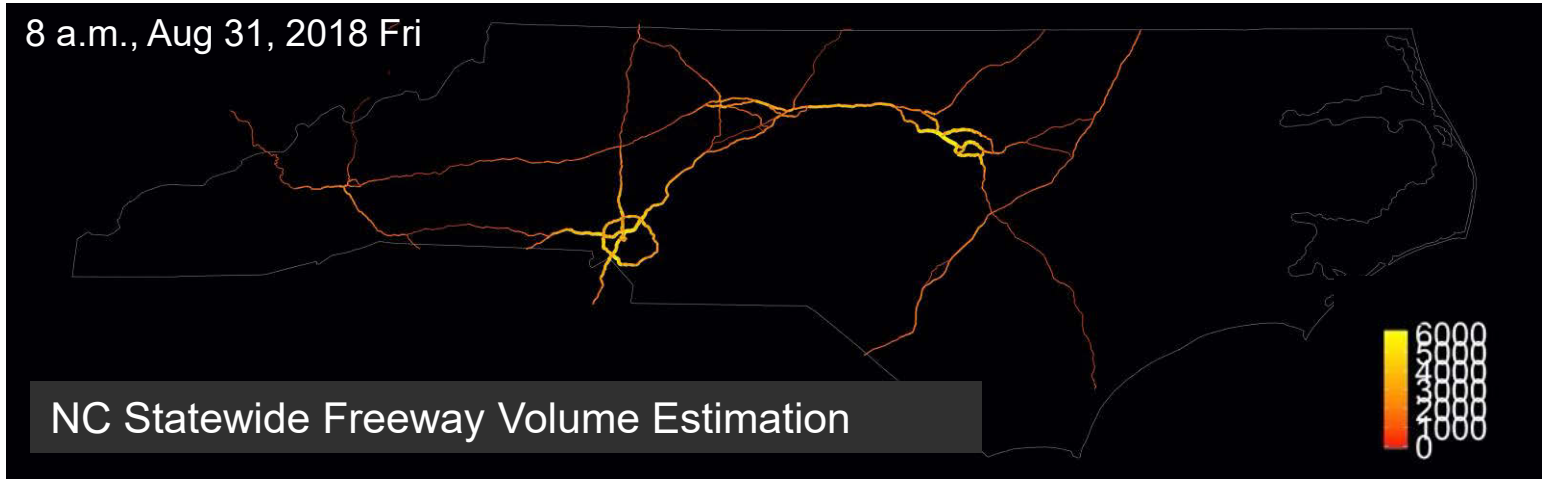


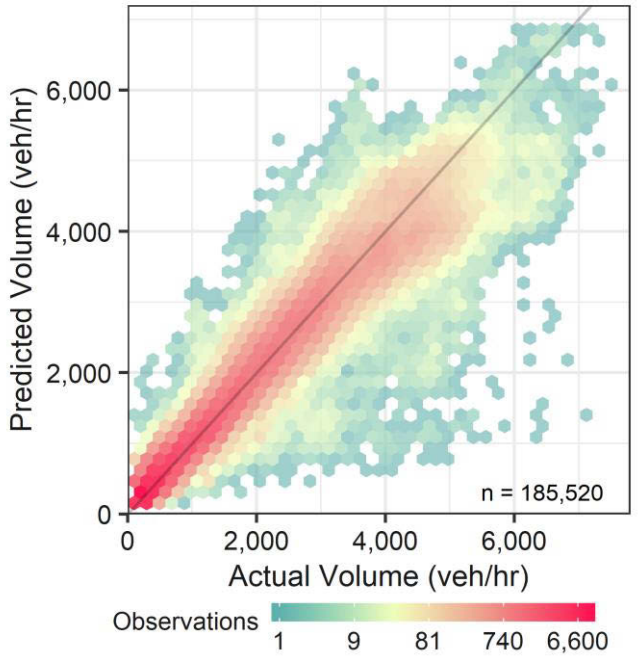
TECHNICAL ACCOMPLISHMENTS AND PROGRESS: FREEWAY VOLUME ESTIMATION RESULTS – NORTH CAROLINA



Overall model performance: **Excellent**

Roadway Type	R^2	MAE	WAPE	EMFR
Freeway	0.92	257	15.4%	6.4%

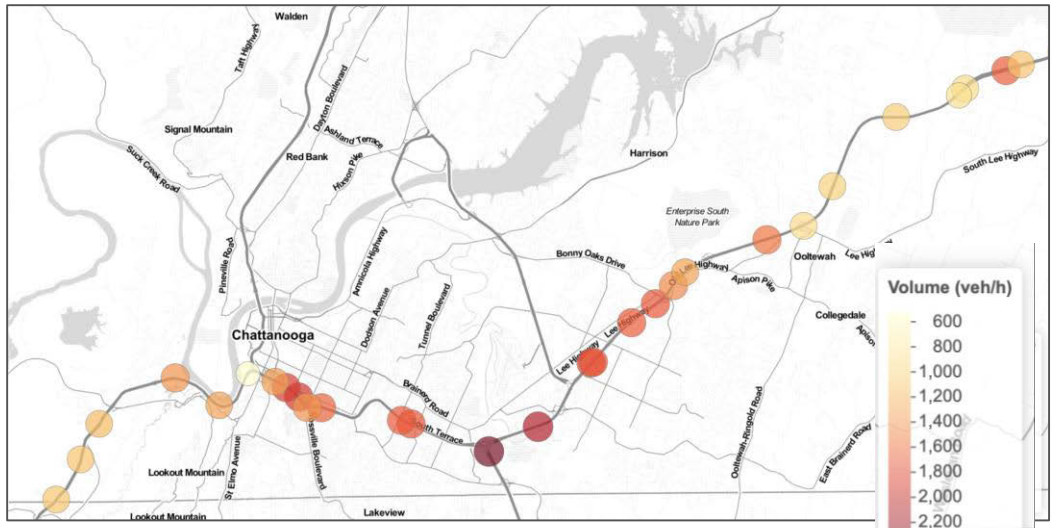




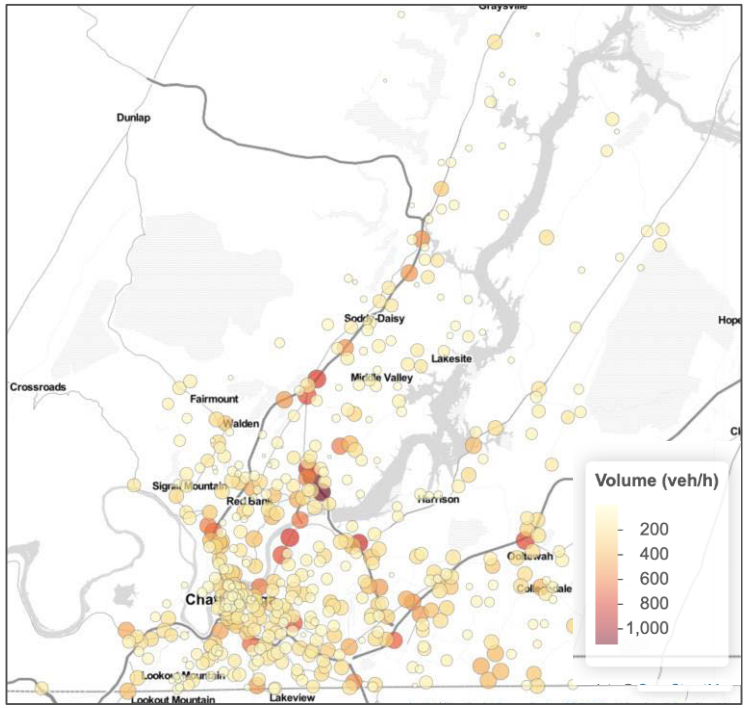
TECHNICAL ACCOMPLISHMENTS AND PROGRESS: DATA FOR MODEL TRAINING – CHATTANOOGA, TN

FHWA Functional Class	# of CCSs
Interstate/Freeway	36
Principal Arterial	55
Minor Arterial	14
Major Collectors	70
Minor Collectors	199
Local	163

	Interstates	Non-Interstates
Data Source	Radar sensors	Short-term counts
Time Period	Jan 1 – Apr 22, 2019	Jan 3 – Jun 5, 2018
# of Stations	36	501
# of Observations	81,918	15,570
Average Probe Penetration Rate	20%	5.7%



Freeway Radar Senor Data

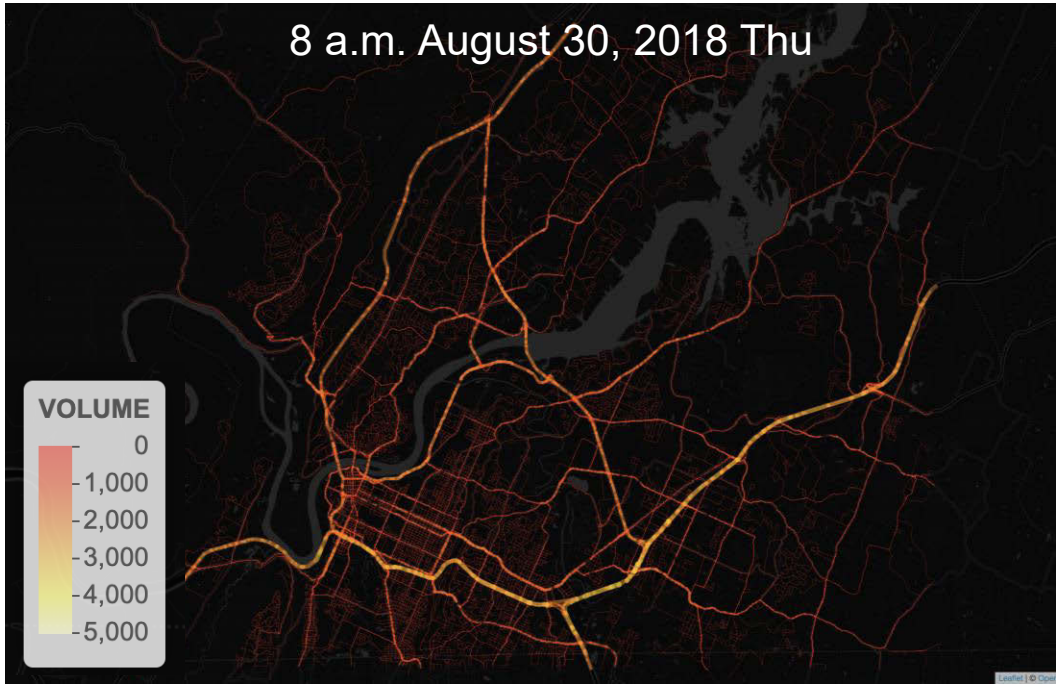


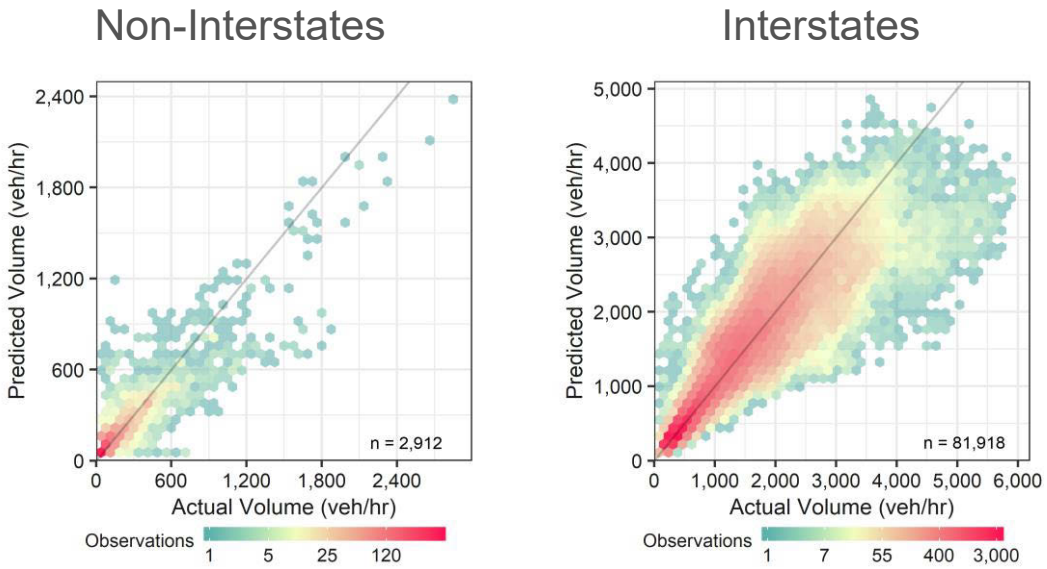
Off-Freeway Short-Term Count Data

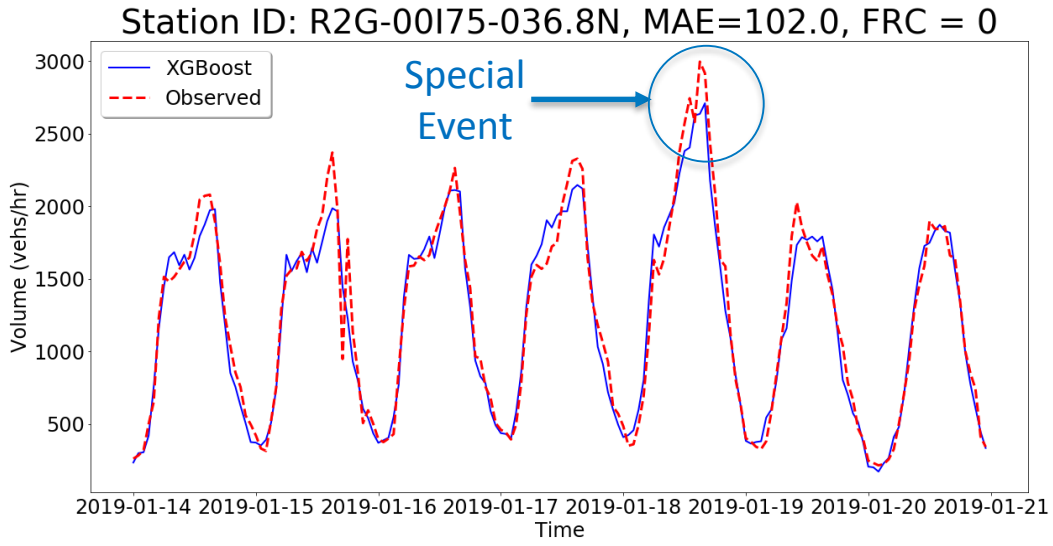
TECHNICAL ACCOMPLISHMENTS AND PROGRESS: VOLUME ESTIMATION RESULTS – CHATTANOOGA, TN

Overall model performance: **Fair**

Roadway Type	R^2	MAE	WAPE	EMFR
Interstates	0.80	284	20.4%	7.6%
Non-Interstates	0.77	81	39.0%	38.2%

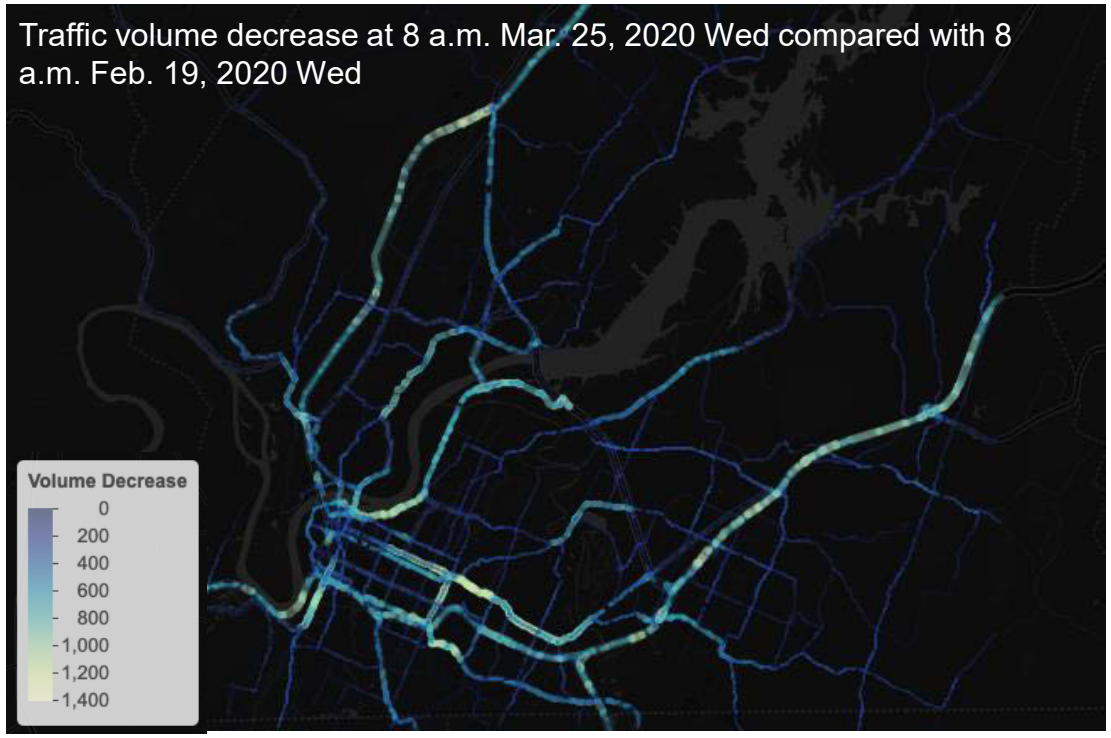




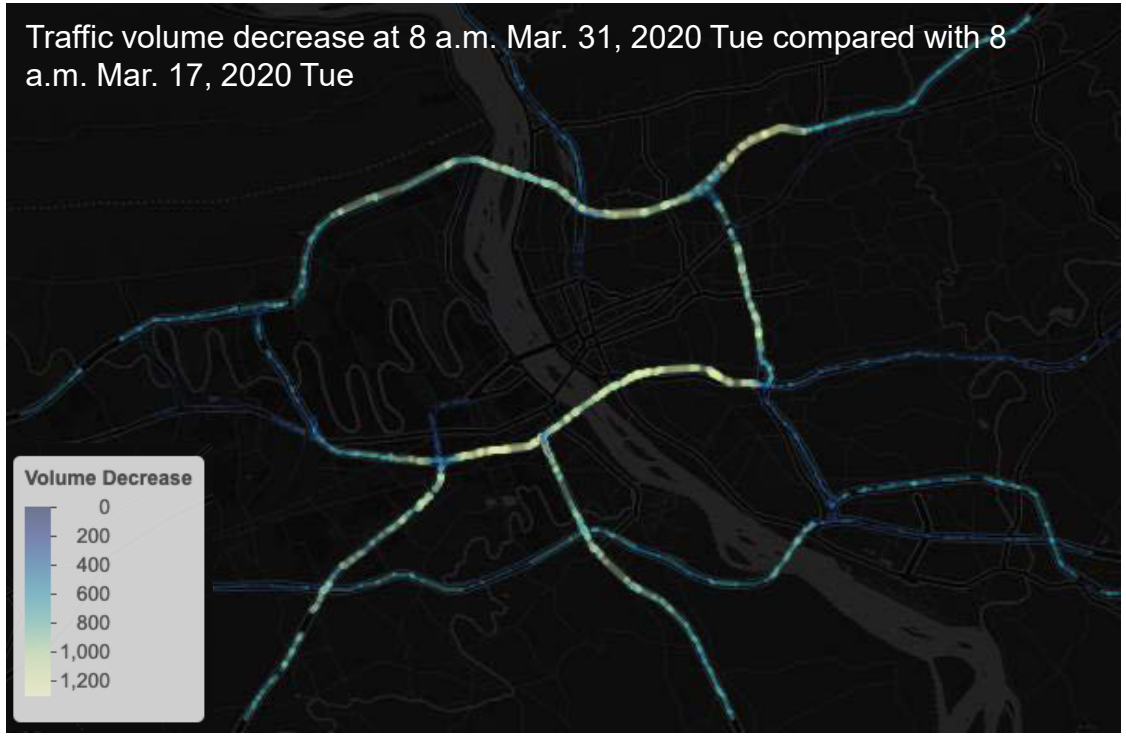


TECHNICAL ACCOMPLISHMENTS AND PROGRESS: IMPACTS OF COVID-19

Volume Decrease at Chattanooga, TN (34% ↓ in 35 days)



Volume Decrease at Harrisburg, PA (17% ↓ in 14 days)



RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

- **"there is no evidence to evaluate collaboration"**
  - Response: This year we have a lot of interactions with our partners, including TomTom, North Carolina DOT, Tennessee DOT, Pennsylvania DOT, and I-95 Corridor Coalition.
- **"This reviewer suggested that the project team take into account other possible forms data as input for volume prediction"**
  - Response: We are considering new vehicle probe data and traffic volume calibration data with higher temporal resolution (i.e. 5-15 min) for real-time traffic volume estimation
- **"develop vehicle classification capabilities that work off traffic camera images/video"**
  - Response: Video analysis for vehicle classification is worth exploring. It might be studied in the next phase of this research.

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

COLLABORATION AND COORDINATION

State Departments of Transportation

- Colorado
- Virginia
- I-95 Corridor Coalition
- Pennsylvania
- North Carolina
- Tennessee
- Georgia
- Maryland State Highway Administration

Private Partners

- TomTom

Universities/Research Entities

- University of Maryland
- Texas Transportation Institute

REMAINING CHALLENGES AND BARRIERS

- Real-time data feed
  - For real-time traffic volume applications, a real-time vehicle probe and sensor data streaming pipeline needs to be developed.

- Data format
  - Traffic volume calibration data coming from different sources or state DOTs have various data formats, which adds more difficulty to streamlining modeling process and commercialization.

- Data quality
  - Data quality significantly affects the traffic volume estimation results. A data quality check mechanism needs to be developed.

PROPOSED FUTURE RESEARCH

- Develop real-time data streaming pipeline and build a model for real-time volume estimation
- Develop an algorithm for data anomaly detection and remove bad data resulting from measurement error
- Develop a data pipeline to accommodate different data formats and get ready for productization
- Estimate Average Annual Daily Traffic (AADT)
- Enhance current estimation capability (i.e., improving accuracy, providing estimation confidence interval)

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

SUMMARY

Volume estimation model has been validated and verified by data from:

- Colorado DOT (see technical backup slides)
- North Carolina DOT
- Tennessee DOT
- Pennsylvania DOT

Machine learning is a powerful tool for volume estimation

Probe data and sensor data quality have a significant impact on volume estimation accuracy

Can be applied for both historical and real-time

Interacted with seven state DOTs and have positive feedback;
Working with TomTom to productize the estimation methodology

Thank You

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NREL/PR-5400-76617

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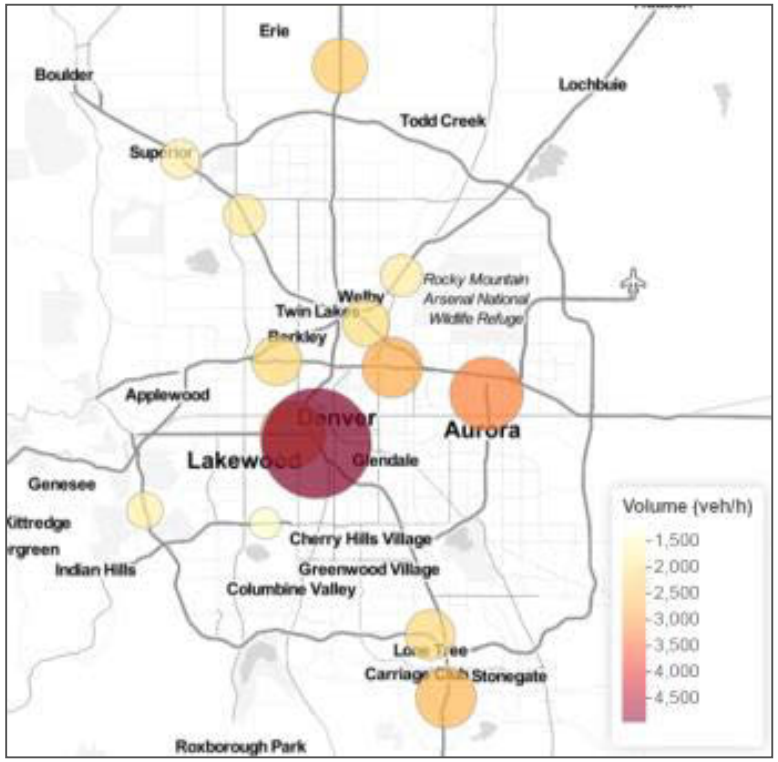
Technical Back-Up Sides

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: DATA FOR MODEL TRAINING – DENVER, CO

- Feb 1– Apr 30, 2017
- 14 stations
- 52,092 observations

Functional Road Class	# of Continuous Count Stations
Interstate	7
Freeway / Expressway	7

Average Traffic Volume by Station

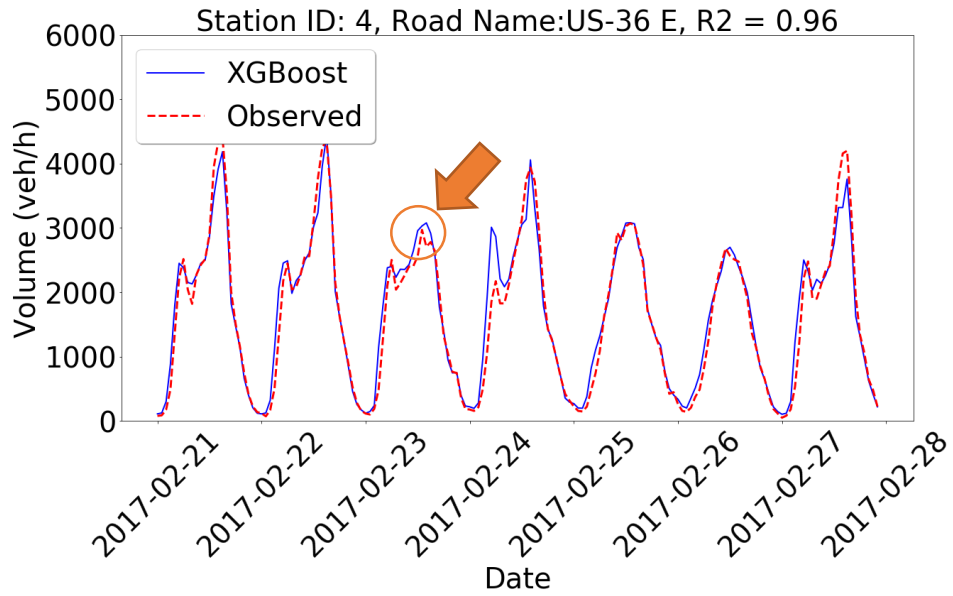


FRC: Functional Road Class

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: VOLUME ESTIMATION RESULTS – DENVER, CO

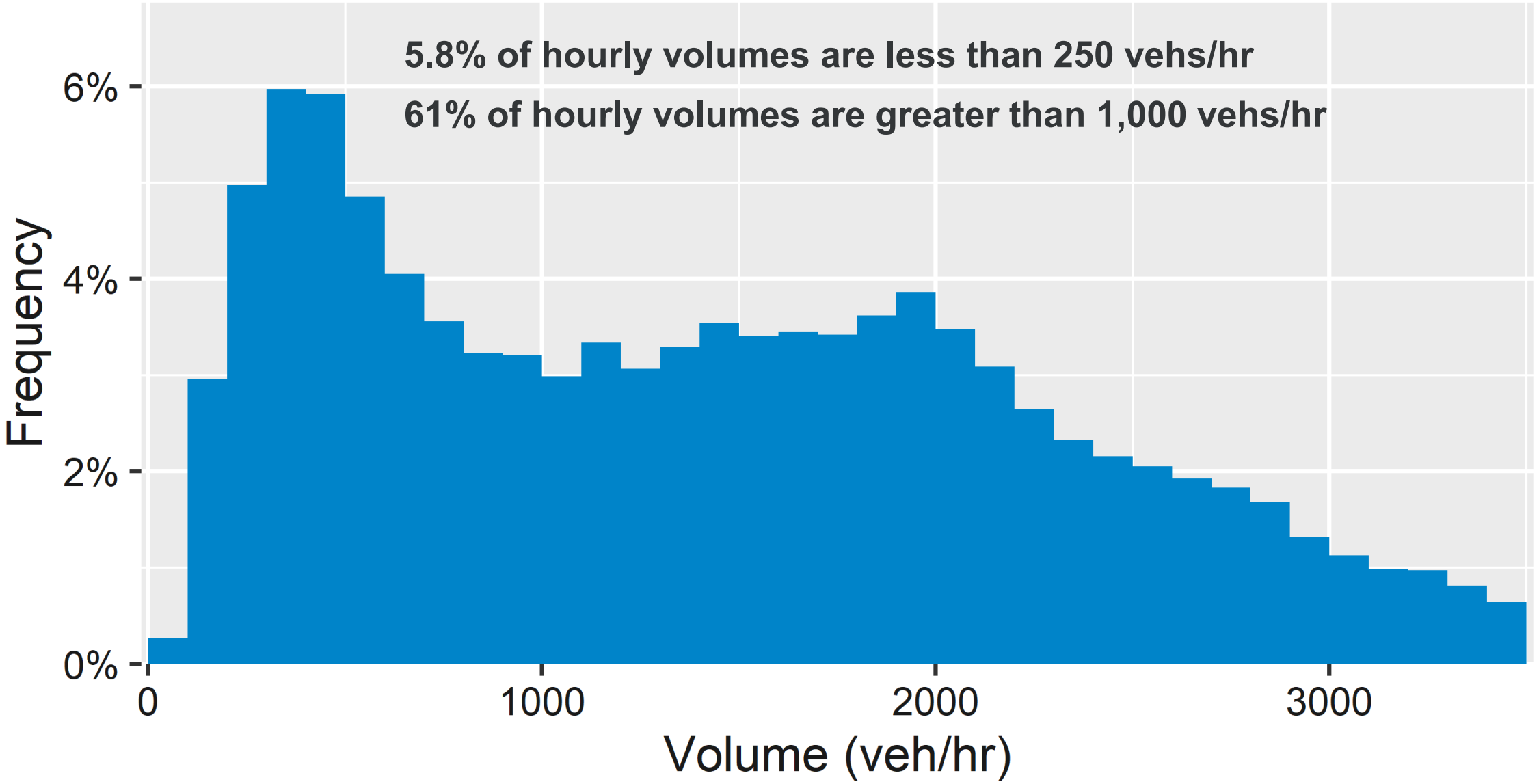
Overall model performance: **Excellent**

Model	MAPE	EMFR	R^2
XGBoost	17.7%	5.3%	0.91



XGBoost 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: FREEWAY & INTERSTATE VOLUME DISTRIBUTION AT HARRISBURG, PA



TECHNICAL ACCOMPLISHMENTS AND PROGRESS: ANOMALY DETECTION AT HARRISBURG, PA

- Anomaly on southbound at station 701 was detected
- Station 701 southbound was excluded from the model training