Volume & Turning Movements Project

Steering Committee Meeting #7

February 13, 2018

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  - Please do not place call “on hold” as your hold music will be heard by the group
- Speakers will answer questions at the end of their presentation
- The audio from this meeting is being recorded
- All materials & contact information will be available to participants after the webcast

Attendees

Agencies	
Colorado DOT	NREL
Durham MPO (NC)	Pennsylvania DOT
FHWA	Port Authority NY & NJ
Georgia DOT	South Carolina DOT
HERE	StreetLight Data
I-95 Corridor Coalition	Texas DOT
Kentucky Transportation Center	Texas A&M Transportation Institute
Maryland DOT/MdSHA	TomTom
MWCOG	UMD CATT
New Hampshire DOT	Virginia DOT
North Carolina DOT	

Speakers

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Thank you!

Agenda

	Topic	Speaker
1	Welcome & Project Status Update	Stan Young, NREL
2	Ubiquitous Volume Estimation on Lower Functional Class Roads	Yi Hou, NREL
3	Traffic Volume Estimation using GPS Traces: Florida and New Hampshire Update	Kaveh Sadabadi, UMD CATT
4	First Look on AADT Estimation	Yi Hou, NREL
5	Next Steps & Wrap Up	Stan Young, NREL Denise Markow, I-95 Corridor Coalition

Project Status Update

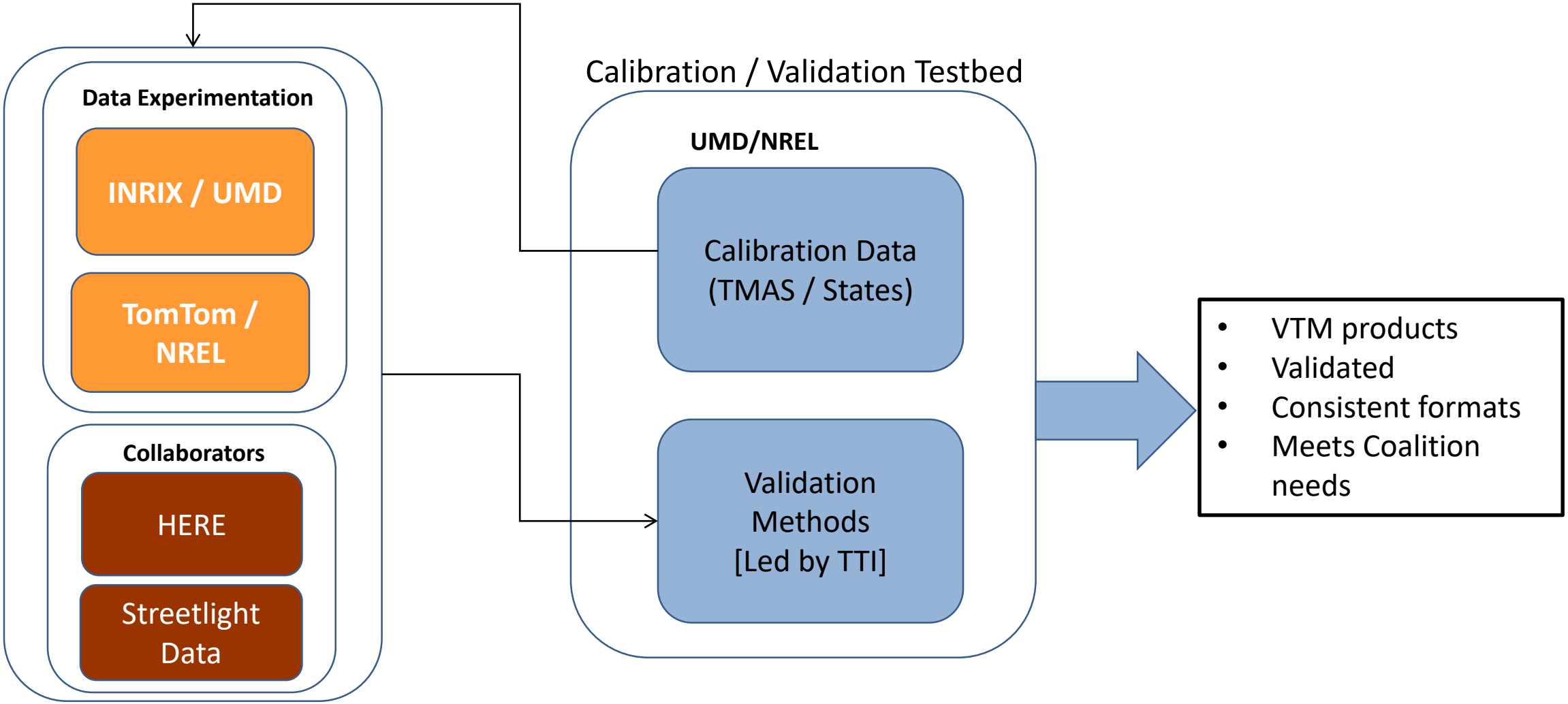
Project Goal

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**

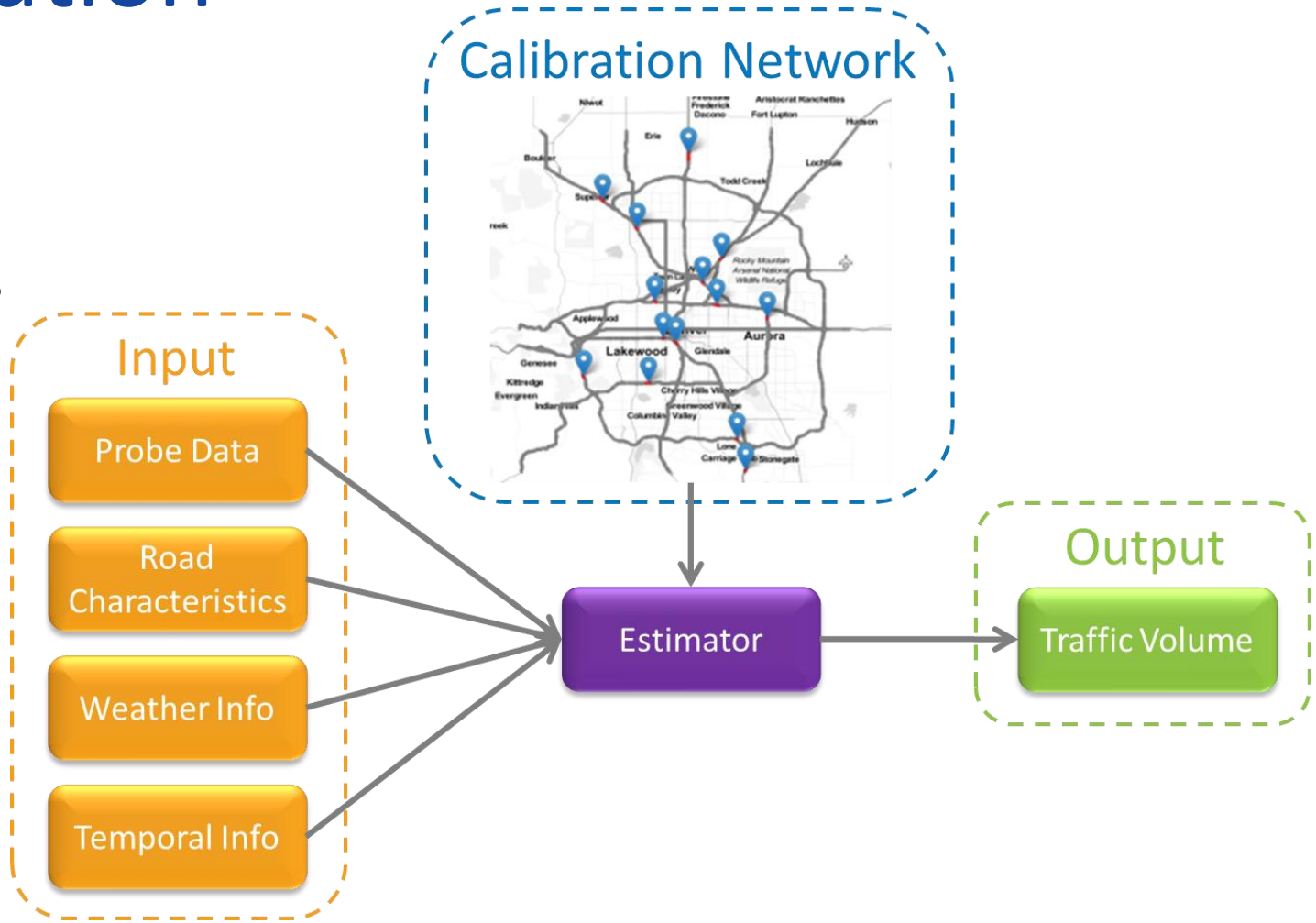
Ensure that initial data products meet members' information needs for operations, performance measurement, and planning.

Status of Project – Feb 2018



Visualizing the Solution

- A volume estimator
- ATRs & 48 hour counts uses as ‘base stations’
  - Calibrate estimate
  - Assess accuracy
- Uses a variety of data
  - Probe data is key
- Complements existing sensors



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)

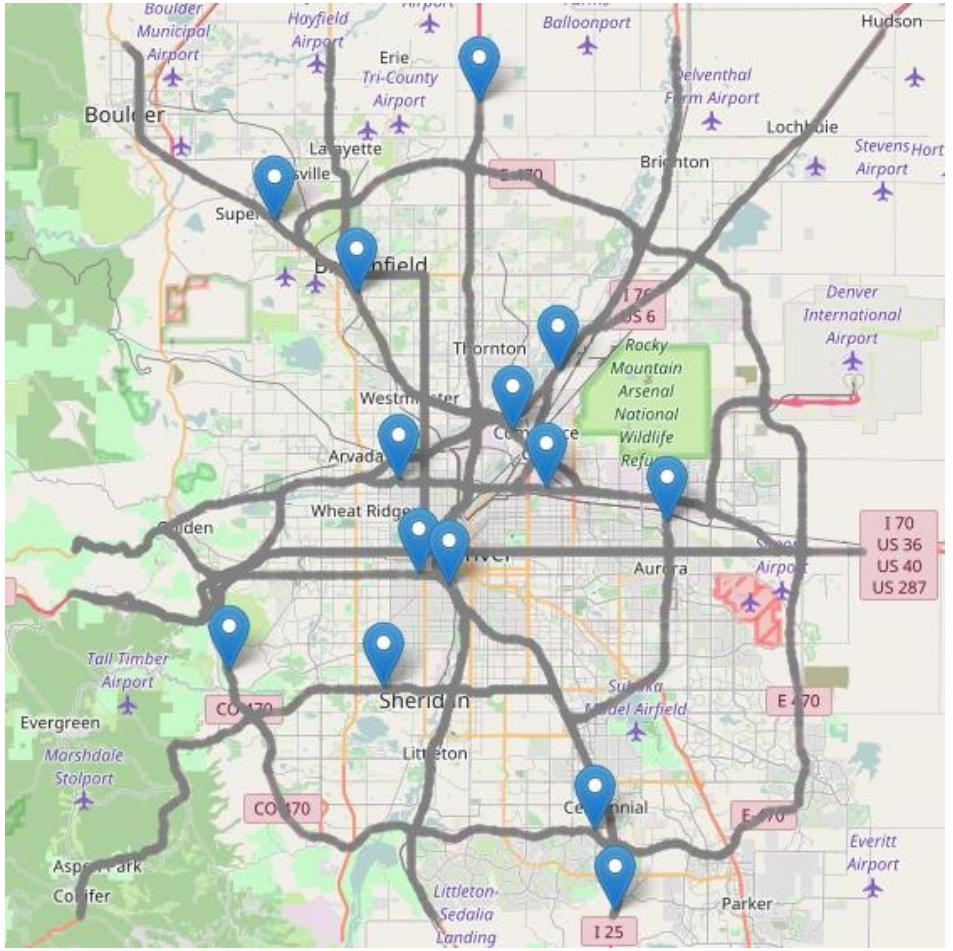
Acceptable % Change

AADT Range	Decreasing (-)	Increasing (+)
0 -19	-100%	400%
20 - 49	-40%	50%
50 - 99	-30%	40%
100 - 299	-25%	30%
300 - 999	-20%	25%
1,000 - 4,999	-15%	20%
5,000 - 49,999	-10%	15%
50,000+	-10%	10%

MNDOT Example

Today's Agenda

- Colorado Off Freeway Results
  - Yi Hou and Venu Garikapti, NREL
- Florida, Full Network
  - Kaveh Sadabadi, UMD
- AADT Estimates
  A First Approximation
  - Yi Hou, NREL
- Summary & Next Steps
  - Stan Young, NREL



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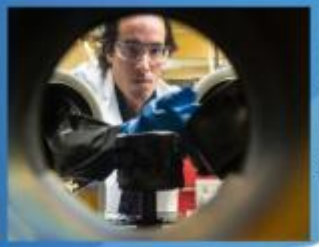
1977 – 2017


Ubiquitous Volume Estimation on Lower Functional Class Roads

Yi Hou, Venu Garikapati, Stan Young

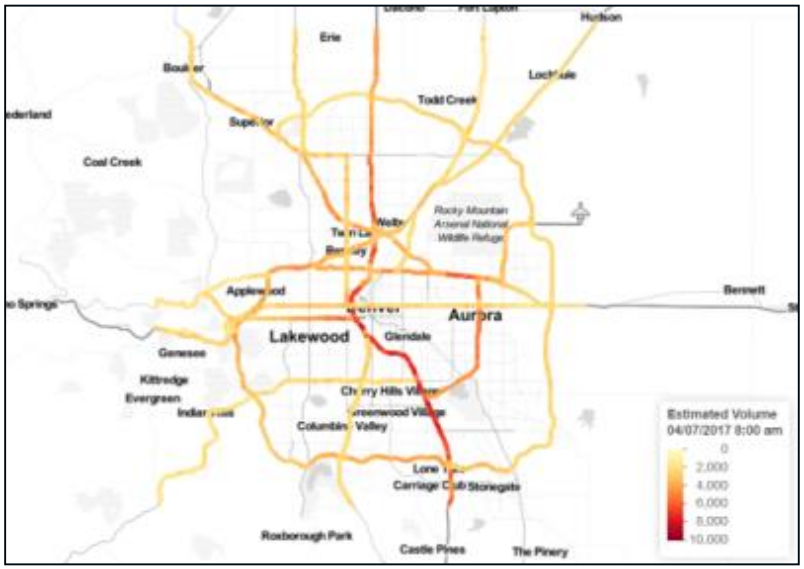
February 13, 2018

Outline

- Motivations & previous study
- Hourly volume estimation on lower functional class roads
- Summary

Motivation & Previous Study

Ubiquitous Traffic Volumes



- Traffic sensors for any given city cover only a small amount of the road network (5-10%), leaving the remaining (90-95%) network with no volume information.
- Increasing availability of probe vehicle data provides a more practical and affordable pathway to obtain network wide traffic volumes.
- **Solution**: Use information from existing traffic sensors and combining it with probe vehicle data as well as other relevant information to estimate network wide traffic volumes.

Volume Estimation Work at NREL

Freeway Volume Estimation	• Previous analysis
Lower Functional Class Roads	• Focus of today's presentation
AADT Estimation	• Sneak peek of preliminary results

Previous Study – Freeway Volume Estimation

Calibration Network

Total 14 Automatic Traffic Recorder stations

Input

- Probe Data
- Road Characteristics
- Daily Weather Info
- Temporal Info

Estimator

Output – Hourly

Results of Freeway Volume Estimation

- Results exceed the survey expectation: ETCR<10%
- All have very similar accuracy
- XGBoost is the most computational efficient

Model	Overall MAPE	Overall ETCR	Median R2	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

MAPE – Mean Absolute Percentage Error ETCR – Error to Theoretic Capacity Ratio
RF – Random Forest GBM – Gradient Boost Machine XGBoost – Extreme Gradient Boost

Hourly Volume Estimation on Lower Functional Class Roads

Lower Functional Class Roads

- FHWA functional classification

Freeways
- Interstates
- Other Freeways

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

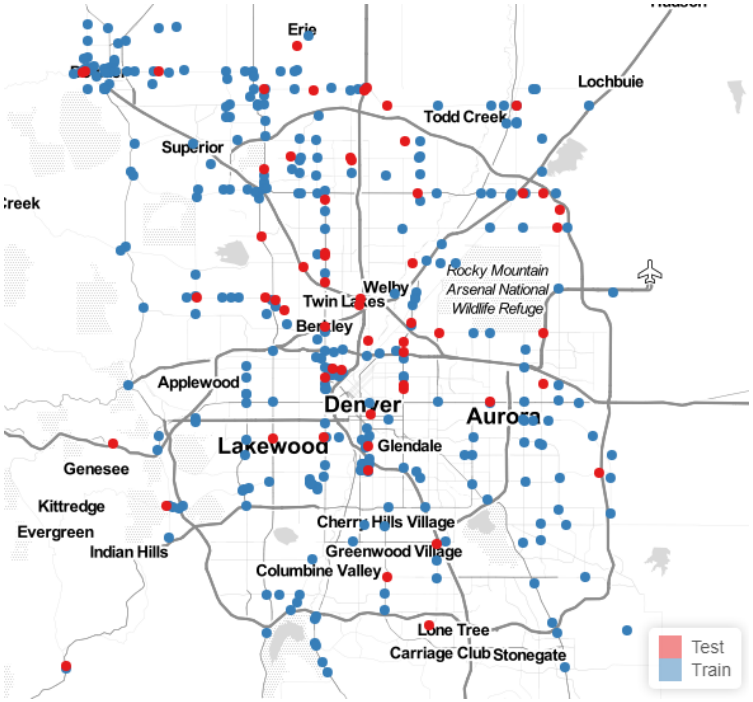
	Lower Class Roads	Freeways
Percentage of Miles	98.5%	1.5%
Percentage of Lane Miles	96.7%	3.3%
Percentage of VMT	68.5%	31.5%
HPMS Monitoring Cycle	6-year	3-year
Monitoring Method	Short-term counts	ATRs & Short-term counts

HPMS – Highway Performance Monitoring System

Locations of 48-hour Volume Count Collection

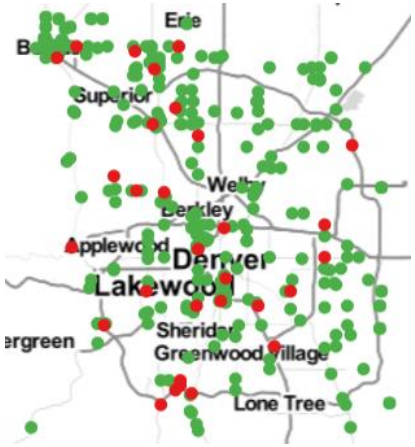
	Lower Class Roads	Freeways
Volume data source	48-hour short-term count	ATR stations
Number of locations / Data points	359 / ~35,000	14 / ~52,000
Data collection period	Jan. – Sep., 2017 (9 months)	Feb. – Apr., 2017 (3 months)

- 300 for training/calibrating
  - Total of 30,096 data points
- 59 locations for testing
  - Total of 5,118 data points
- Fully randomized

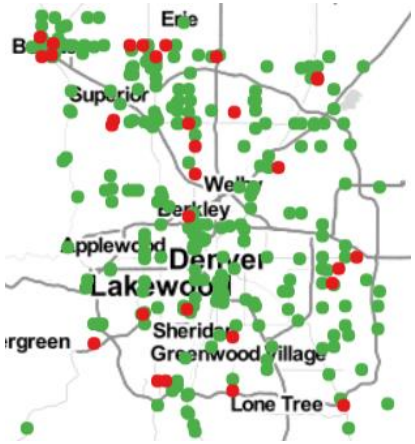


Model Validation and Test Method

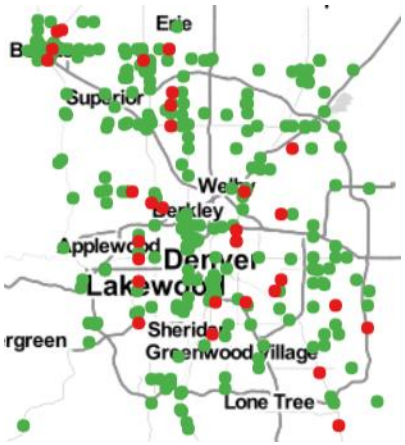
- Training locations were randomly and evenly divided into 10 groups
- Repeat this for 10 times
  - 9 groups are used for model training
  - 1 group is used for model validation
- Find model hyperparameters that yield the best estimation results
- Train a model using all training data and test model on test data



1st iteration



2nd iteration



3rd iteration

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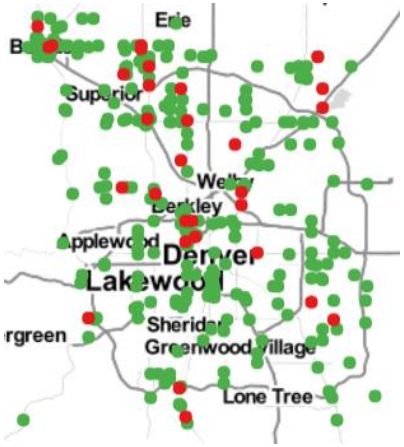
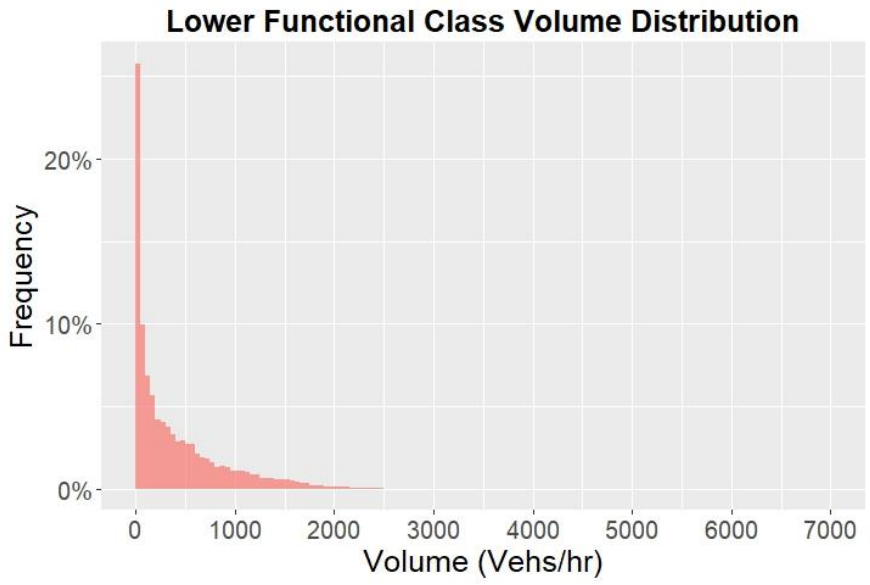
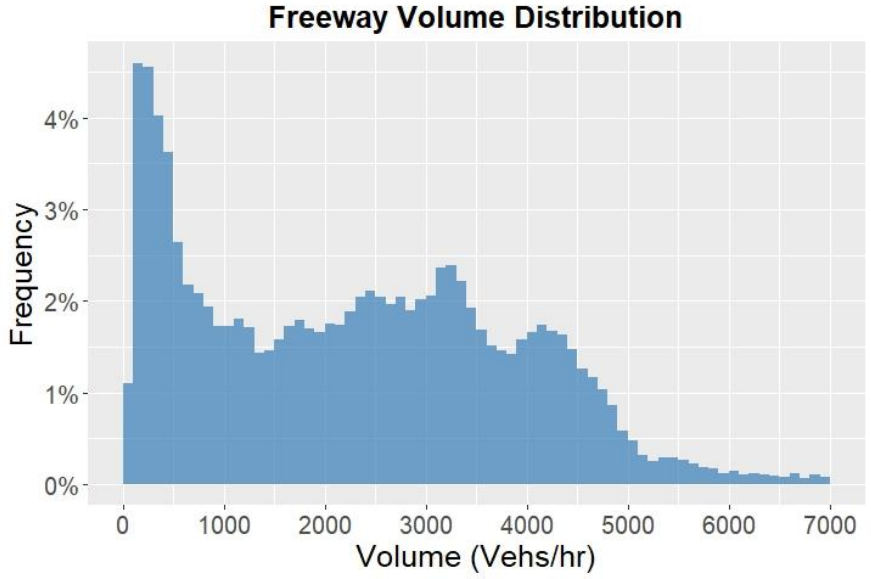


10th iteration

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





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

Functional Class	Ptg. of Observations	Avg. Hourly Volume	Avg. Hourly Probe Count	Avg. Hourly Penetration Rate
Principal Arterial	52%	619	47.1	7.7%
Minor Arterial	27%	257	16.9	7.7%
Major Collector	13%	129	5.9	4.1%
Local Street	8%	19	0.6	3.1%
Overall	100%	414	29.8	6.4%

Input Variables for Hourly Volume Estimation

- TomTom Traffic data from probes
  - Hourly average speed and probe count
  - **Only included present hour, not previous hours**
- **Hourly weather information (previously daily)**
  - Temperature, precipitation, visibility, fog, rain, snow
- Road characteristics
  - Road class, urban or not, speed limit
  - **2015 AADT**
  - **Longitude, latitude**
- Temporal information
  - Month, day of week, hour of day

Estimation Methodology

- Machine Learning
  - A subfield of computer science that gives computers the ability to learn from data without being explicitly programmed
- Extreme Gradient Boost (XGBoost)
  - One of the most recent developed tree-based machine learning models
  - Used successfully in classification and regression predictive modeling problems

Model Evaluation Criteria

- Mean Absolute Percentage Error: $\mathrm{MAPE} = \frac{1}{N}\sum_{i=1}^{N}\frac{|V_i - \widehat{V_i}|}{V_i}$
  - Reflect the absolute volume accuracy
- Coefficient of Determination: $R^2 = 1 - \frac{(\widehat{V_i} - V_i)^2}{(V_i - \bar{V})^2}$
  - Explanatory power of model

- Error to Maximum Flow Ratio: $\mathrm{EMFR} = \frac{1}{N}\sum_{i=1}^{N}\frac{|V_i - \widehat{V_i}|}{V_{max}}$
  - Reflect volume to capacity fidelity
- Mean Absolute Error: $\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{N}\left|V_i - \widehat{V_i}\right|$
  - Reflect the absolute error
  - Effective for low volume roads

V_i – Observed volume $\widehat{V_i}$– Estimated volume V_{max} – Max volume at the location

Model Results Comparison

- Much more accurate than linear regression and AADT based methods

Model	MAPE*	MAE	EMFR	R2
XGBoost	50.6%	89.2	13.2%	0.88
Linear	314.7%	153.1	29.5%	0.80
AADT Based Method	161.7%	304.4	26.5%	0.16

*The results include extreme low volume

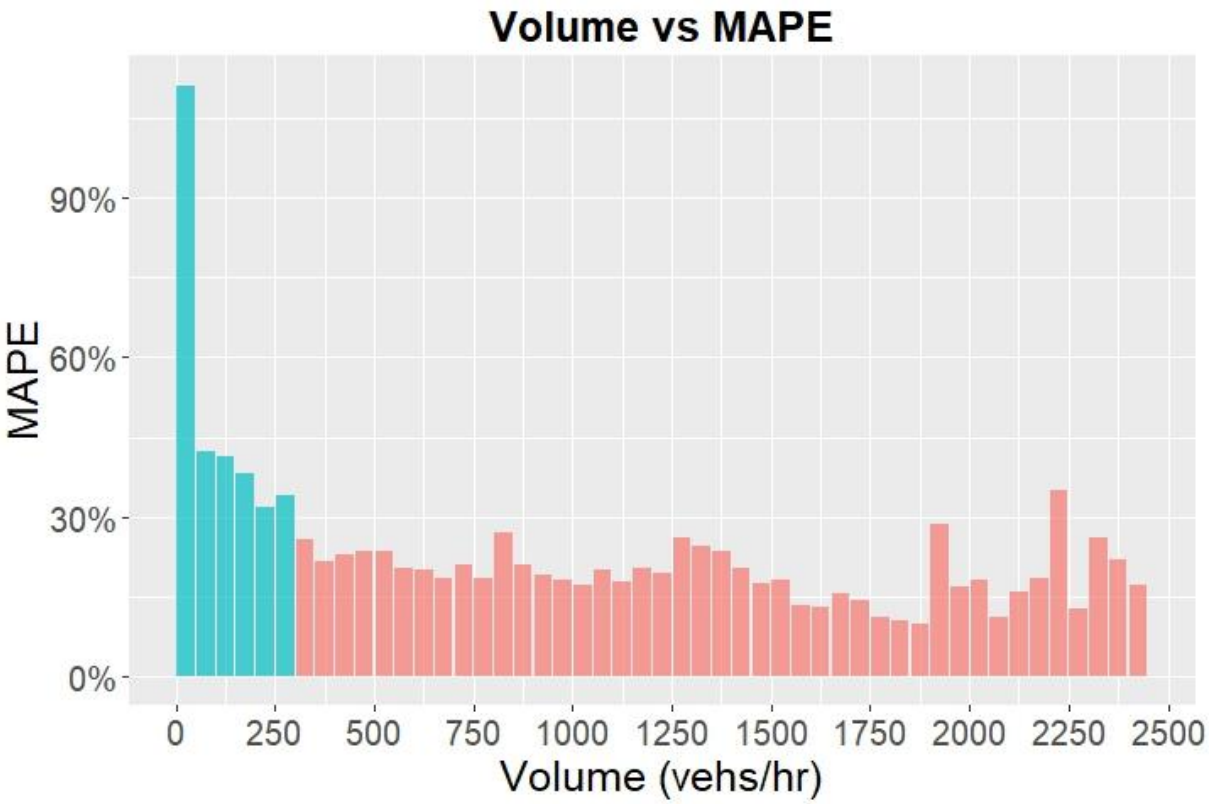
- Further examine MAPE and EMFR for volume > 20 vehs/hr

Model	MAPE (Vol>20)	EMFR (Vol>20)
XGBoost	29.7%	10.8%
Linear Regression	90.4%	20.5%
AADT Based Method	124.9%	28.1%

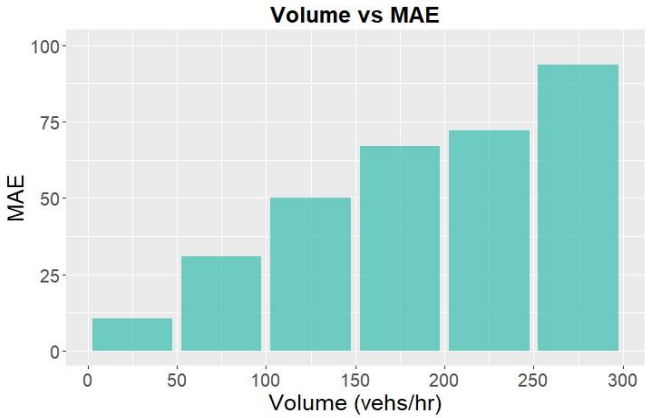
- **Need to look at accuracy in volume ranges**

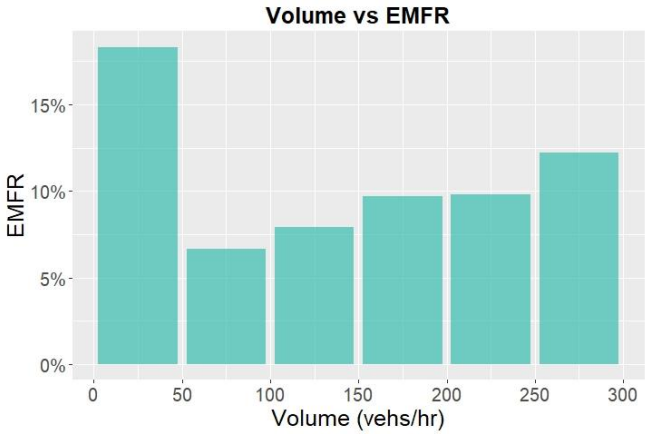
MAPE of Different Volume Range – PAY ATTENTION

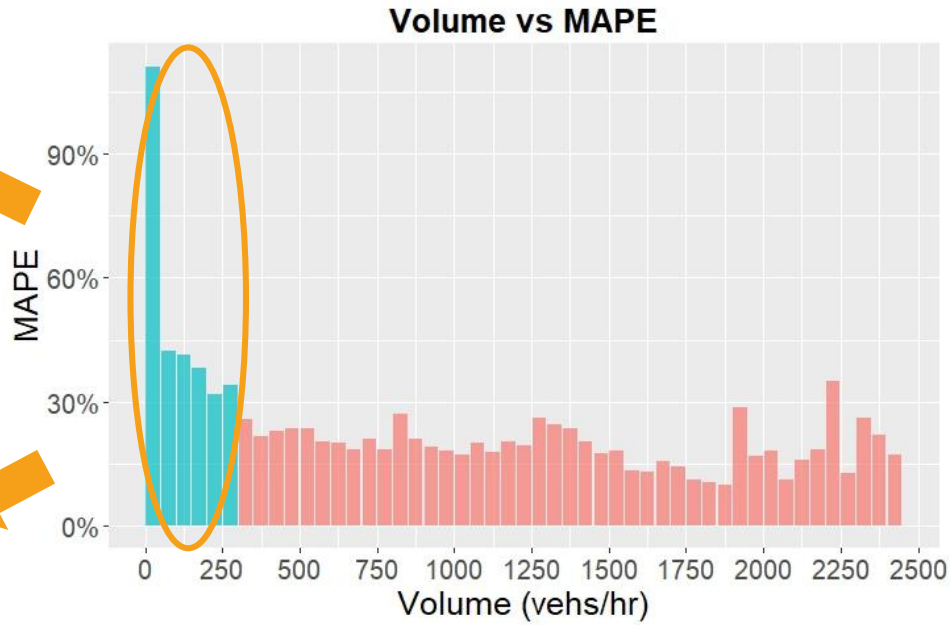
- Volume>300 vehs/hr: MAPE is low and stable
- Volume<300 vehs/hr: MAPE is high, but model is still good



MAPE of Different Volume Range – PAY ATTENTION

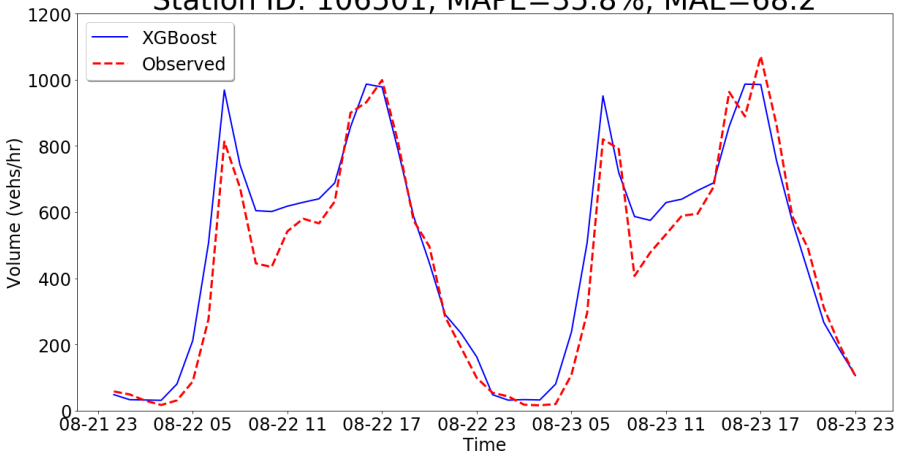




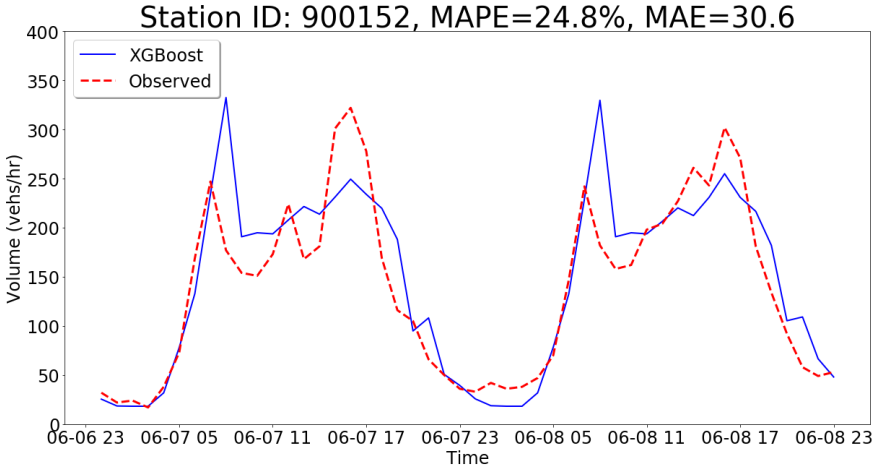


48-Hour Prediction on Test Locations

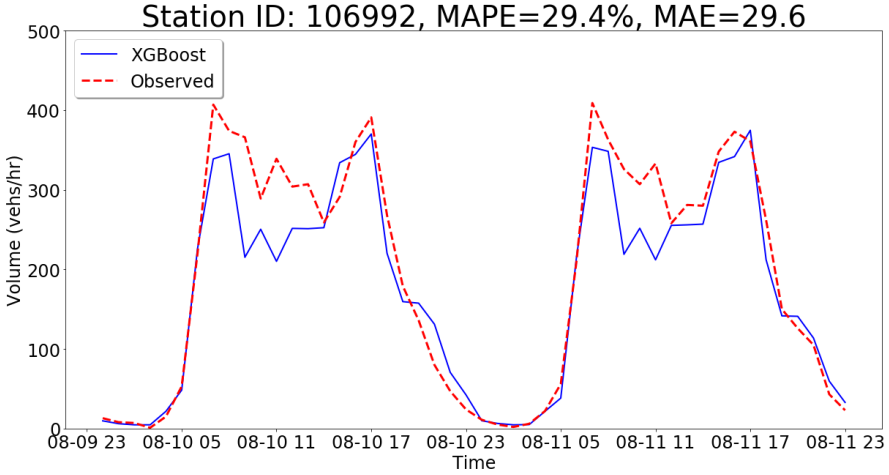
Principal Arterial



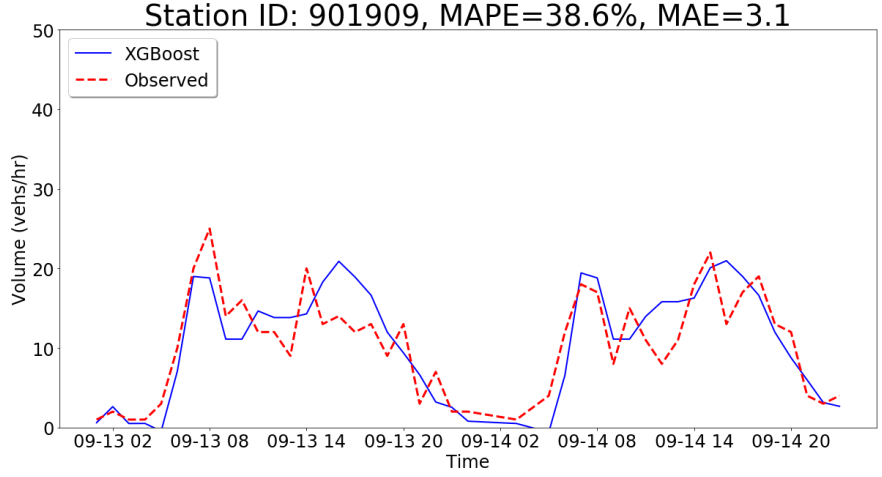
Minor Arterial



Major Collector

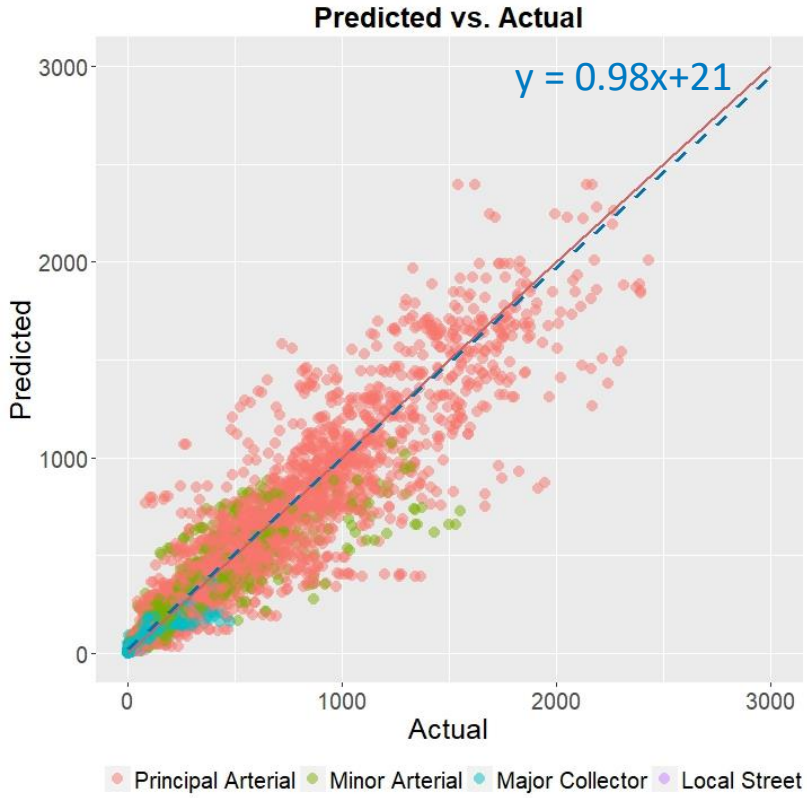


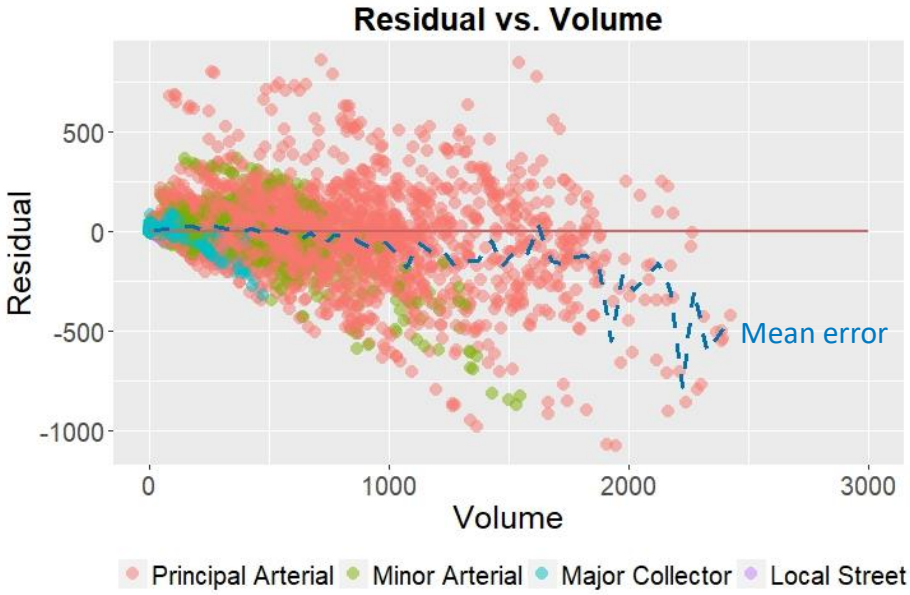
Local Street



Residual Analysis

- **Model is well fitted!**
- **Model is not biased!**
- Underestimate for extreme high volumes (likely training set issue)

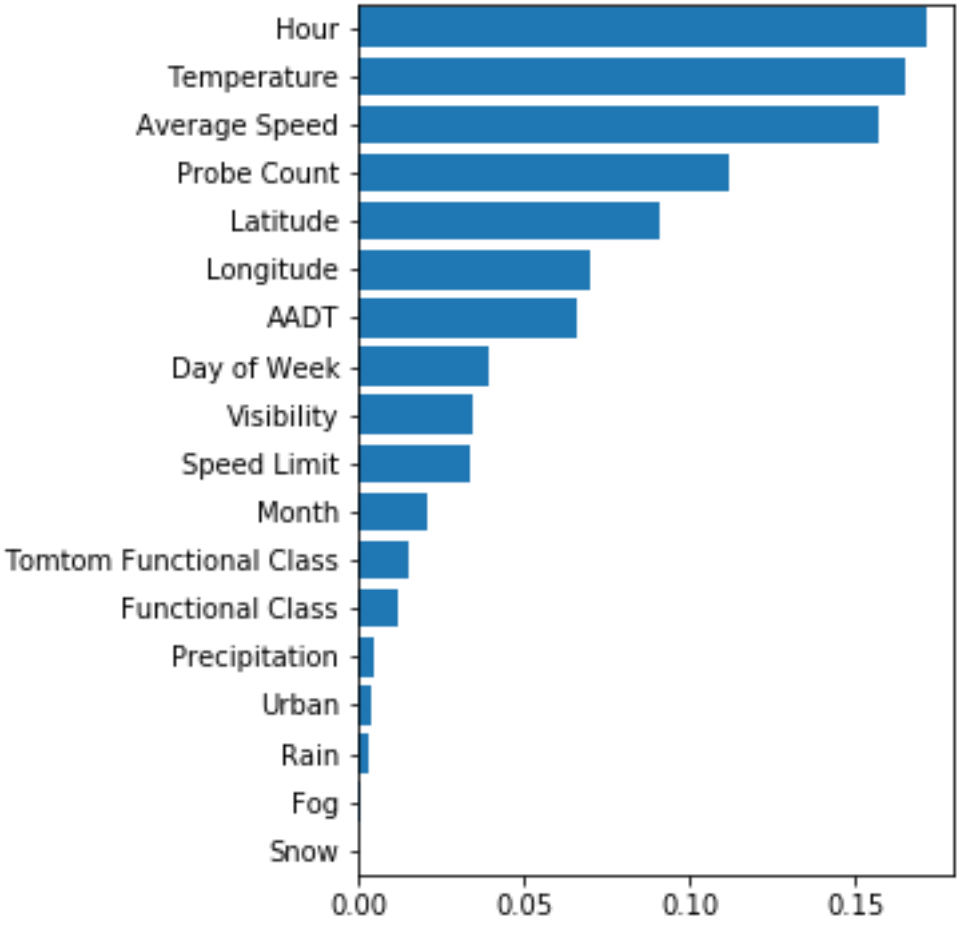




Machine learning methods not great at extrapolating beyond bounds of training set

Variable Importance

- Most relevant factors for volume estimation: Hour, temperature, speed, probe count, GPS location, and AADT



Summary

- Machine learning rocks!
  XGBoost, are promising tools for hourly volume estimation on lower functional class roads
- Model performs well for all ranges of volume
  - Extremely low volume – use MAE, not MAPE
- Underestimation at higher volumes: likely due to lack of sufficient observations to appropriate train
- Temp, hour of day, GPS, & probe count significant; Probe count less significant for off-freeway

Thank You!

Discussion

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Traffic Volume Estimation using GPS Traces: Florida and New Hampshire Update

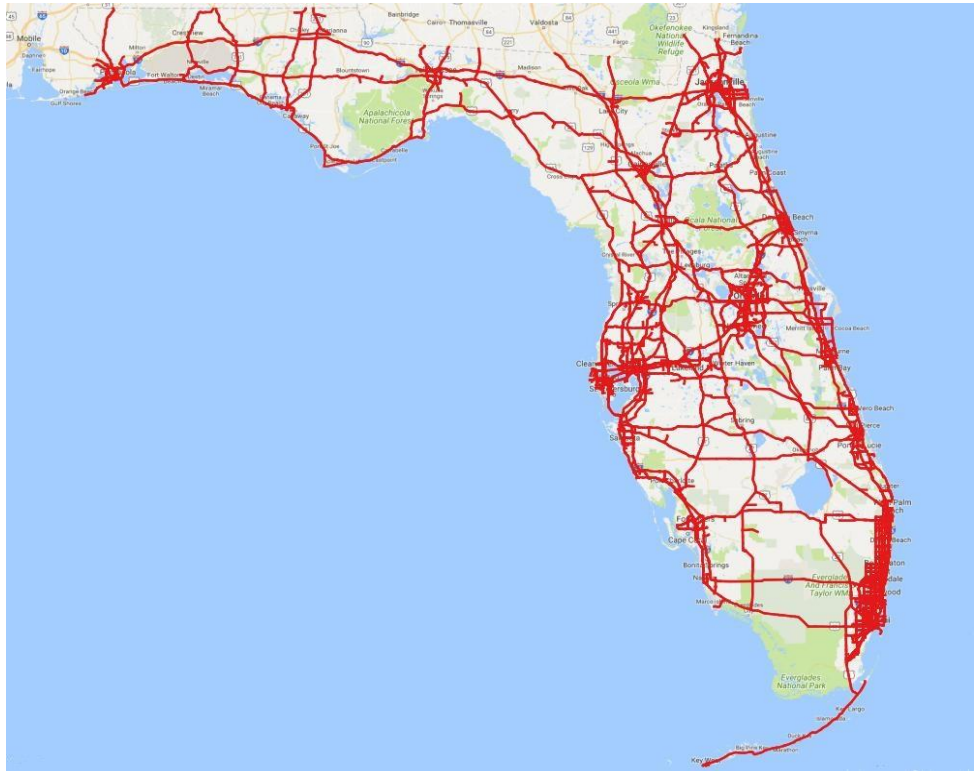
Analysis Performed by:
Przemyslaw Sekula and Zachary Vander Laan

Presented by:
Kaveh Farokhi Sadabadi

VTM Steering Committee Meeting
February 13, 2018

Presentation Overview

- Status update
- Florida analysis
  - Dataset
  - Results
  - Statewide Estimation
- New Hampshire analysis
  - Dataset
- Next Steps
- Q & A

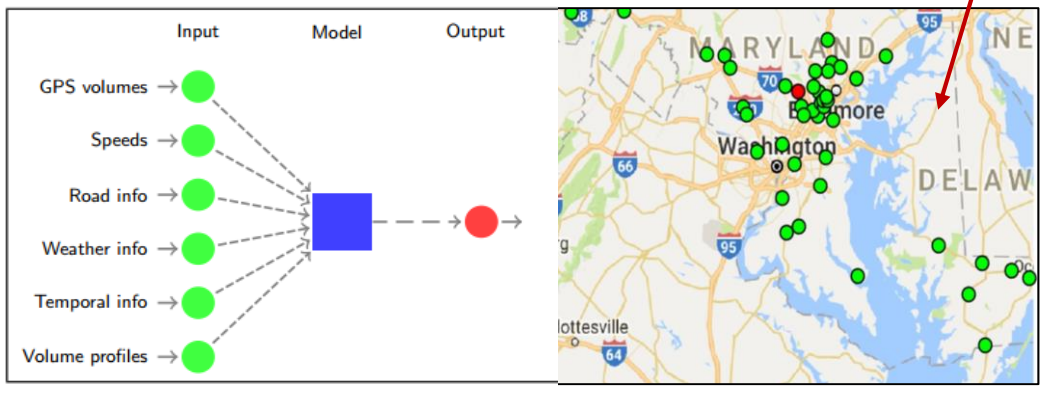


Status Update

Previously:

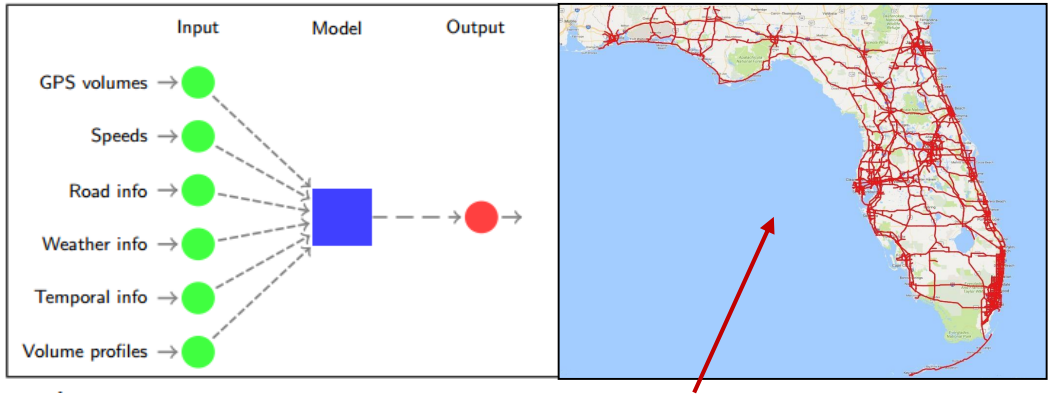
- Maryland INRIX dataset (2015)
- Develop / evaluate MD model: 45 ATR locations
  - 23% MAPE, 4-7% Error-to-capacity ratio
  - Estimation accuracy depends on probe penetration rate

Primary focus: model development / feature selection at ATR locations



Currently:

- Florida (2016 Q4) & New Hampshire (2017 Q3) INRIX datasets
- Develop / evaluate FL model: 173 ATR locations
- **Apply FL model statewide**!
  - INRIX data snapped to XD
  - Requires input data collection at ~20k TMCs
- Will repeat with NH

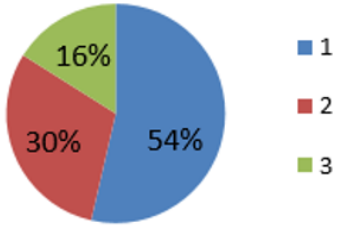


Primary focus: statewide application of model

Florida Dataset (Q4 2016)

Data needed at all TMCs

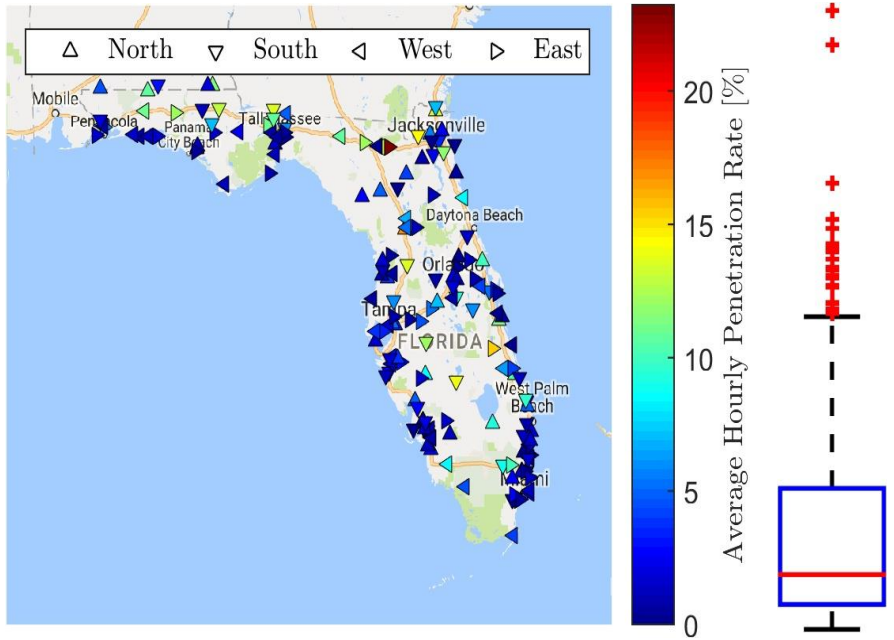
- **GPS probe data** (INRIX)
  - 75M trips, 3.4B pts (20M trips, 1.4B pts in MD)
  - Penetration rate: 2.1% median (1.9% in MD)
  - Snapped to XD segments
- **Probe Speed data** (HERE)
- **Road characteristics**
  - NPMRDS TMC shape file features
  - Open Street Map (OSM) conflation
- **Weather data** (permanent stations)
- **TTI hourly volume estimates**



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

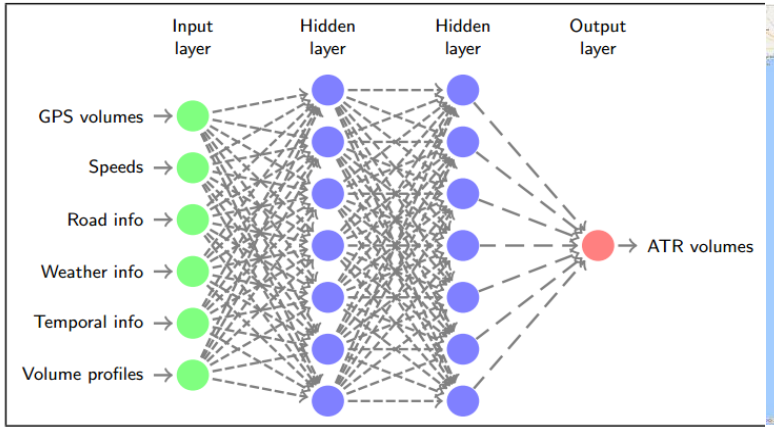
Data needed only at ATR stations

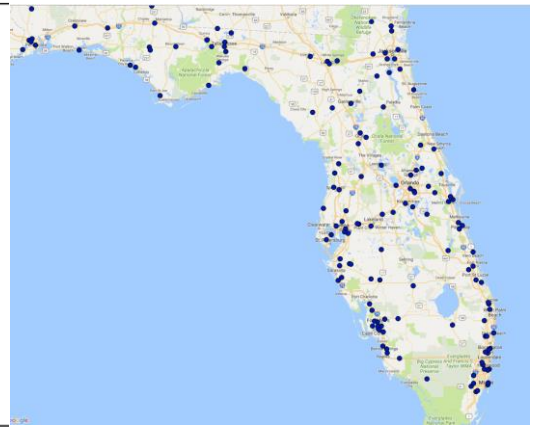
- **ATR counts** (FDOT)
  - Used for model training / evaluation
  - Used to estimate probe penetration rate

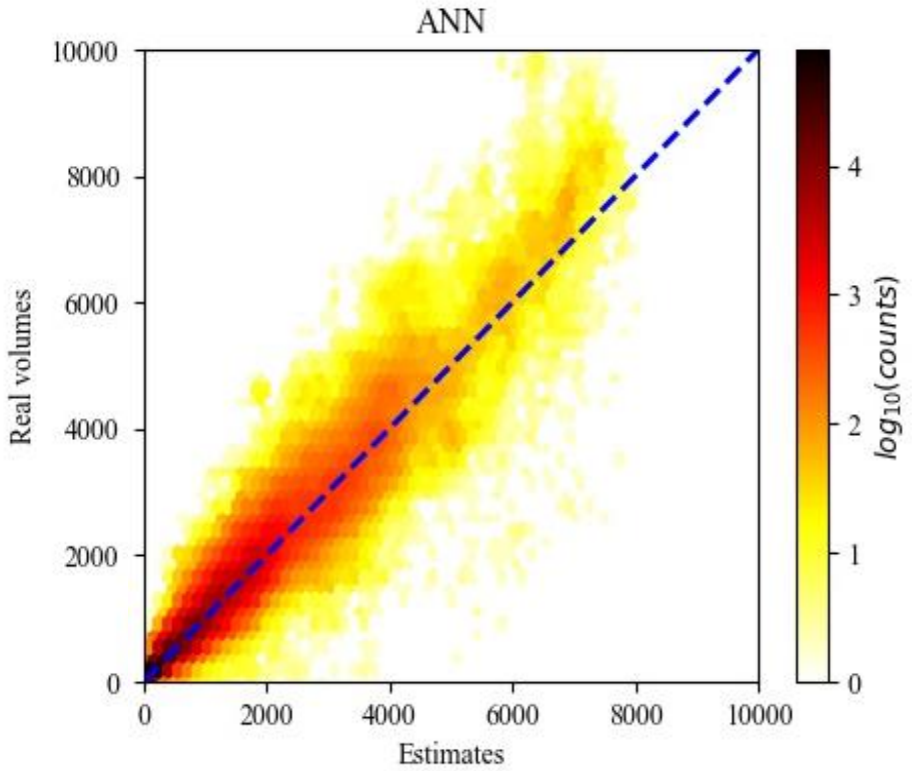


Florida Model Evaluation

- Model: "Dense" Artificial Neural Network (ANN)
- Cross validation (repeat 173 times)
  - Train model using data from 172 of 173 ATR stations
  - Generate model predictions using data from remaining station







- Evaluation: Compare predictions / ATR volumes & generate metrics

Florida Results: Summary

- FL error metrics comparable to MD
  - FL analysis includes lower class roads which weren't in MD dataset
  - XD-snapped data not as high-res
  - Simpler model architecture
- EMFR around 7%
  - ETCR likely lower
  - "Beginning to become useful"
- Challenges with low-volume roads
  - 7 locations have 0 observed GPS counts for entire dataset

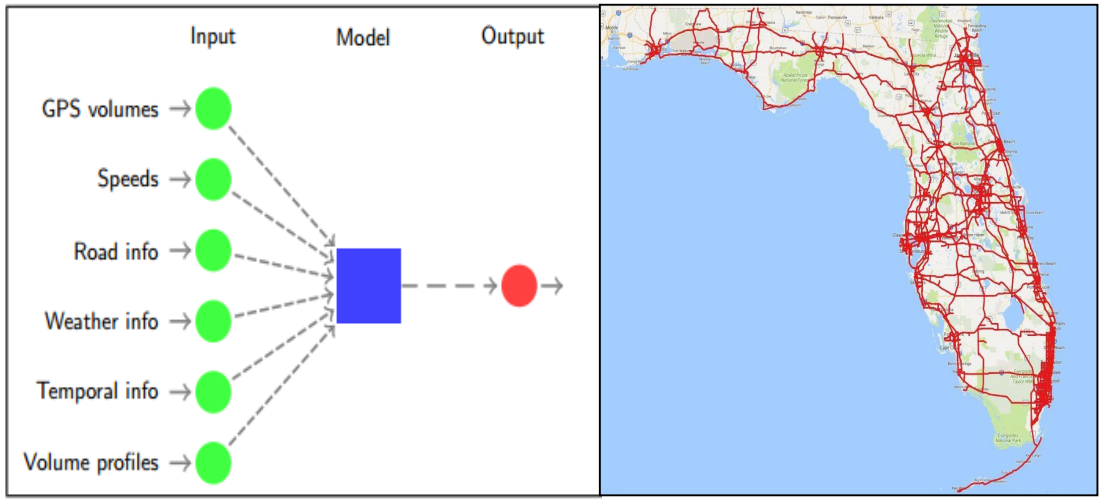
Median Error Metrics	R2	MAPE (%)	EMFR (%)	Obs
Overall	0.83	25	7	694690

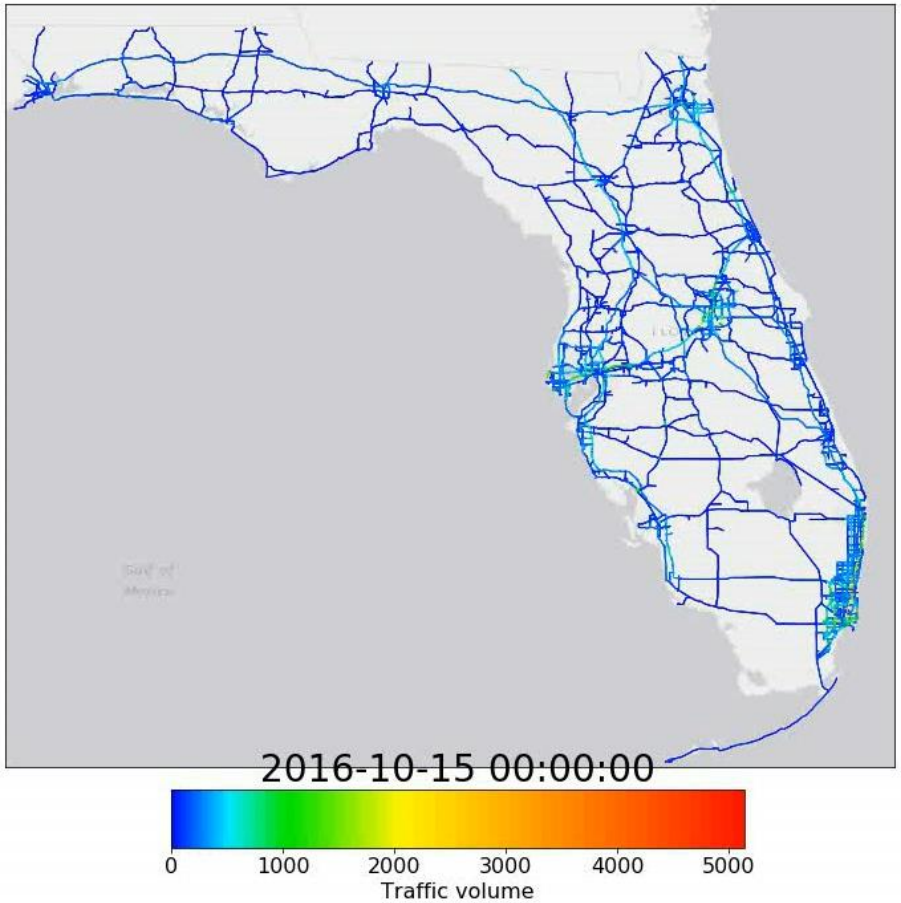
Road Classification	R2	MAPE (%)	EMFR (%)	Obs
Freeways (FRC 1)	0.86	21	6	195704
Maryland (mostly FRC 1)	0.86	23	7	158040
Principal Arterials (FRC 2)	0.82	26	7	370567
Major/Minor Arterials (FRC 3 & 4)	0.83	33	7	128419

Hourly Volume (vph)	R2	MAPE (%)	EMFR (%)	Obs
0-1k	0.81	29	7	465591
1k-2k	0.86	22	6	164465
2k-3k	0.88	18	6	49221
3k+	0.87	19	6	15413

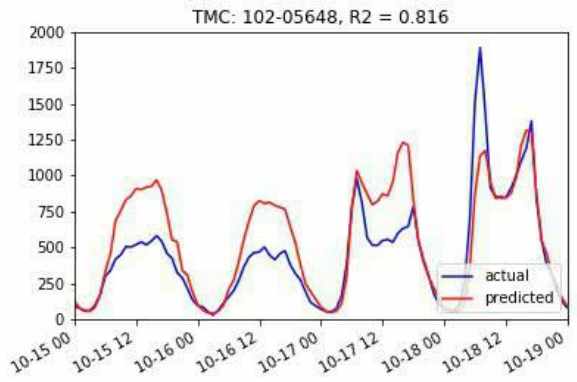
Florida Statewide Model

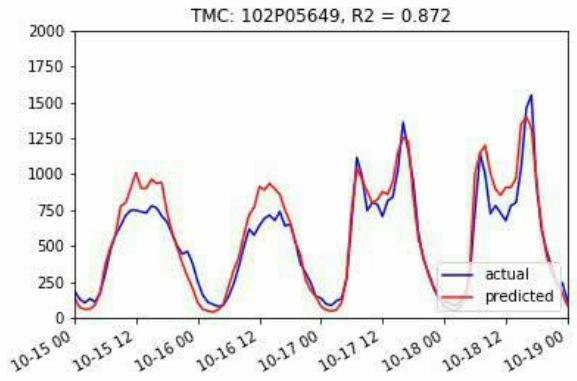
- Apply trained model to entire road network
  - Requires 3 months of hourly input data at ~20k TMCs
  - Generate hourly volume estimates at each input time/location

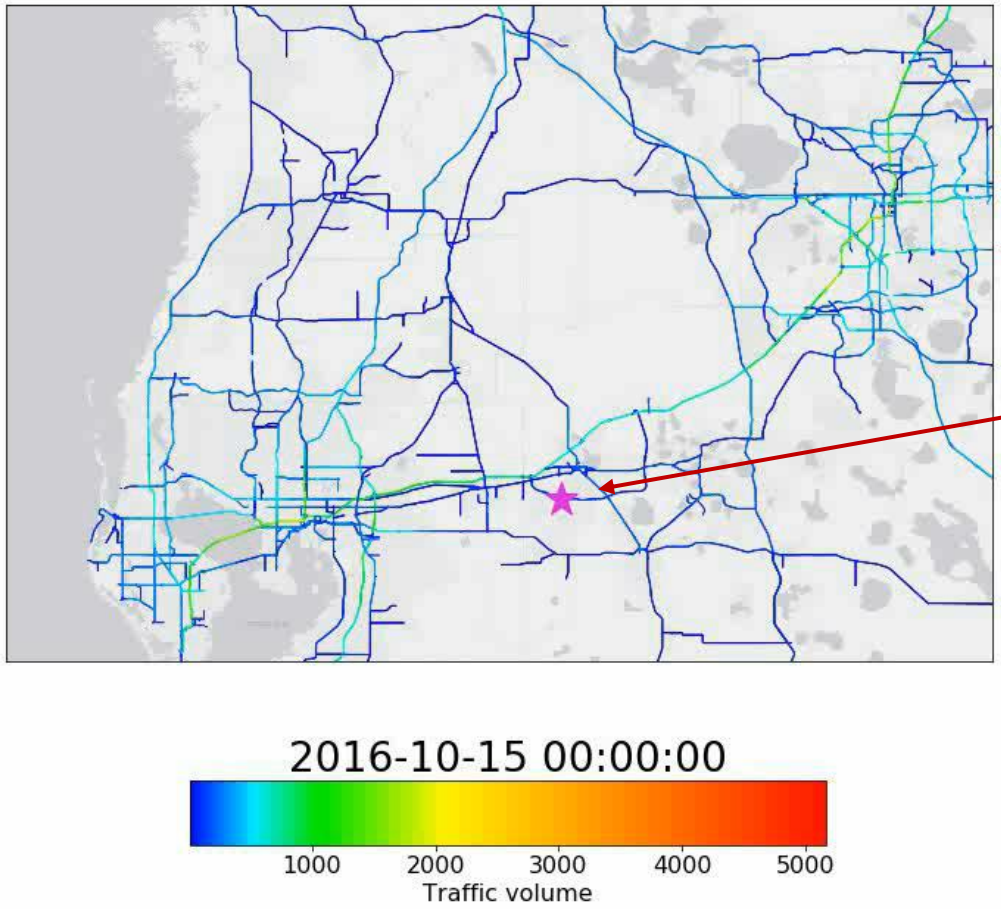




Florida Statewide Model: Tampa Bay Area





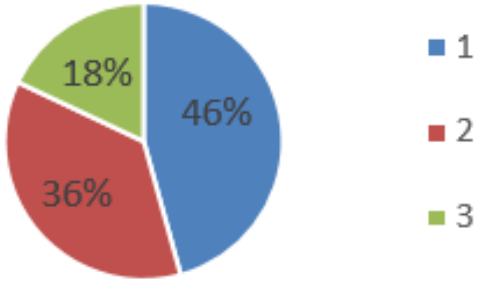


ATR station selected that exhibits typical (median) model performance

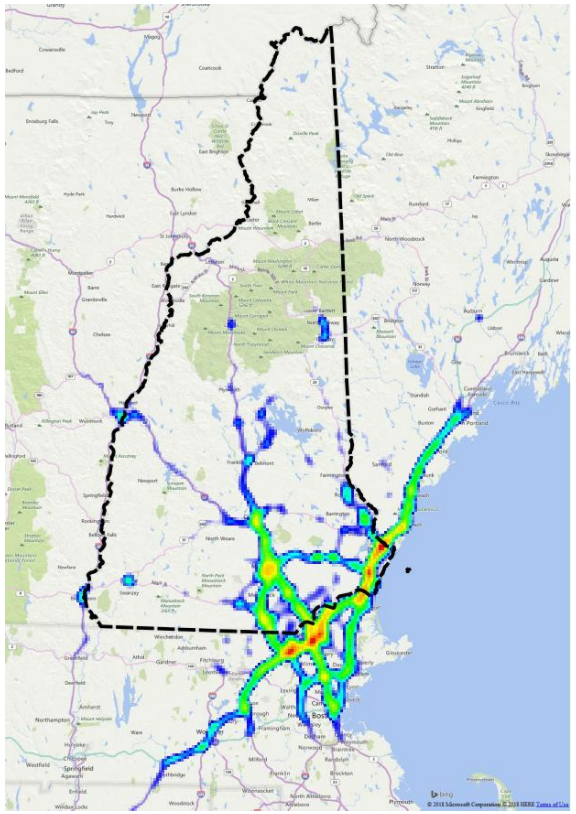
New Hampshire Dataset (Q3 2017)

Data preparation currently in progress

- **GPS probe data** (INRIX)
  - 7M trips, 595M pts (20M trips, 1.4B pts in MD)
  - Snapped to XD segments
  - Problem: ~70% of snapped waypoints in NH dataset are located outside of NH



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



Snapping problem: Majority of waypoints are outside NH (along I-95 or in Boston metro)

Questions

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1977 – 2017





First Look on AADT Estimation

Yi Hou, Venu Garikapati, Stan Young

February 13, 2018

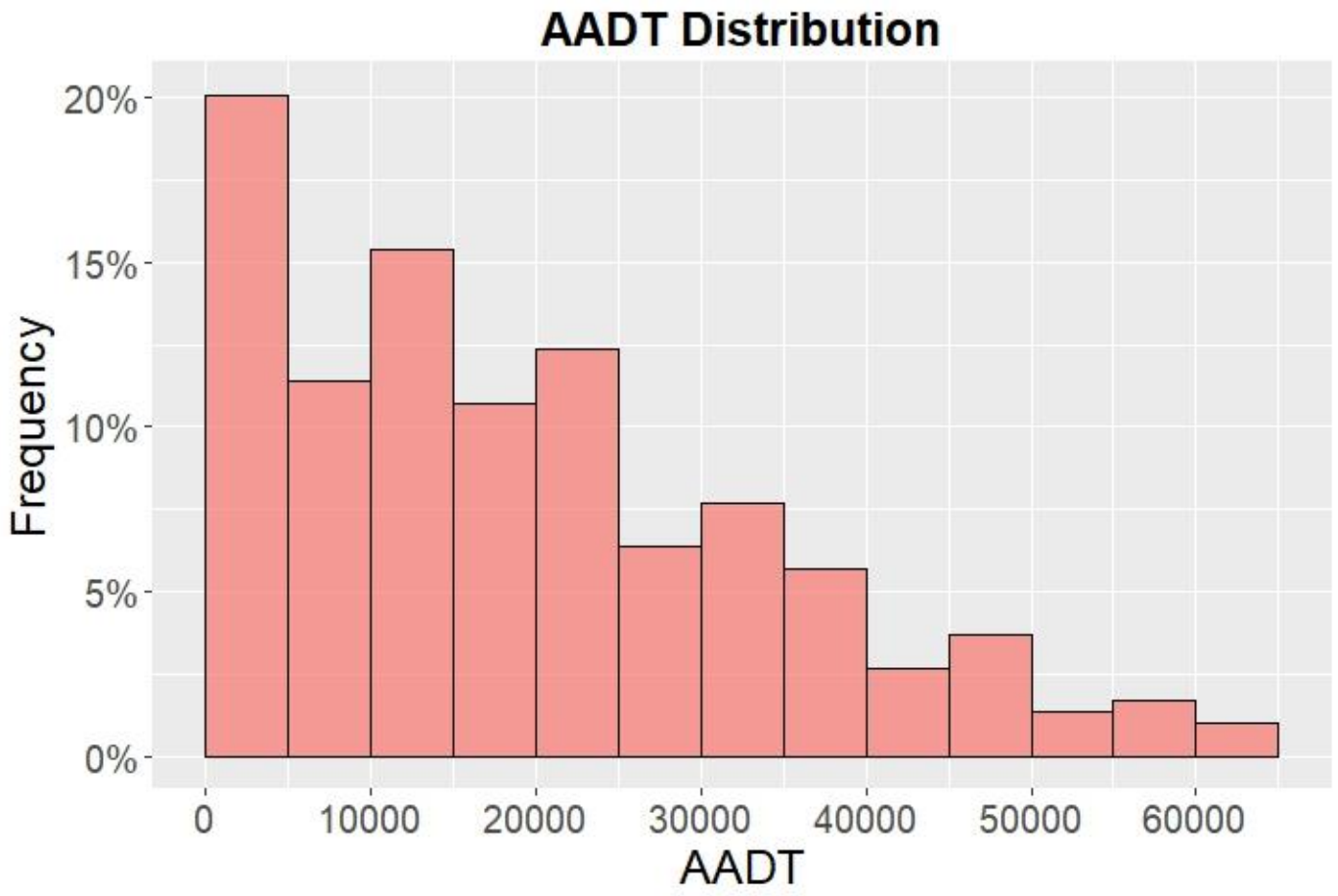
AADT Estimate

- Now take a look at Estimating AADT
- Same modeling method
- Built a whole new model (rather than aggregate current)
- Used daily average volume of 48-hour count to approximate ground truth AADT
- First attempt ----- need feedback

- Inputs – Daily (not hourly)
- Compare estimated daily volume to 48 hour average

AADT Distribution

- ~20% of locations has AADT less than 5000



AADT Estimation Input Variables

Variables included	Variables not included

• TomTom GPS data
  • Daily average speed
  • Total daily probe count
• Road characteristics
  • Road class
  • Urban or not
  • Speed limit
  • Longitude
  • Latitude
	• Hourly weather information
	  • Temperature, precipitation, visibility, fog, rain, snow
	• 2015 AADT
	• Temporal information
	  • Month, day of week, hour of day

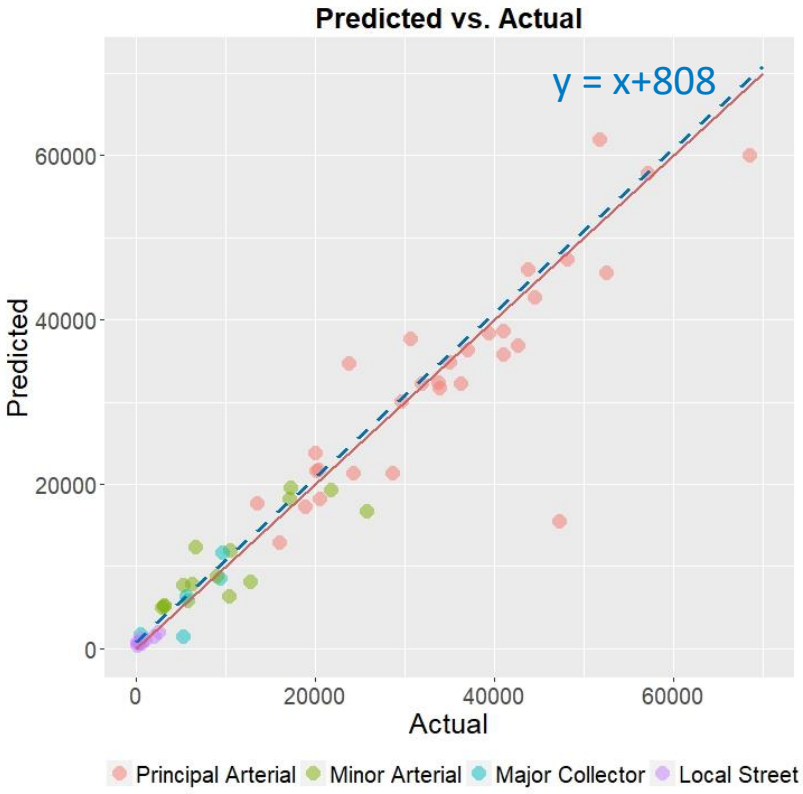
Model Comparison

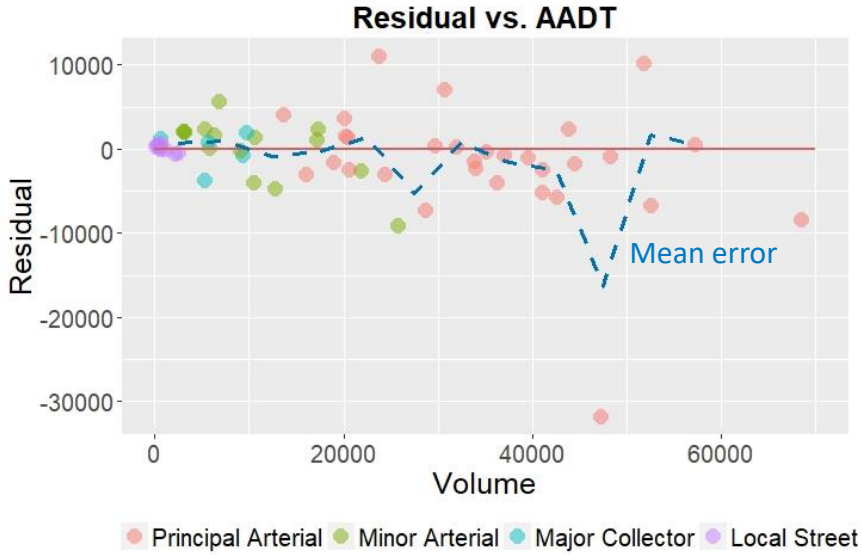
- MAPE: 33.7%
- Significant progress with machine learning
- “Average error rates can rise quickly to 100% or above” (Gadda et al. 2007)
- Significant improvement compared with linear regression

Model	MAPE	MAE	R2
XGBoost	33.7%	3140	0.90
Linear Regression	165.0%	5427	0.81

Residual Analysis

- Model is well fitted
- Model is not biased





Contribution of Probe Vehicle Data

- Probe vehicle data has significant impact on AADT estimation accuracy

Model	MAPE	MAE	R2
Without Probe Data	74.9%	5116	0.80
With Probe Data	33.7%	3140	0.90
Difference	-41.2%	-1976	+0.1

MAPE – Mean Absolute Percentage Error MAE – Mean Absolute Error

Summary

- Basic modeling approach is effective
  - Machine learning Rocks!
  - Need to verify structure of model (are we estimating and comparing the right things)
- Probe data count very important to accuracy
- Need feedback ….

Thank You!

Discussion

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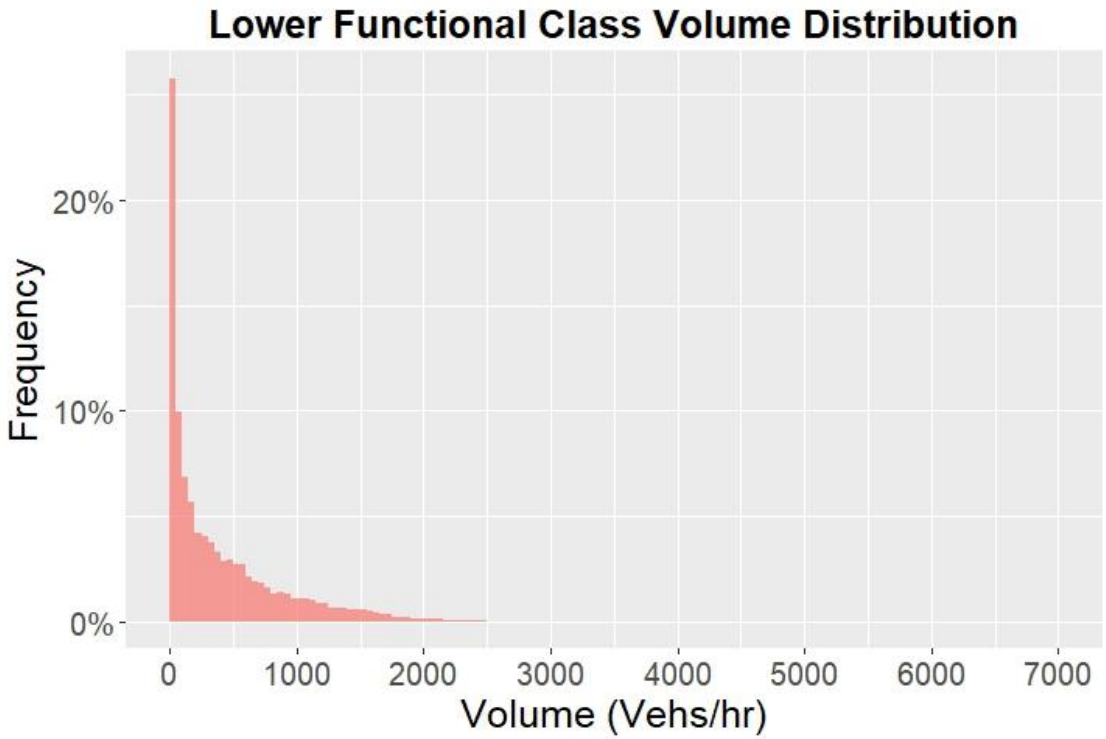
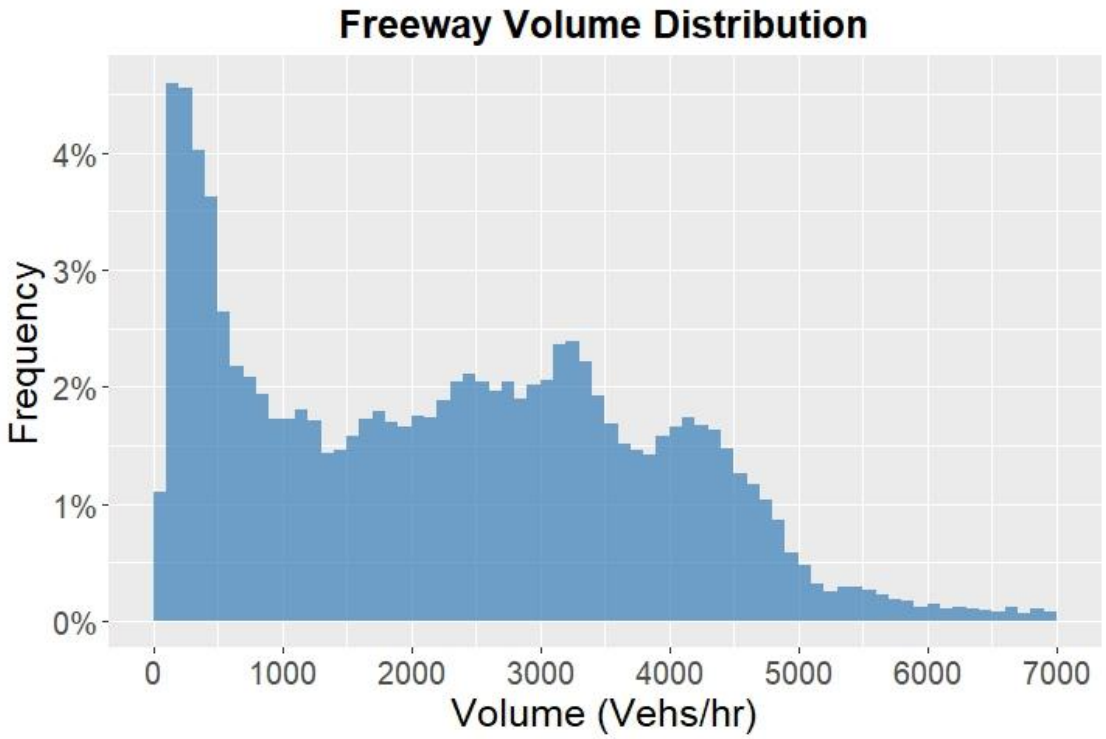
Next Steps & Wrap Up

Summary

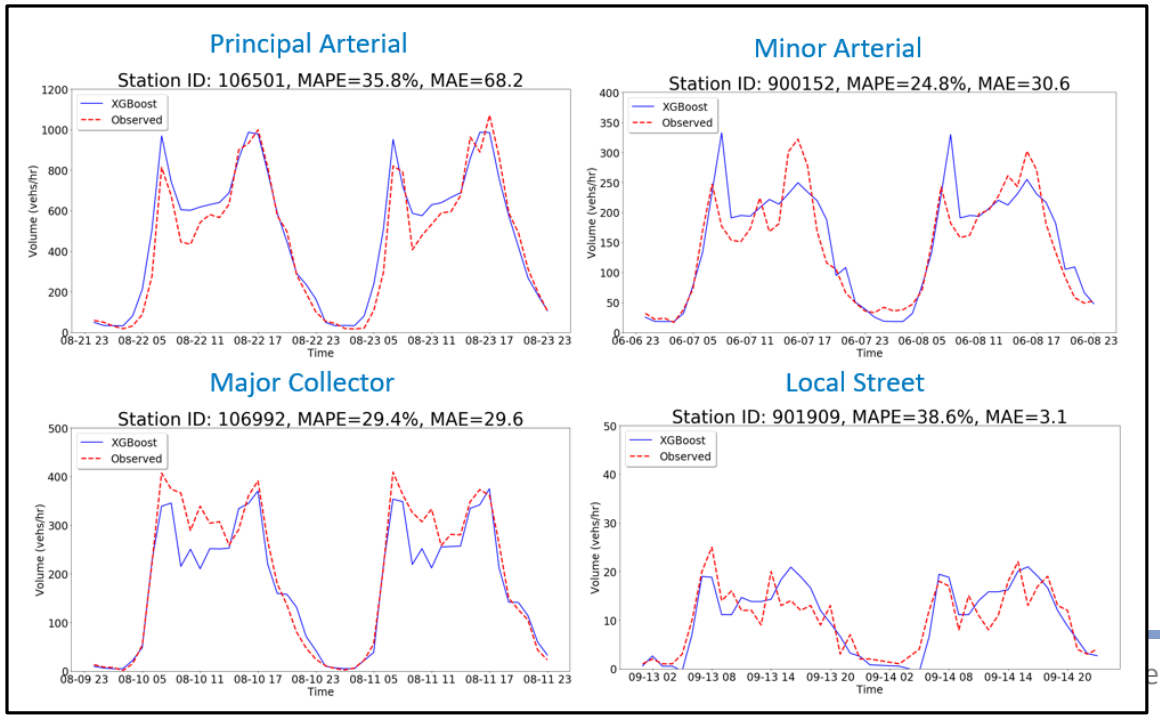
- Off-Freeway volumes significantly less

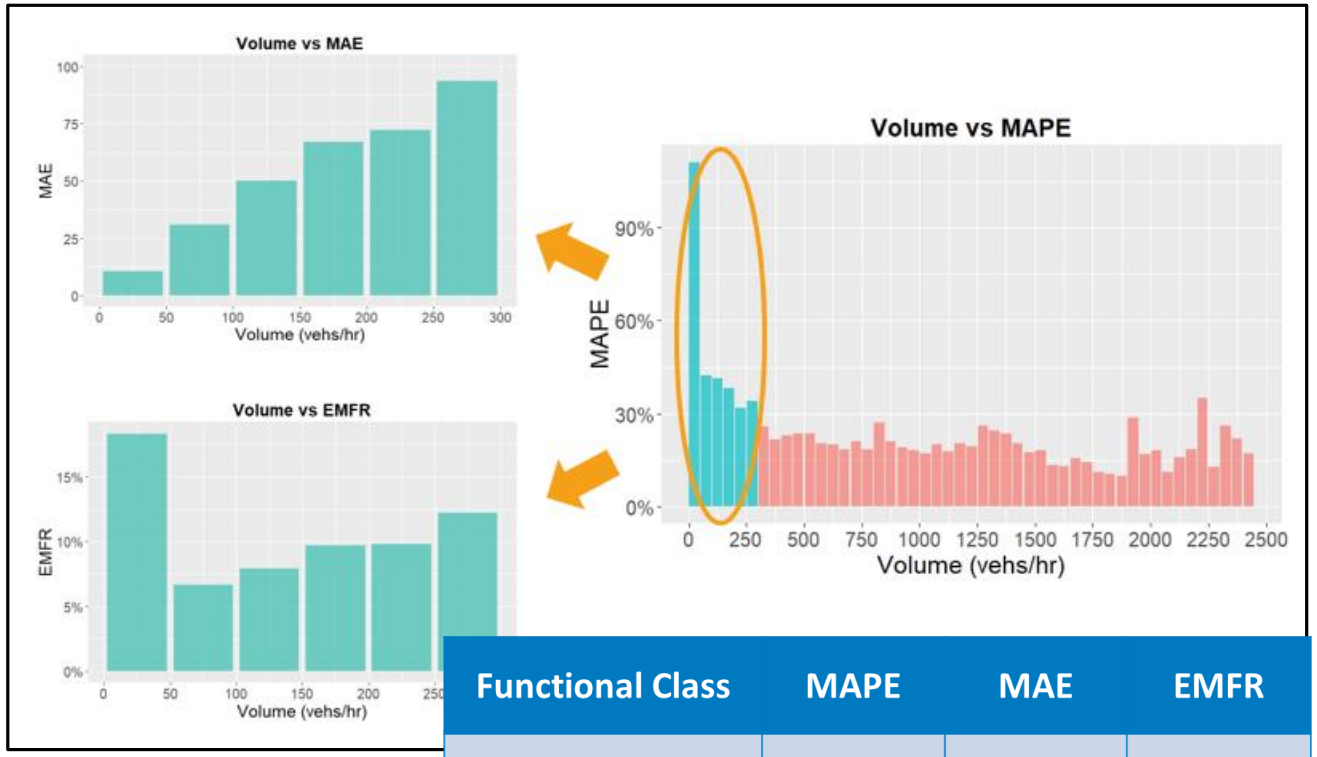




Colorado Off-Freeway Results

- **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**

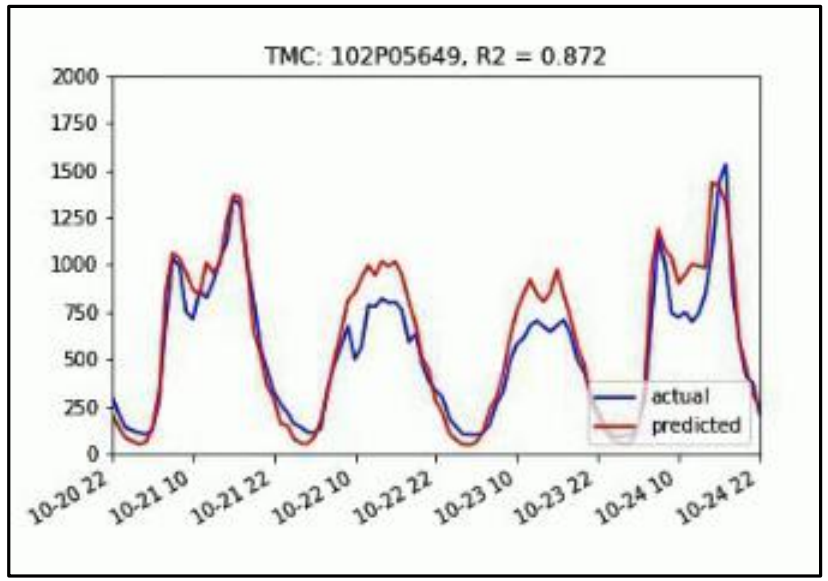




Functional Class	MAPE	MAE	EMFR
Principal Arterial	31.3%	123.3	9.8%
Minor Arterial	44.1%	71.0	9.4%
Major Collector	115.7%	29.4	24.8%
Local Street	101.7%	6.6	26.9%

Florida Results

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



Road Classification	R2	MAPE (%)	EMFR (%)	Obs
Freeways (FRC 1)	0.86	21	6	195704
Maryland (mostly FRC 1)	0.86	23	7	158040
Principal Arterials (FRC 2)	0.82	26	7	370567
Major/Minor Arterials (FRC 3 & 4)	0.83	33	7	128419

Hourly Volume (vph)	R2	MAPE (%)	EMFR (%)	Obs
0-1k	0.81	29	7	465591
1k-2k	0.86	22	6	164465
2k-3k	0.88	18	6	49221
3k+	0.87	19	6	15413

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)

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%
1,000 - 4,999	-15%	20%
5,000 - 49,999	-10%	15%
50,000+	-10%	10%

MNDOT Example

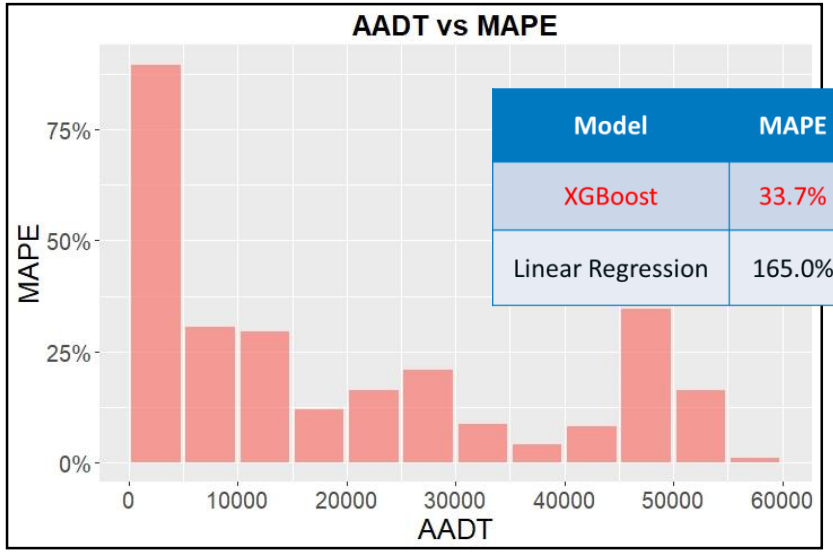
Off–Freeway Take-aways

- Stable, unbiased estimates at low volume
- Performance is volume dependent
  - High Volume – 10-20% MAPE (Freeways, Principal Arterials)
  - Mid Volume – 20-30% MAPE (Minor Arterials and Major Collectors)
  - Low Volume - 30-50% MAPE (Major Collectors and Local Streets)
- Accuracy targets by volume class are met
  - Need consistent accuracy metrics by volume class
- Need confidence or error estimate

Initial AADT Results

- Initial compared to average of 48 hour counts
- MAPE or MAE depending on volume
- Initial results positive, but requires iteration
- Compares favorably with MNDOT Results – however - NOT Apples to Apples
- Need consistent evaluation framework
- Stay-Tuned

  Provide Input



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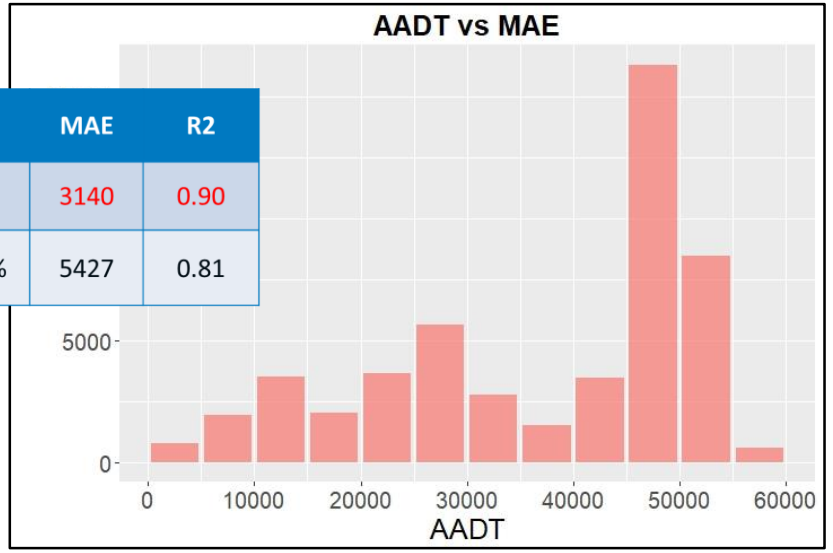
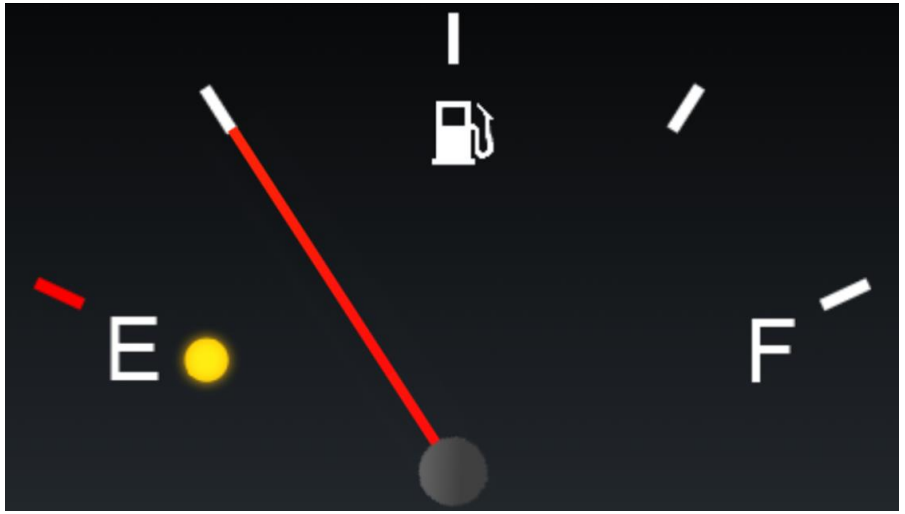


MNDOT Results

Traffic Volume Level Category	Number of Hourly Values	Mean Absolute Percent Error	Mean Absolute Difference	Mean Signed Difference
< 1,000 vehicles per hour (vph)	1,247	53%	165	-63
1,000 to 5,000 vph	334	34%	535	-433
5,000 to 10,000 vph	0	-	-	-
> 10,000 vph	0	-	-	-
All Traffic Levels Combined	1,581	49%	243	-141

Future Work – Next Steps



- NREL – Refine AADT initial efforts
- UMD to extend work to NH
- (Candidate) Next Steps
  - Technical work
    - Low-volume / Confidence flag or metric
    - Accuracy metric indexed to abnormal/special events
    - Relative importance of input (temp, time of day, location, probe data)
    - Issues when volumes exceed training data
    - Error with respect to probe counts
  - AADT work – framework, high and low volume, PFS
  - Truck Volumes / Turning movements

Wrap Up

- Next Meeting/Webinar
  - June 2018
  - Look for more information!

Final Questions

Thank You!

For Questions, please contact:

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