I-95 Corridor Coalition

Webinar on Accurate Estimates of Traffic Volume - anywhere, anytime - from GPS Probe Samples

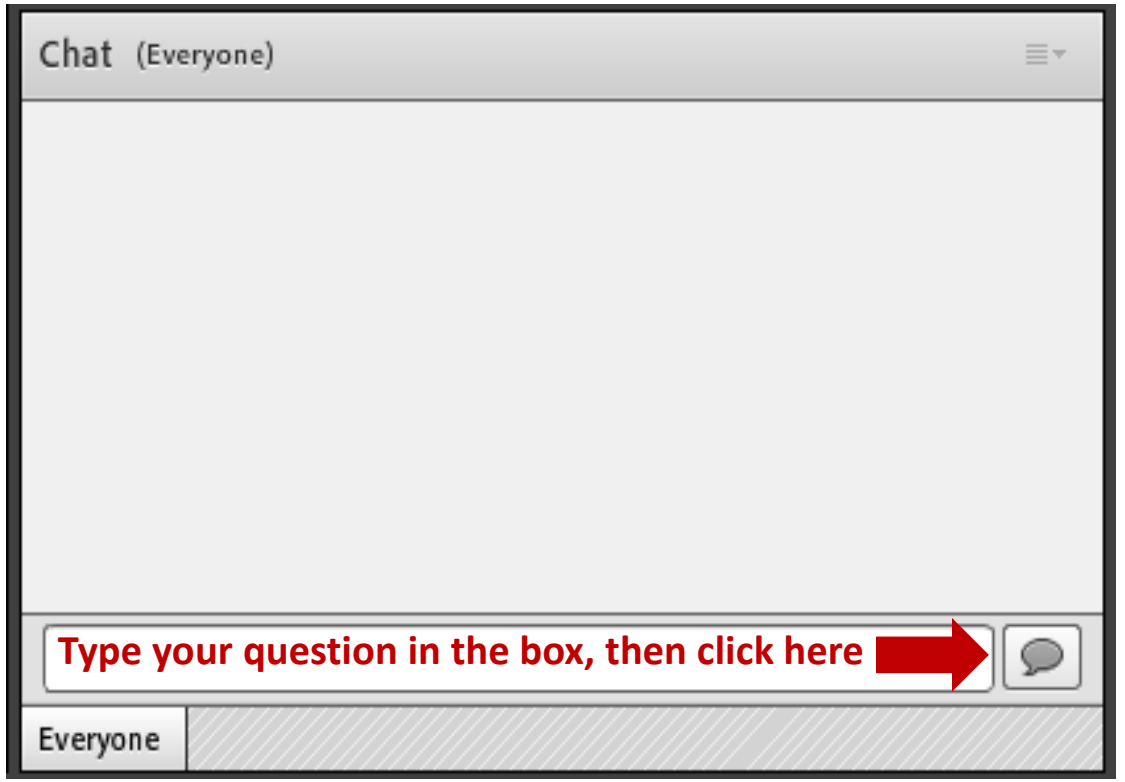
May 23, 2018

Webinar & Audio Information

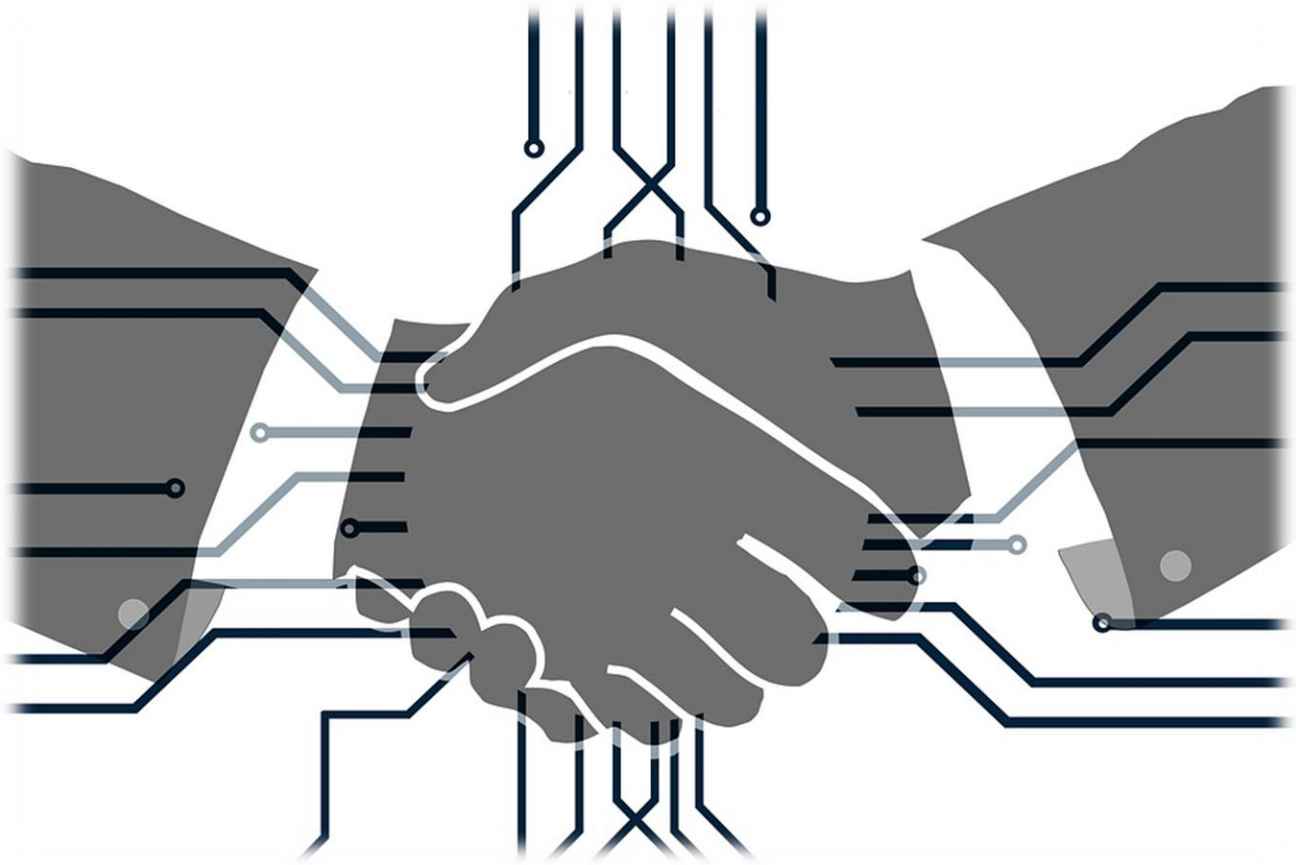
- The call-in phone number is: **xxx-xxx-xxxx & enter xxxxxxx# at the prompt**
- **Participants will be in "Listen Only" mode throughout the webinar**
- Please press *0 to speak to an operator for questions regarding audio
- Please call xxx-xxx-xxxx for difficulties with the web or audio application
- This webinar will be recorded
- Presentations will be posted to the I-95 Corridor Coalition website. Participants will receive a link to the presentations after they are posted.

Asking Questions

- Please pose your questions using the **chat box**
- Questions will be monitored then answered by the speakers at the end of the webinar

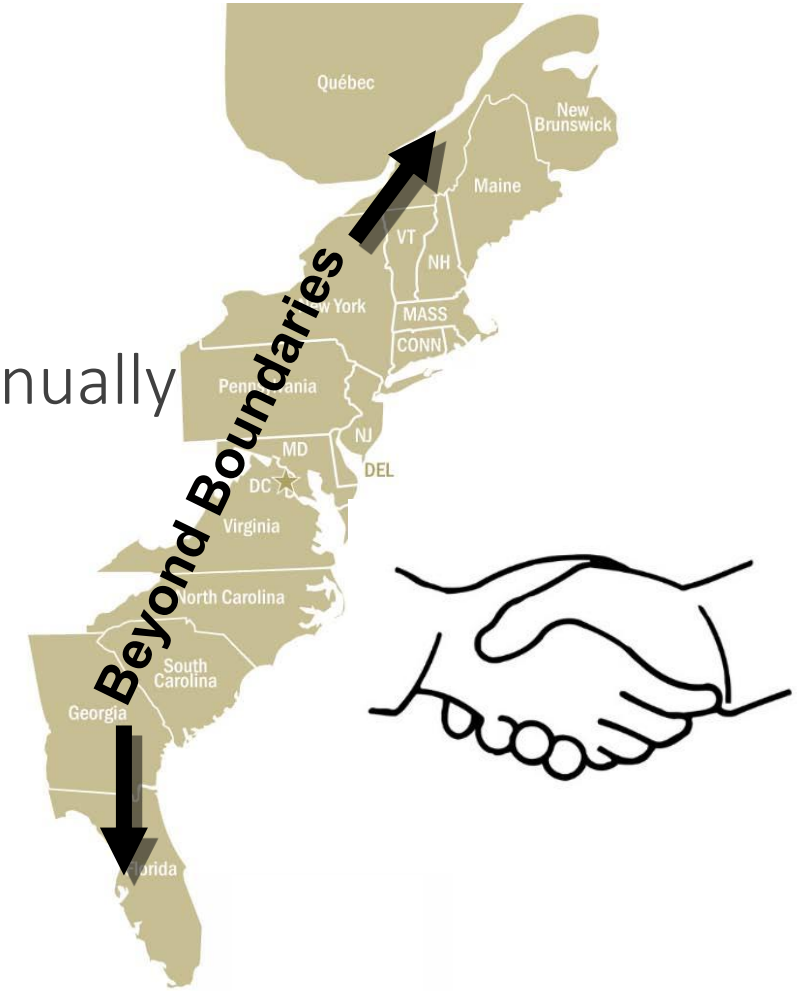


Welcome



Who is the I-95 Corridor Coalition?

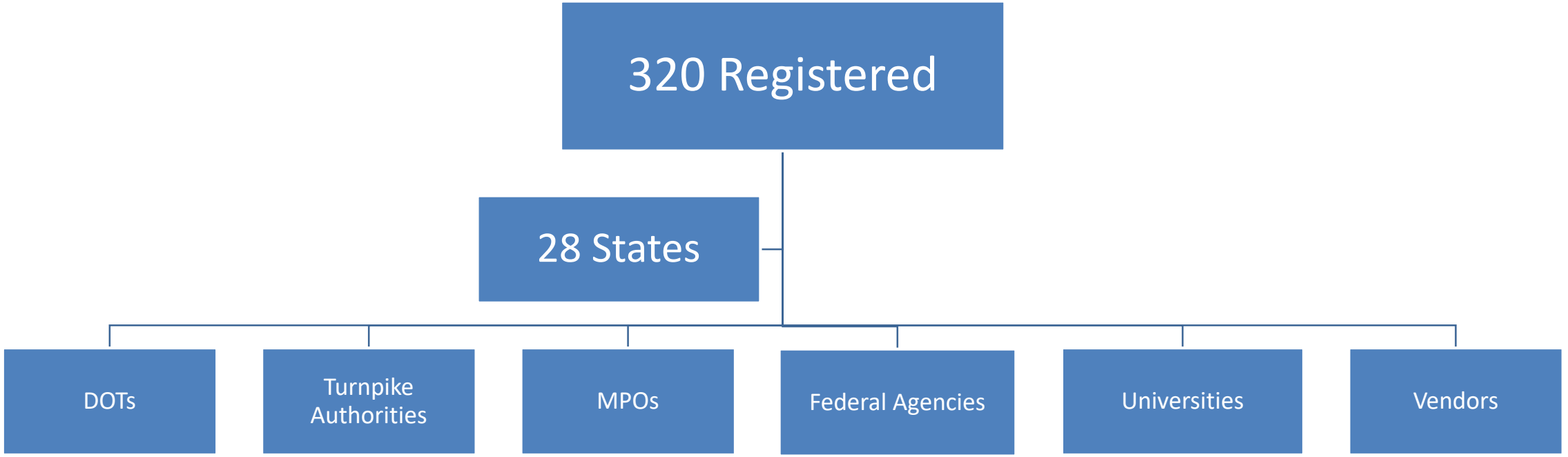
- 16 States and the District of Columbia
- 35% of nation's VMT (21% of road miles)
- 565 million long-distance (>100 miles) trips annually
- Corridor = third largest economy in world



How can we better message TSMO strategies Regionally?

…a partnership of multi-state, multi-modal public agencies working together to create a seamless and efficient transportation system

I-95 Corridor Coalition Sponsored Event



Speakers

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Yi Hou, PhD
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Outline

- Introduction – Stan Young
- Results from University of Maryland – Kaveh Sadabadi
- Results on Colorado Roadways – Yi Hou
- Summary and Discussion – Stan Young

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.

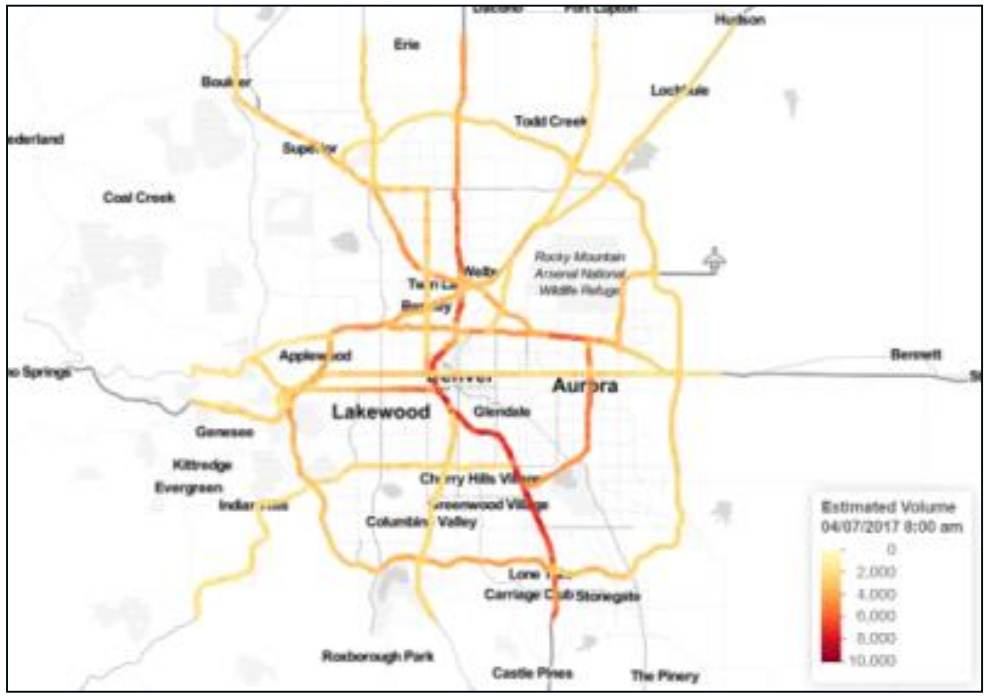
Why Do We Need More and Better Volume Data?

- **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

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

Standard Error Measures

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

Traffic Engineer

Highway Operations

Statistician/ Planner

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

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%

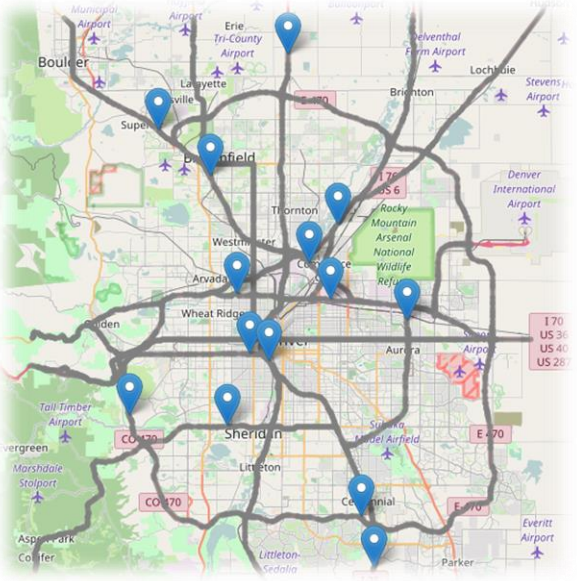
MNDOT Example

Estimation vs. Observation (Median R^2)

Framework, Details of Analysis, Statistical Evidence

- Florida, Full Network
  - Kaveh Sadabadi, UMD

- Colorado Results
  - Yi Hou, NREL



Traffic Volume Estimation using GPS Traces

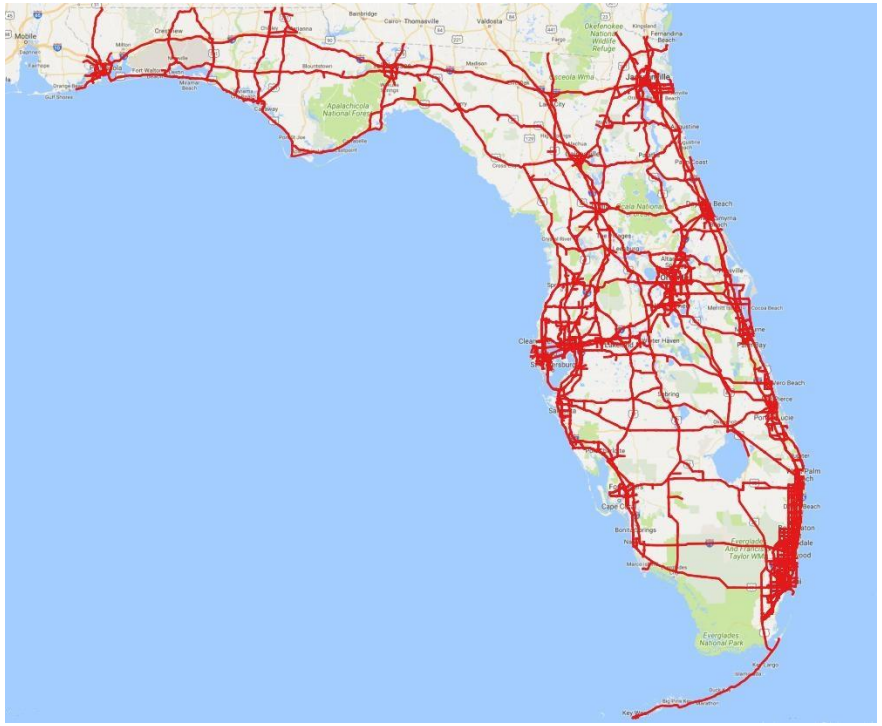
Presented by:
Kaveh Farokhi Sadabadi

Analysis Performed by:
Przemyslaw Sekula and Zachary Vander Laan

National Webinar
May 23, 2018

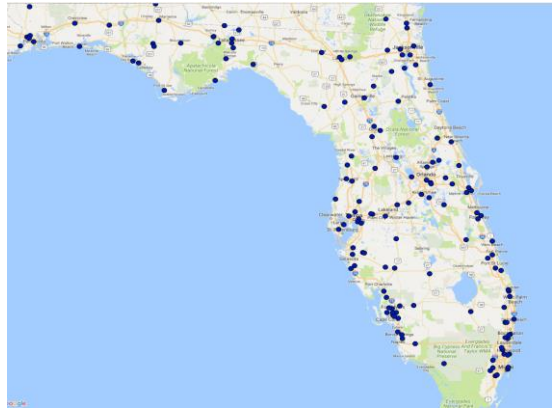
Presentation Outline

- Overview
  - Objectives
  - Volume estimation approach
- Florida case study
  - Dataset
  - Results
  - Statewide Estimation
  - AADT & AAWDT
- Summary & Next Steps

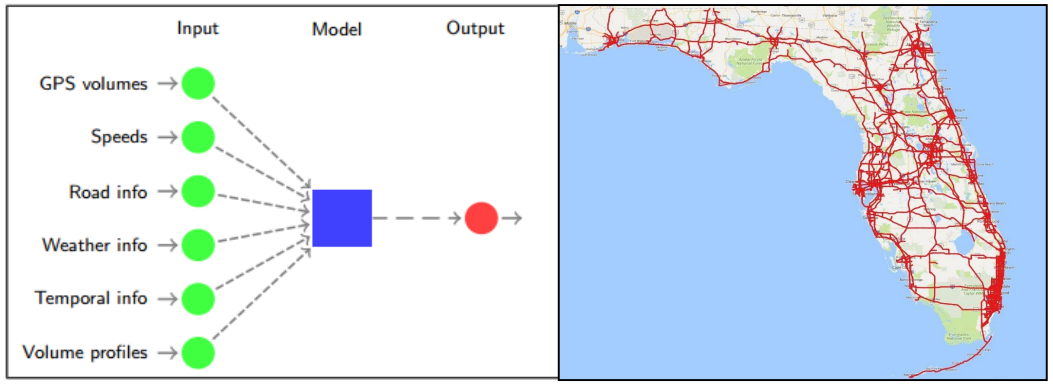


Objectives

- Given the following:
  - Probe volumes (processed from GPS traces of a subset of vehicles),
  - Other archived data (speeds, road geometry, weather, etc.)
  - Counts at permanent traffic monitoring stations
  - TTI volume estimates



- Can we build a model to accurately estimate statewide volumes?



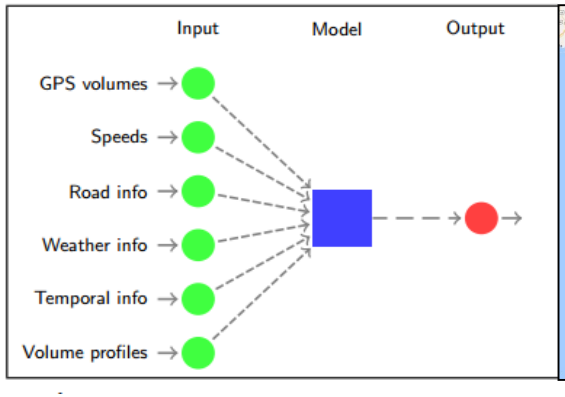
Volume Estimation: General Approach

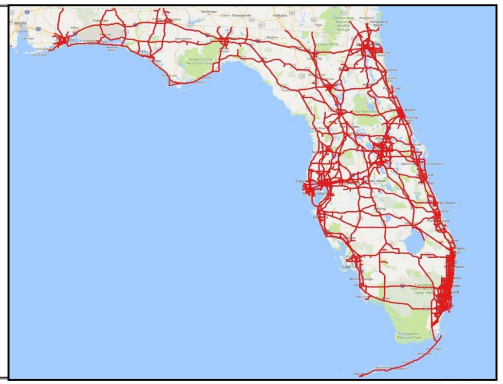
Develop and Train Model

- Where? TMC segments associated with permanent count stations
- How? Construct machine learning model to learn relation between input variables and permanent count station volumes

Apply model to state road network

- Where? All TMC segments on road network
- How? Apply trained model to input variables from any TMC segment on the network

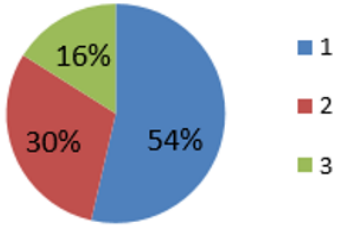




Florida Dataset (Q4 2016)

At all TMC segments

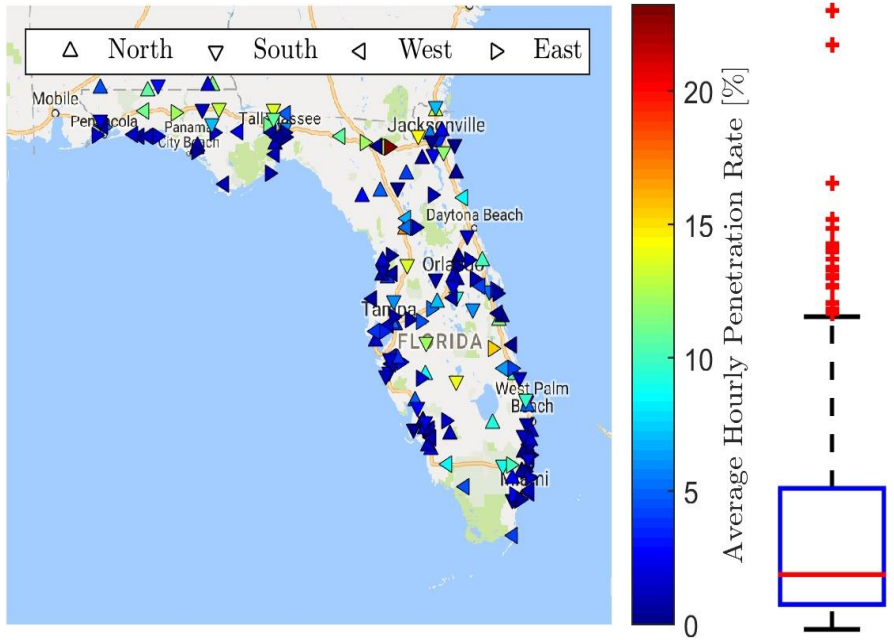
- **GPS probe data** (INRIX)
  - 75M trips, 3.4B pts (20M trips, 1.4B pts in MD)
  - Penetration rate: 2.1% median (1.9% in MD)
  - Snapped to XD segments
- **Probe Speed data** (HERE)
- **Road characteristics**
  - NPMRDS TMC shape file features
  - Open Street Map (OSM) conflation
- **Weather data**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



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

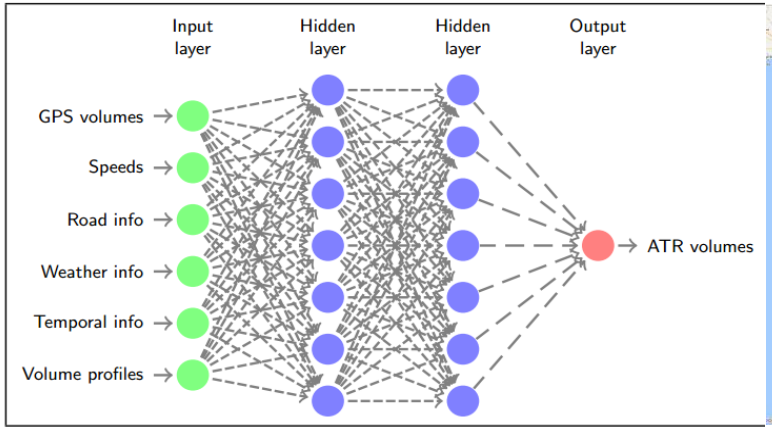
At permanent count stations

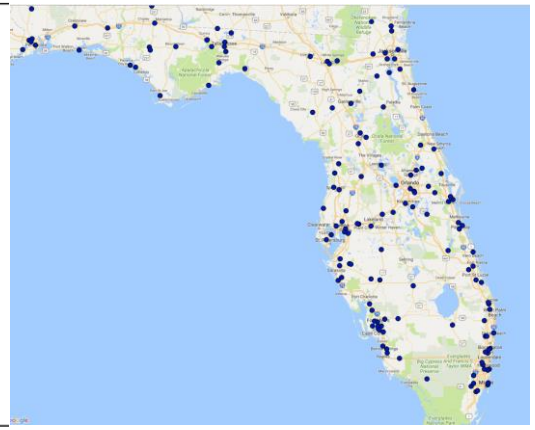
- **Traffic counts** (FDOT)
  - Used for model training / evaluation
  - Used to estimate probe penetration rate

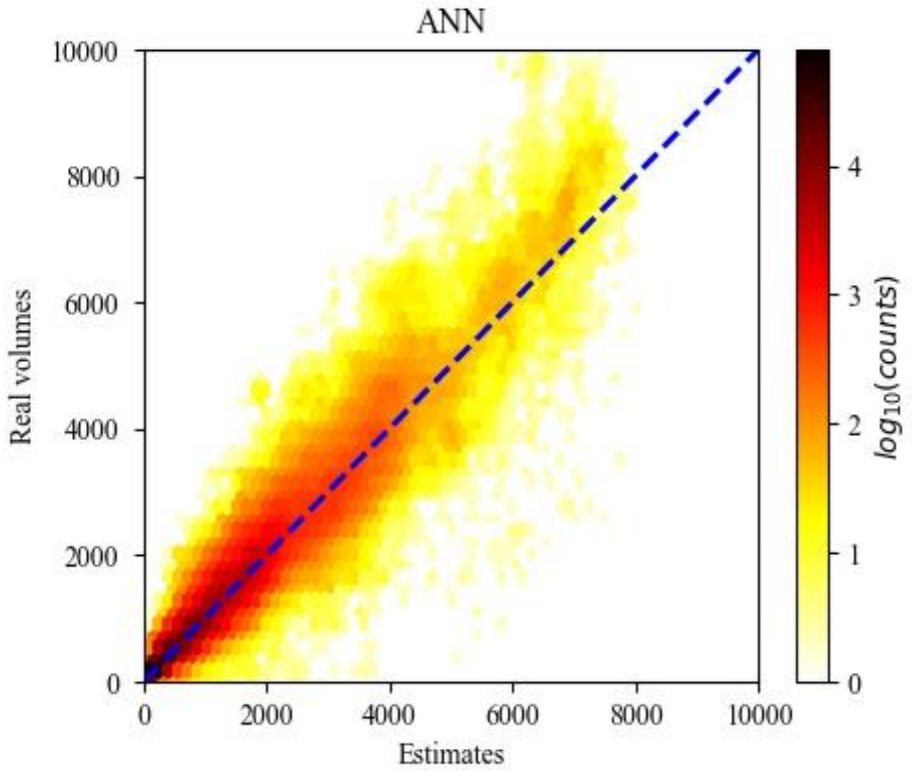


Florida Model Evaluation

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







- Evaluation: Compare estimated / observed volumes & generate metrics

Florida Results: Summary

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

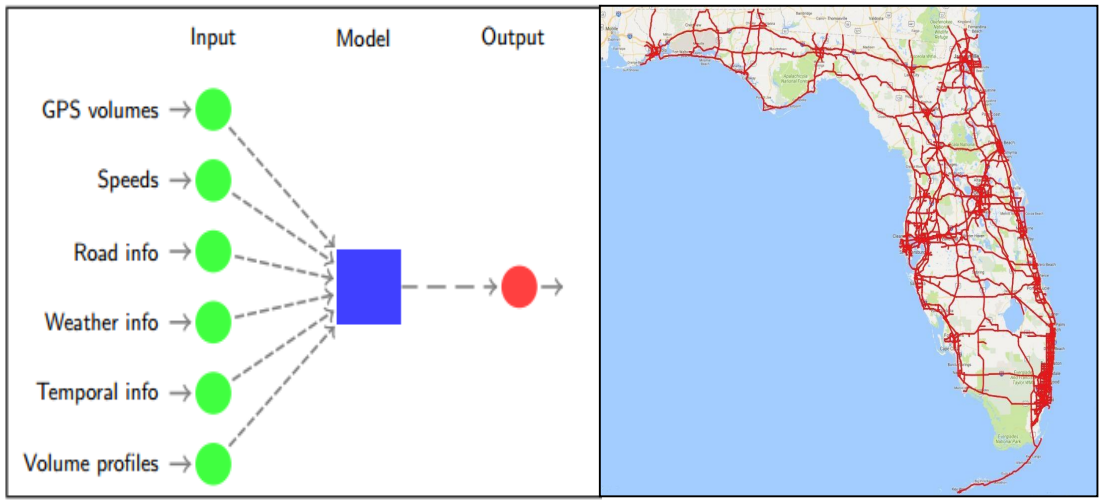
- Promising model performance, over a variety of scenarios
- Better performance on higher road classes
- Better performance as average traffic volume increases

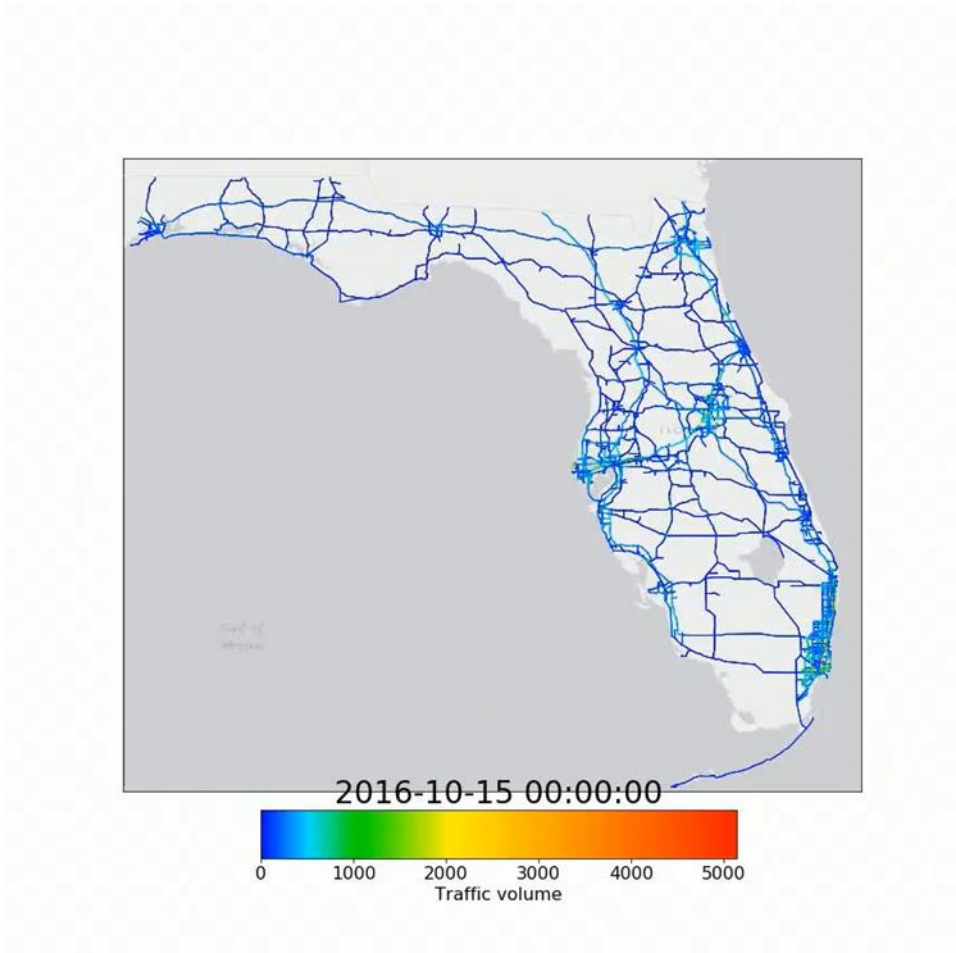
Median Error Metrics by Scenario

Road Classification	R2	MAPE (%)	EMFR (%)	Obs
FRC 1 (Interstates)	0.86	21	6	195704
FRC 2 (Other freeways & Expressways)	0.82	26	7	370567
FRC 3 & 4 (Other principal & minor arterials)	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
Time Period	R2	MAPE (%)	EMFR (%)	Obs
Day (6am-8pm)	0.49	20	9	405759
Night (8pm-6am)	0.72	32	3	288931
Peak (7am-9am & 4pm-6pm)	0.51	22	10	116542
Off-peak	0.85	26	6	578148

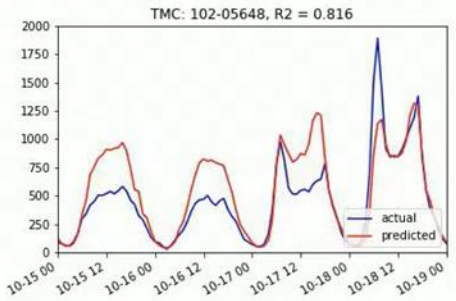
Florida Statewide Model

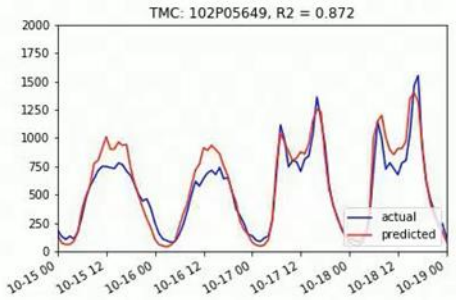
- Apply trained model to entire road network
  - Requires 3 months of hourly input data at ~20k TMC segments
  - Generate hourly volume estimates at each input time/location

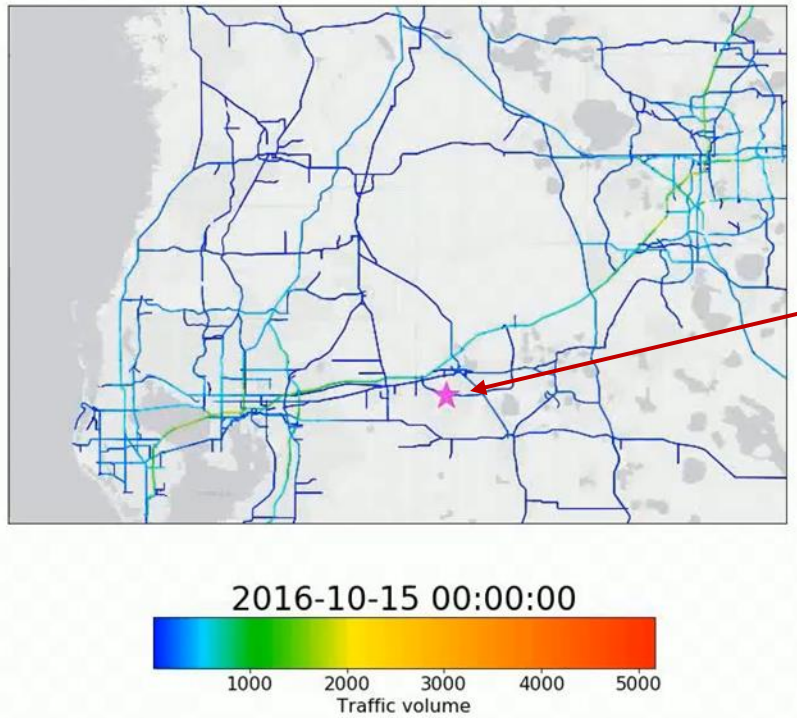




Florida Statewide Model: Tampa Bay Area



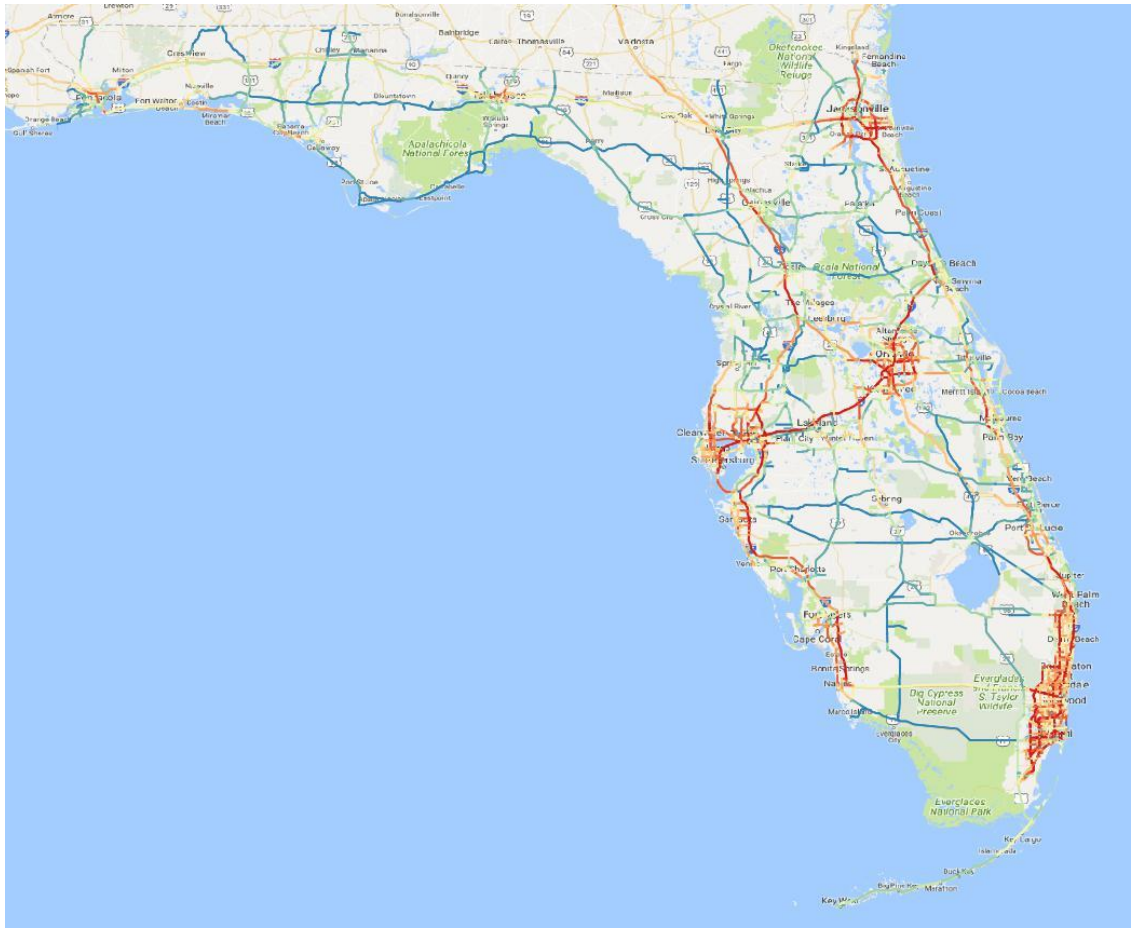




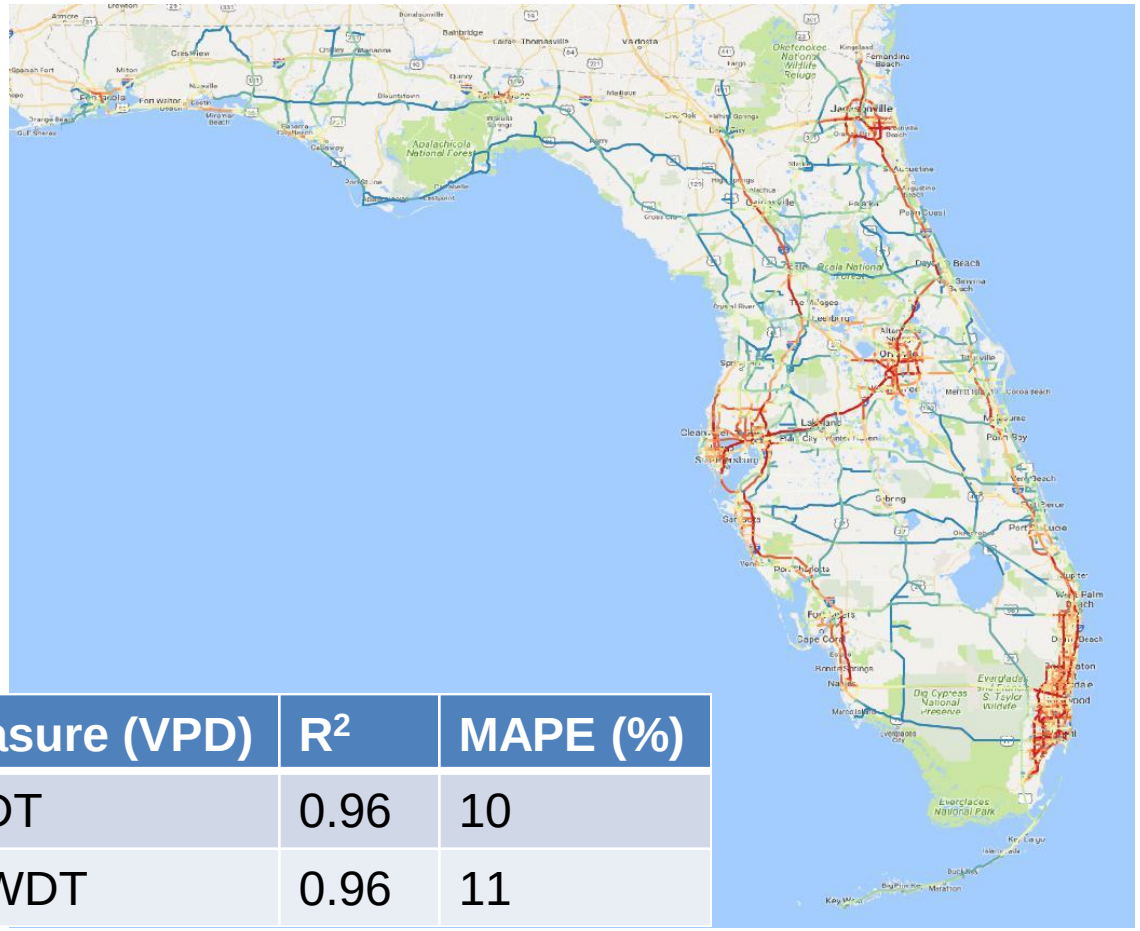
ATR station selected that exhibits typical (median) model performance

Florida Results: AADT & AAWDT

AADT



AAWDT

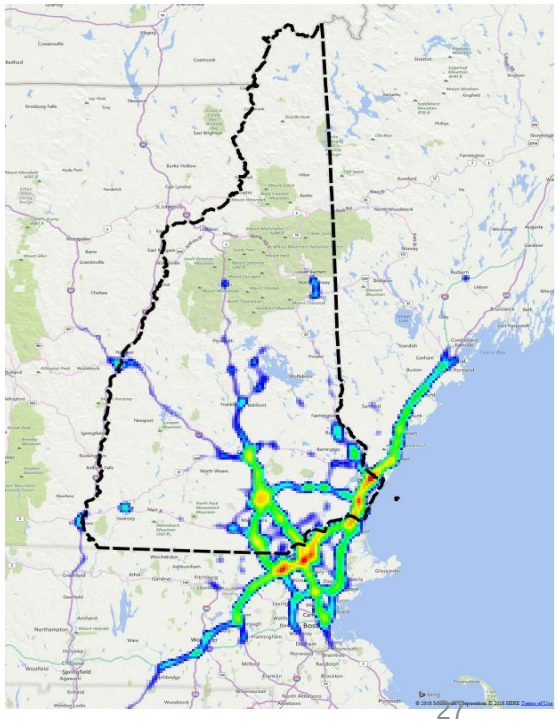


Measure (VPD)	R^2	MAPE (%)
AADT	0.96	10
AAWDT	0.96	11

Summary & Next Steps

- Hourly volumes:
  - Results are good and can be a useful product for both public and private sector
  - Estimation quality improves with road class and actual volumes (number of probes)
  - Estimates meet requirements for most planning and operational purposes
  - Estimates can be safely used for performance measurement and reporting

- AADT and AAWDT estimates:
  - Results are astoundingly good!
  - Consistent with expectation along major highways and urban areas



- Freight volumes
  - Generated volume estimates for light and heavy trucks
  - Results are very promising. Details will be shared in future presentations.

- Test spatial transferability of models
  - Can a model be trained with data from one location, and applied elsewhere?
  - Working with Florida, Maryland and New Hampshire datasets

Questions

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Ubiquitous Volume Estimation – Both Freeway and Off-Freeway

Results on Colorado Roadways
Freeways and Off-freeways

Volume Estimation on Freeways

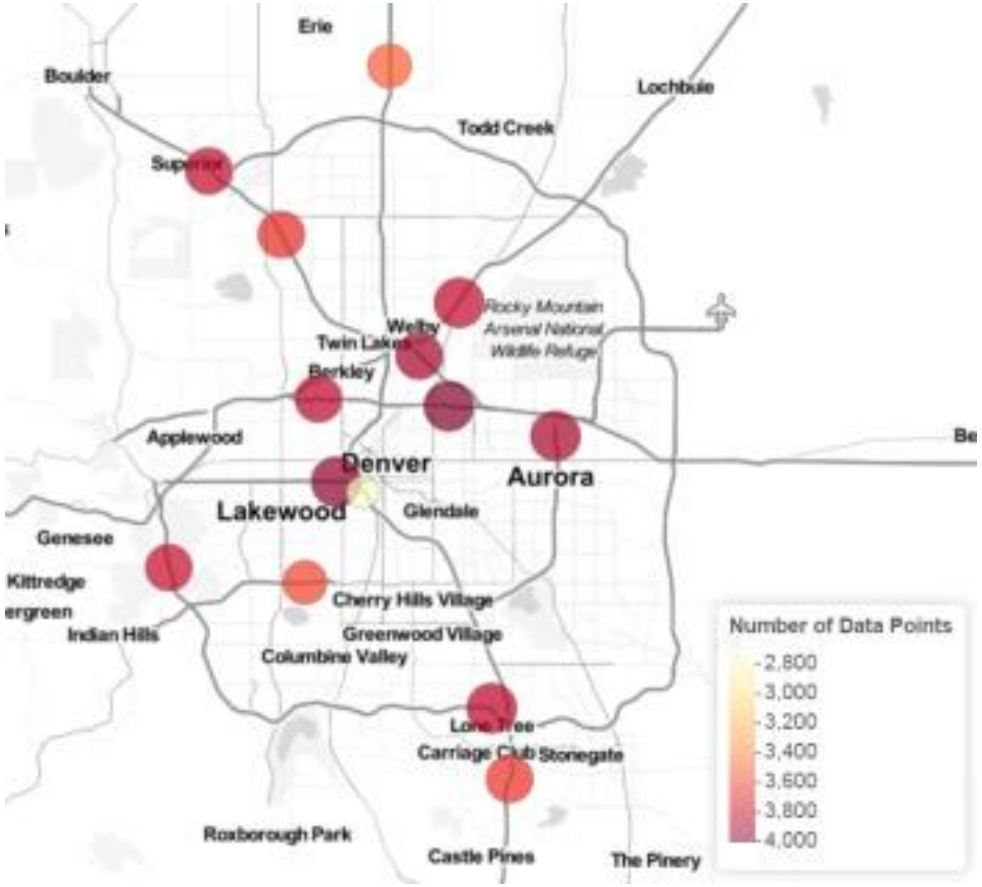
- 14 CCS locations and TomTom segments

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

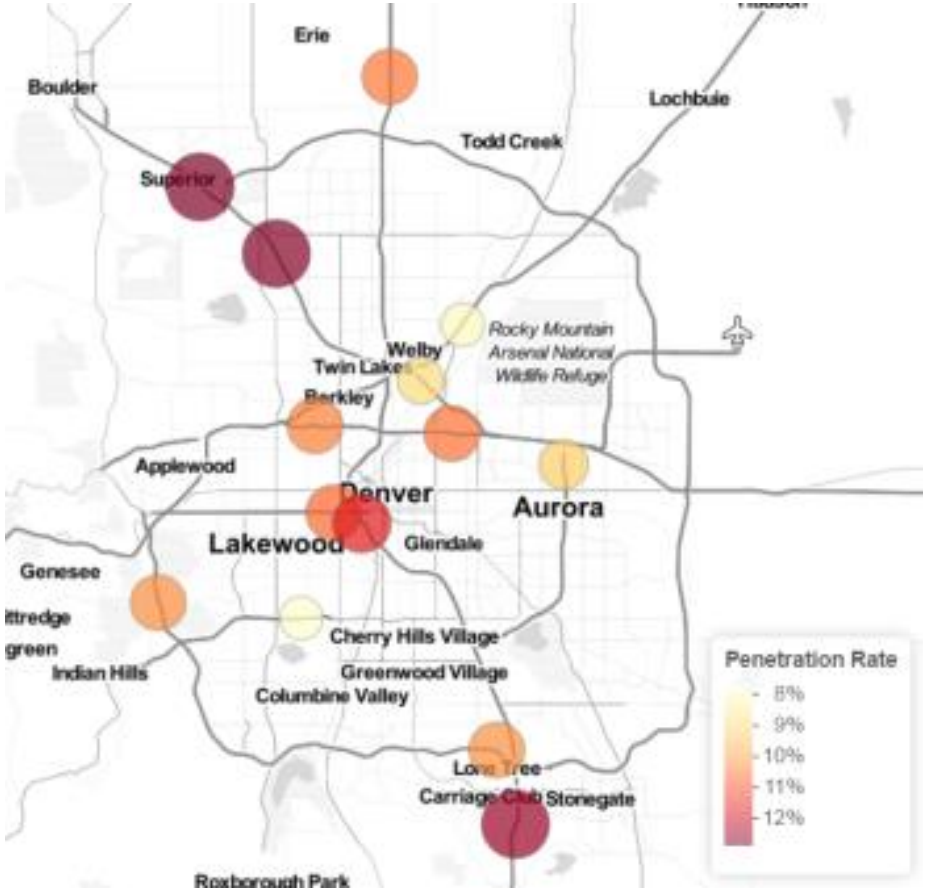
Data Points – Freeway Analysis

- Feb 1, 2017 – April 30, 2017
- A total of 52,092 observations
- Ranges from 2800-4000 observations at each CC location



Penetration Rates – Freeway Analysis

- Percentage of traffic covered by GPS probe data
- Ranges from 8%-12%



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

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 (similar method used for off-freeway)

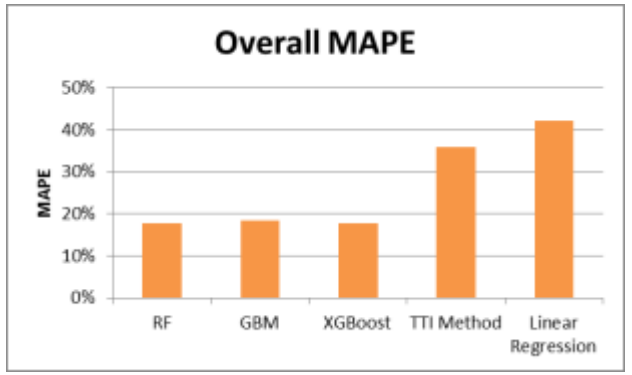
Model Results

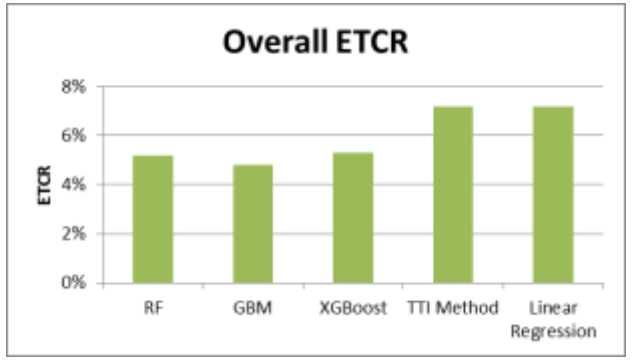
- Results exceed the survey expectation: ETCR<10%
- About 18% error relative to observed volume
- XGBoost is the most computational efficient

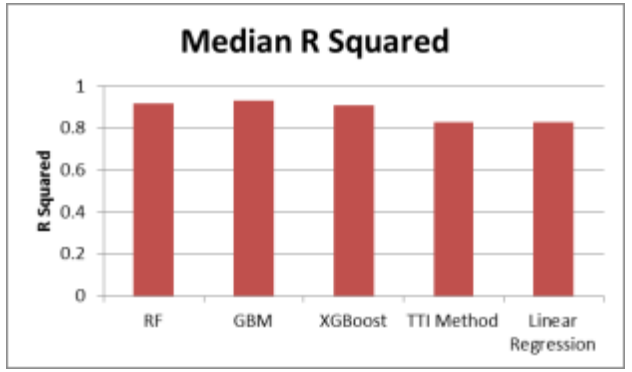
Model	MAPE	ETCR	R2	Training Time
RF	17.8%	5.2%	0.92	73s
GBM	18.3%	4.8%	0.93	124s
XGBoost	17.7%	5.3%	0.91	13s

Model Comparison

- Compare with TTI Method
  - MAPE: ~50% reduction
  - ETCR: ~30% reduction
  - R^2 : ~10% increase
- Compare with linear regression:
  - MAPE: ~60% reduction
  - ETCR: ~30% reduction
  - R^2 : ~10% increase





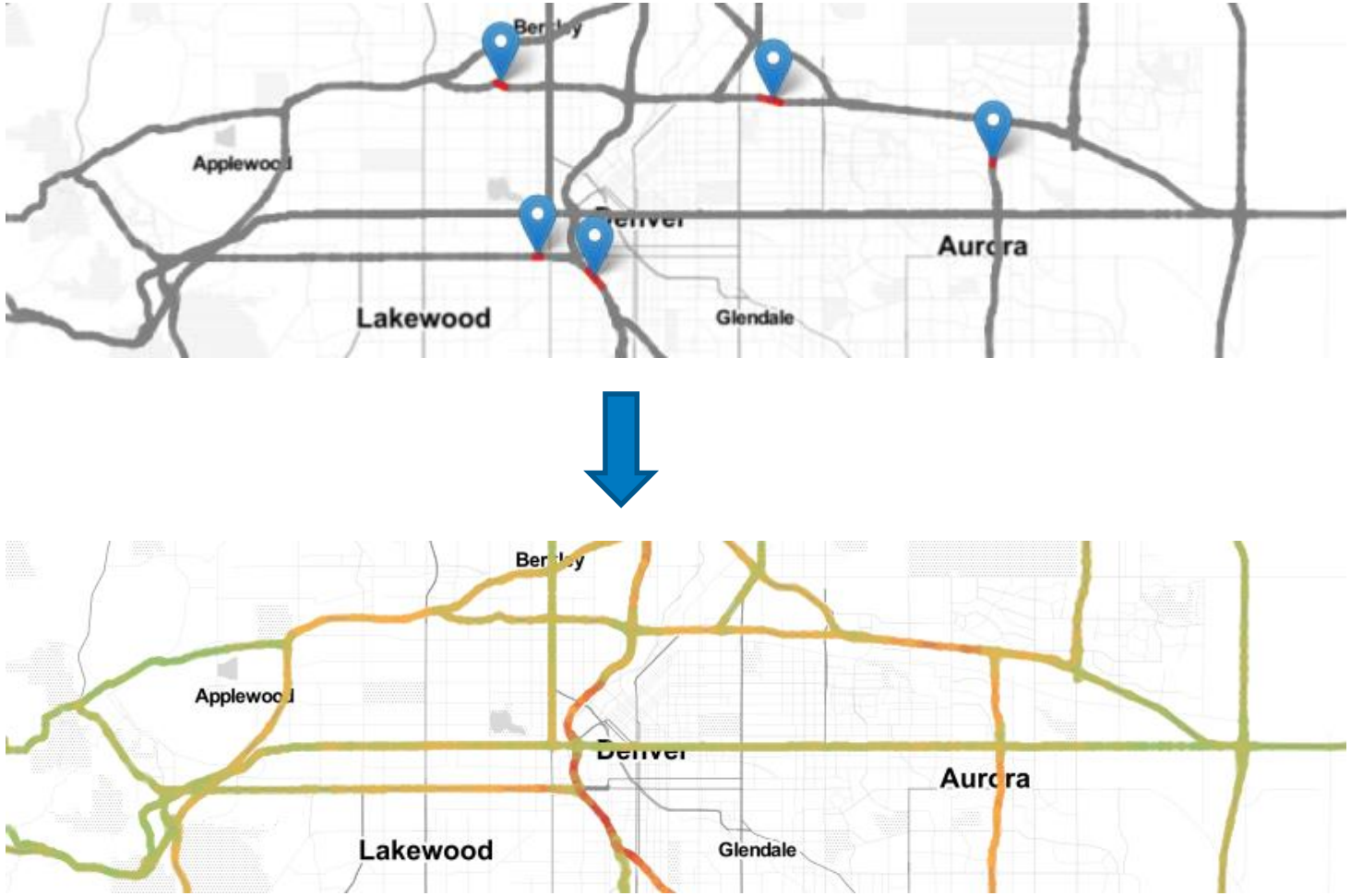


Contribution of Probe Vehicle Data

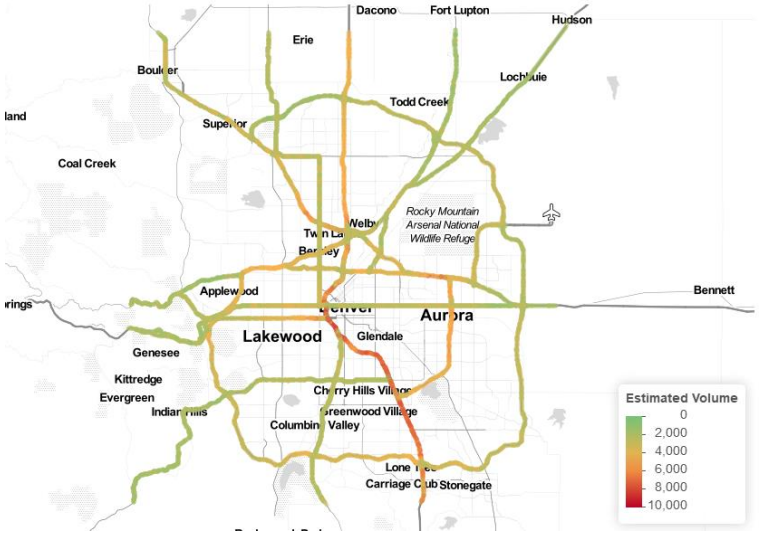
- Probe vehicle data has significant impact on volume estimation accuracy

	Overall MAPE	Overall ETCR	Median R^2
Without Probe Data	39.4%	12.4%	0.65
With Probe Data	**17.7%**	**5.3%**	**0.91**

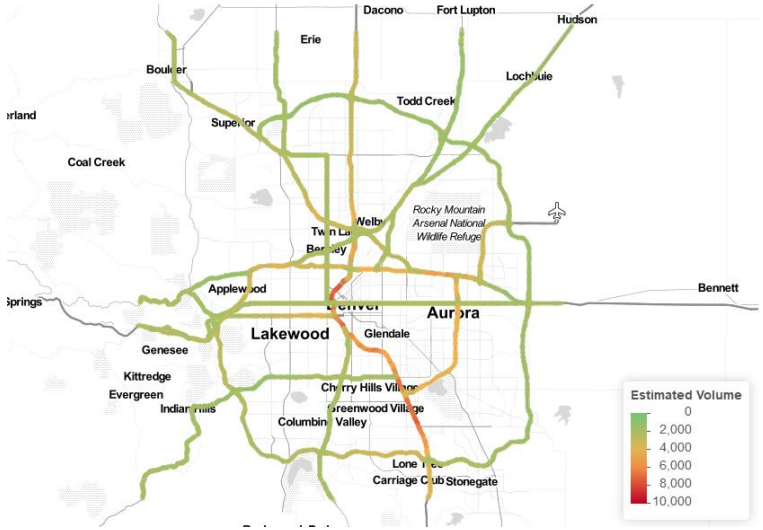
Solution to Enhancing Network Observability



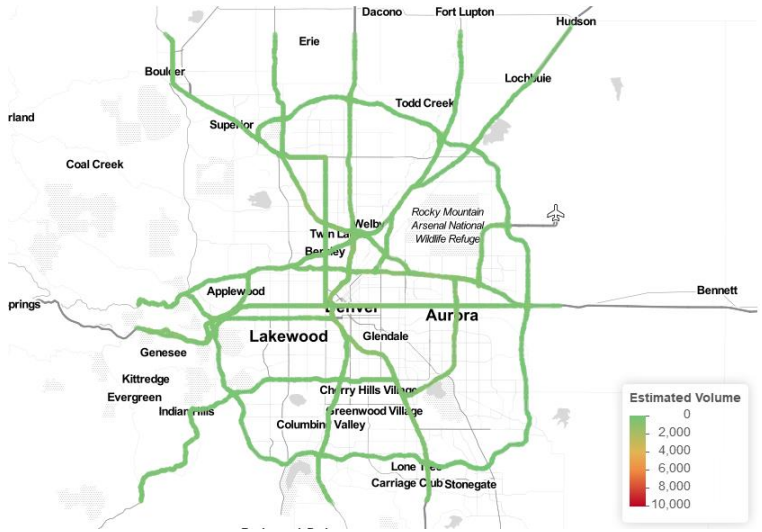
Traffic for Different Time Periods



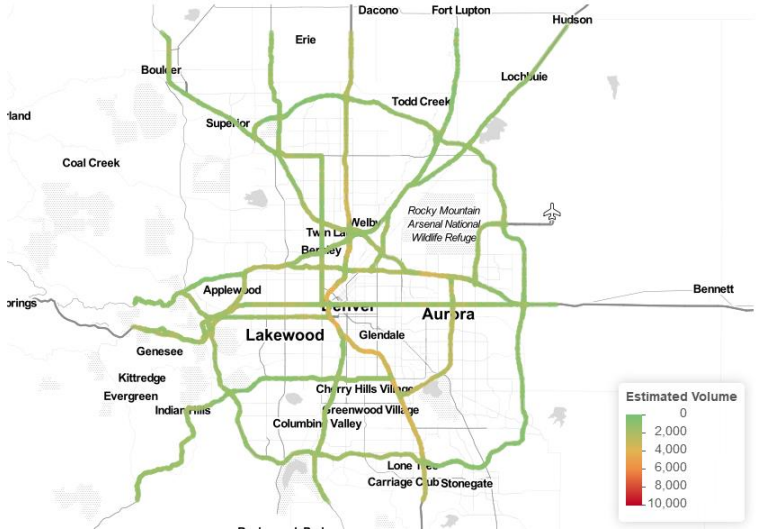
Wednesday 8:00 am



Wednesday 2:00 pm



Wednesday 1:00 am



Saturday 8:00 am

Does It Work Off Freeways?

Road Functional Class

- FHWA functional classification

Freeways
- Interstates
- Other Freeways

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

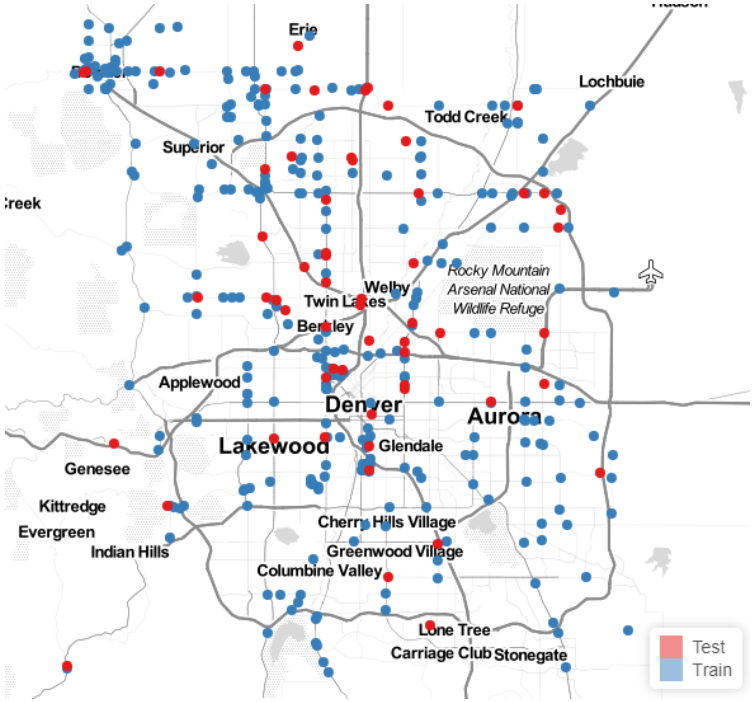
	Lower Class Roads	Freeways
Percentage of Miles	98.5%	1.5%
Percentage of Lane Miles	96.7%	3.3%
Percentage of VMT	68.5%	31.5%
Monitoring Method	Short-term counts	Continuous count stations & Short-term counts

Data source: FHWA Highway Statistics 2013

Volume Estimation on Lower Functional Class Roads

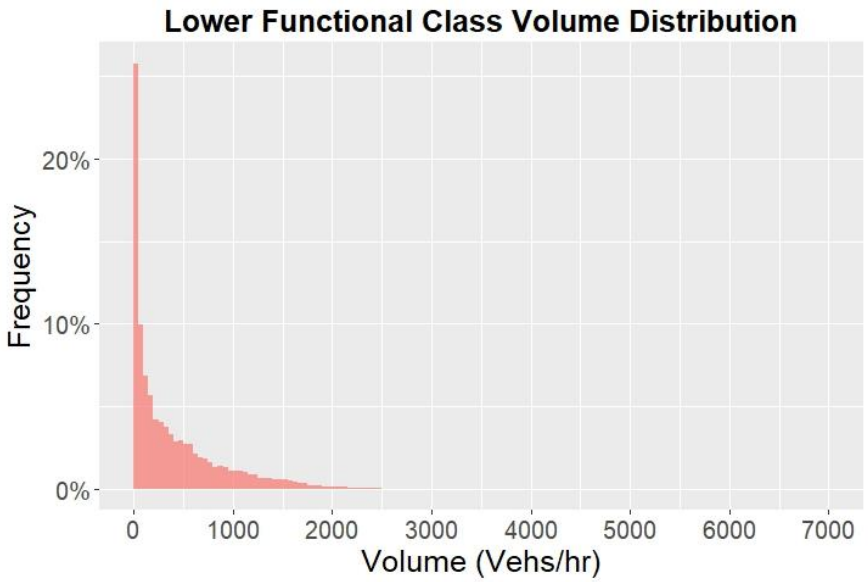
	Lower Class Roads	Freeways
Volume data source	48-hour short-term count	Continuous count stations
Number of locations / Data points	359 / ~35,000	14 / ~52,000
Data collection period	Jan. – Sep., 2017 (9 months)	Feb. – Apr., 2017 (3 months)

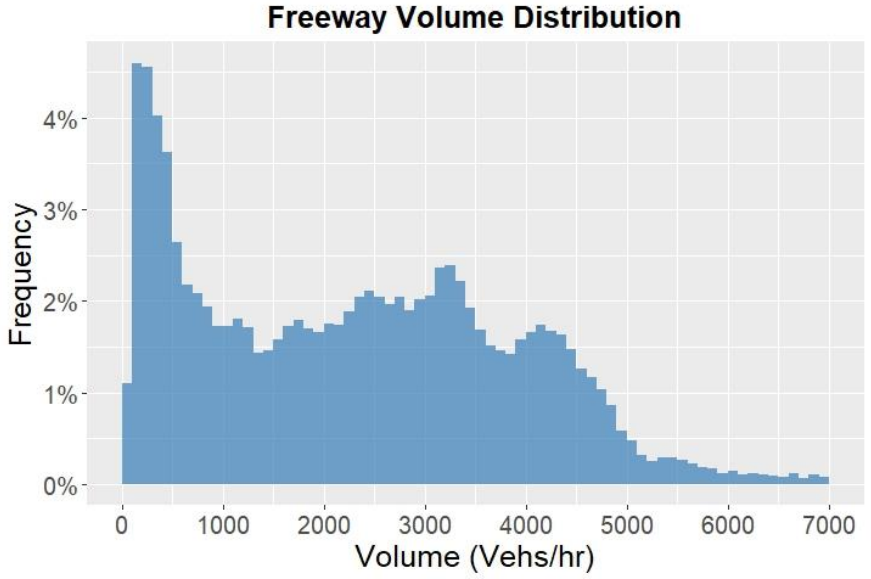
- 300 for training/calibrating
  - Total of 30,096 data points
- 59 locations for testing
  - Total of 5,118 data points



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





48-hour Count 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
- **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
- Model training and validation used similar procedures (Random assignment to 10 groups : train on 9, validate 10^{th})

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

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

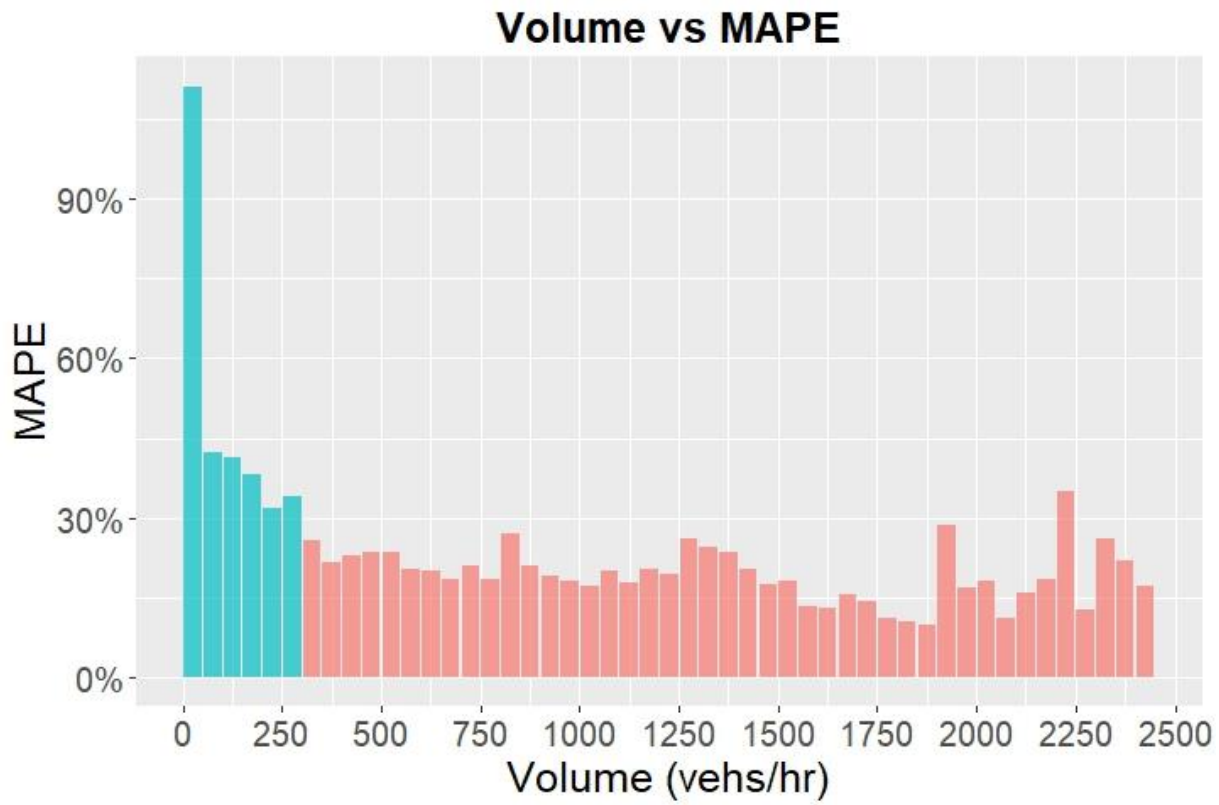
- Further examine MAPE and EMFR for volume > 20 vehs/hr

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%

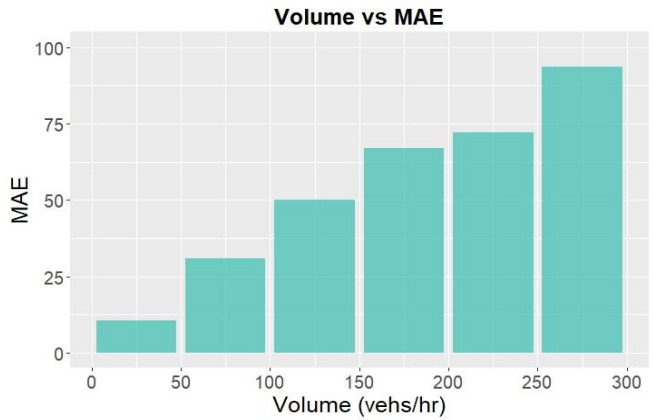
- **Need to look at accuracy in volume ranges**

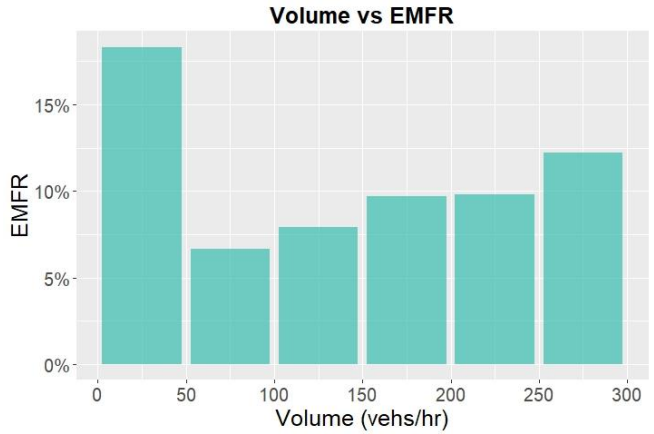
MAPE of Different Volume Range

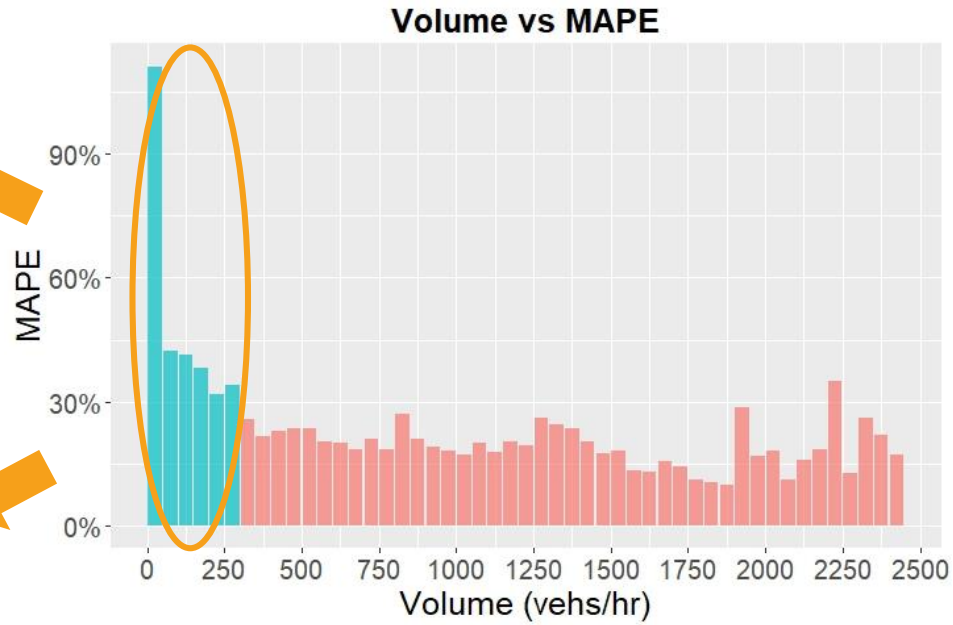
- Volume>300 vehs/hr: MAPE is low and stable
- Volume<300 vehs/hr: MAPE is high, but model is still good



MAPE of Different Volume Range

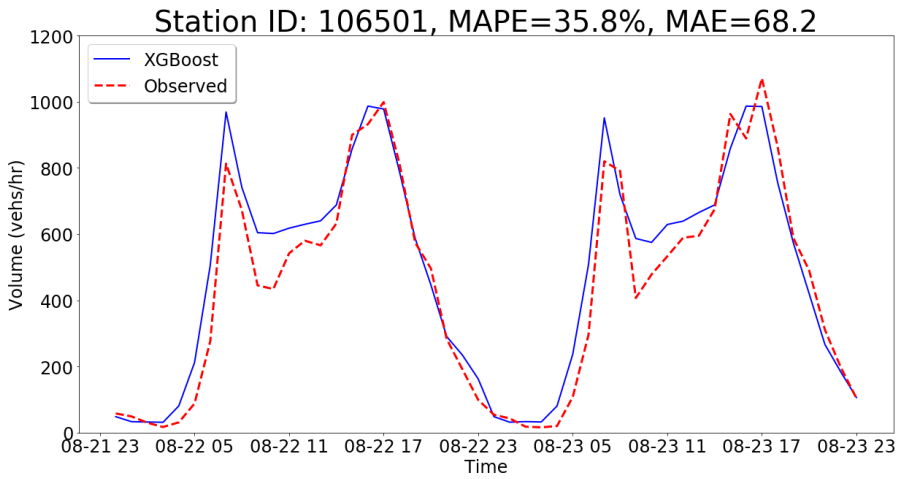




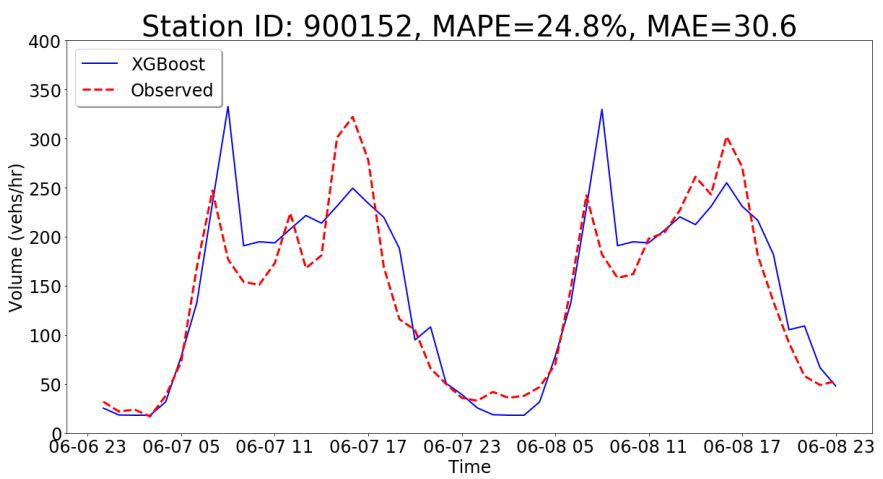


48-Hour Prediction on Test Locations

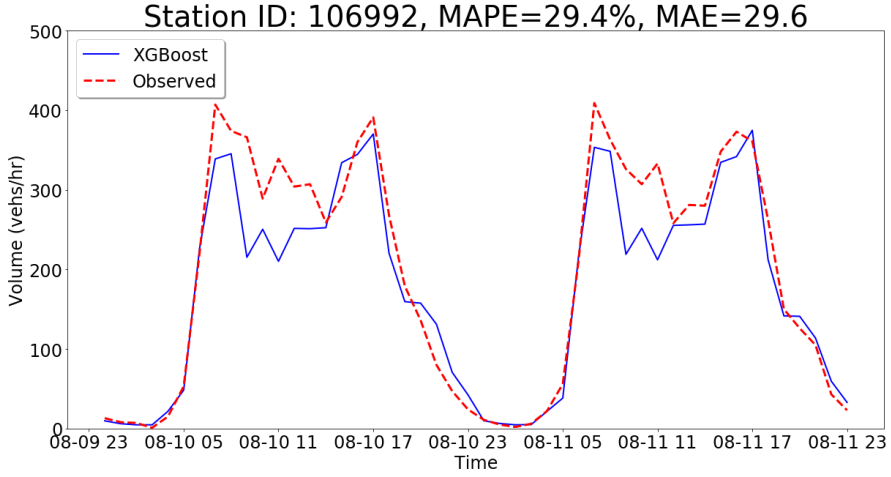
Principal Arterial



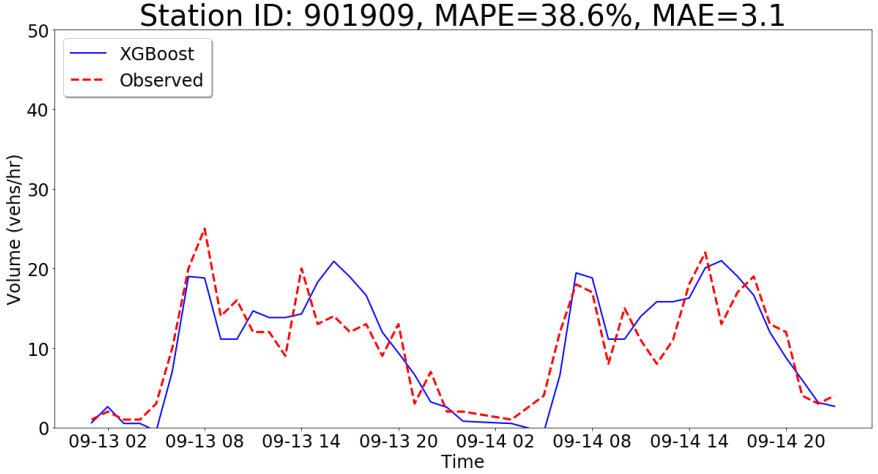
Minor Arterial



Major Collector



Local Street



Summary

- Machine learning provides high accuracy for hourly volume estimation on unmonitored segments
- XGBoost is promising tools for hourly volume estimation on both freeways and lower functional class roads
- GPS probe data has significant impact on volume estimation
- Next steps
  - Integrate to one single model to estimate volume on all functional class
  - Scale up to state level estimation
  - AADT estimation

Questions?

Yi Hou, PhD
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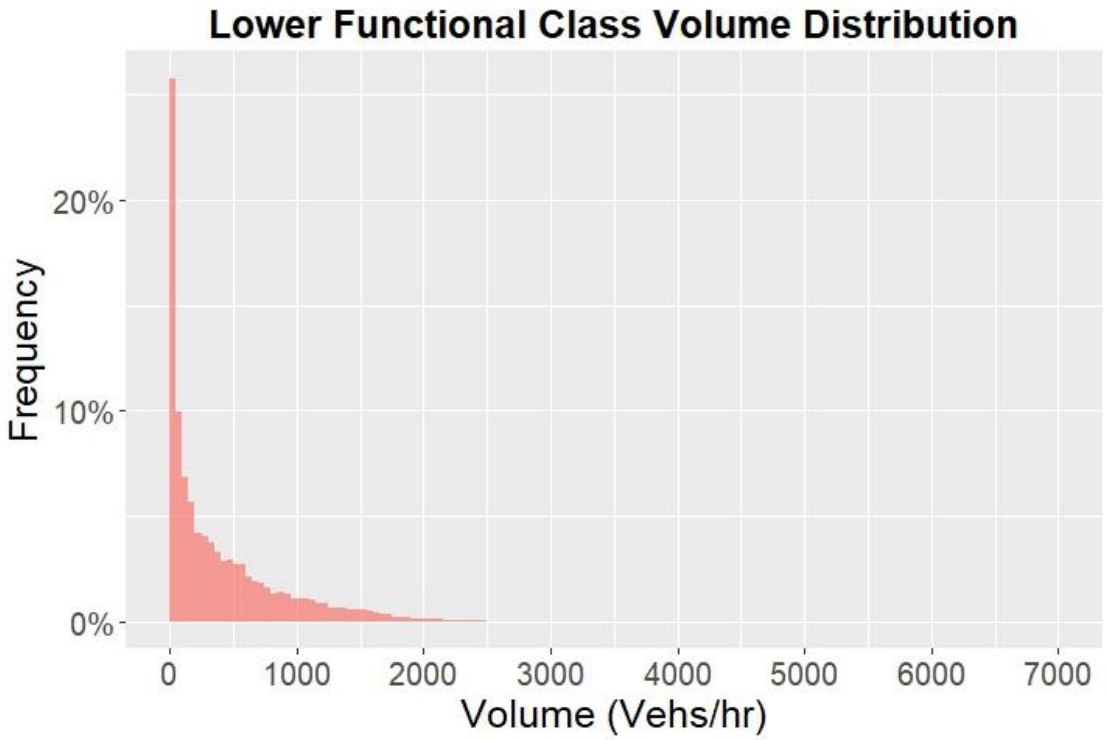
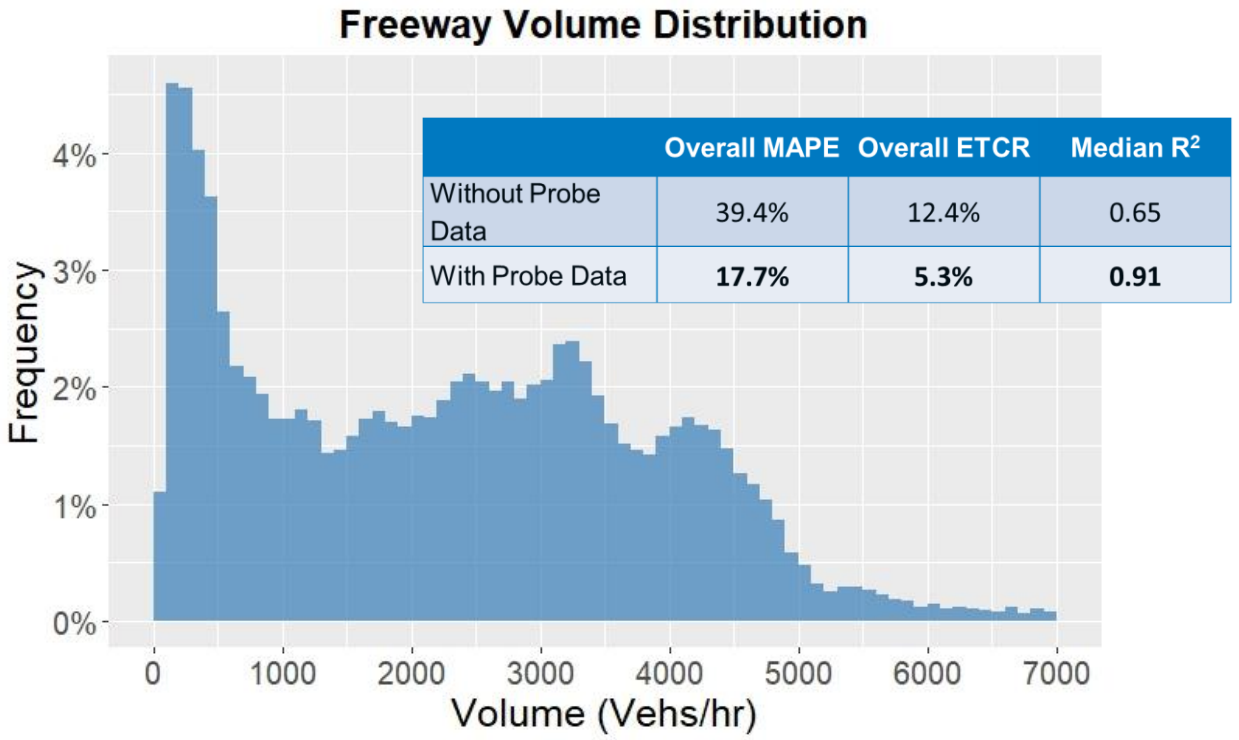
yi.hou@nrel.gov

Summary

- Off-Freeway volumes significantly less

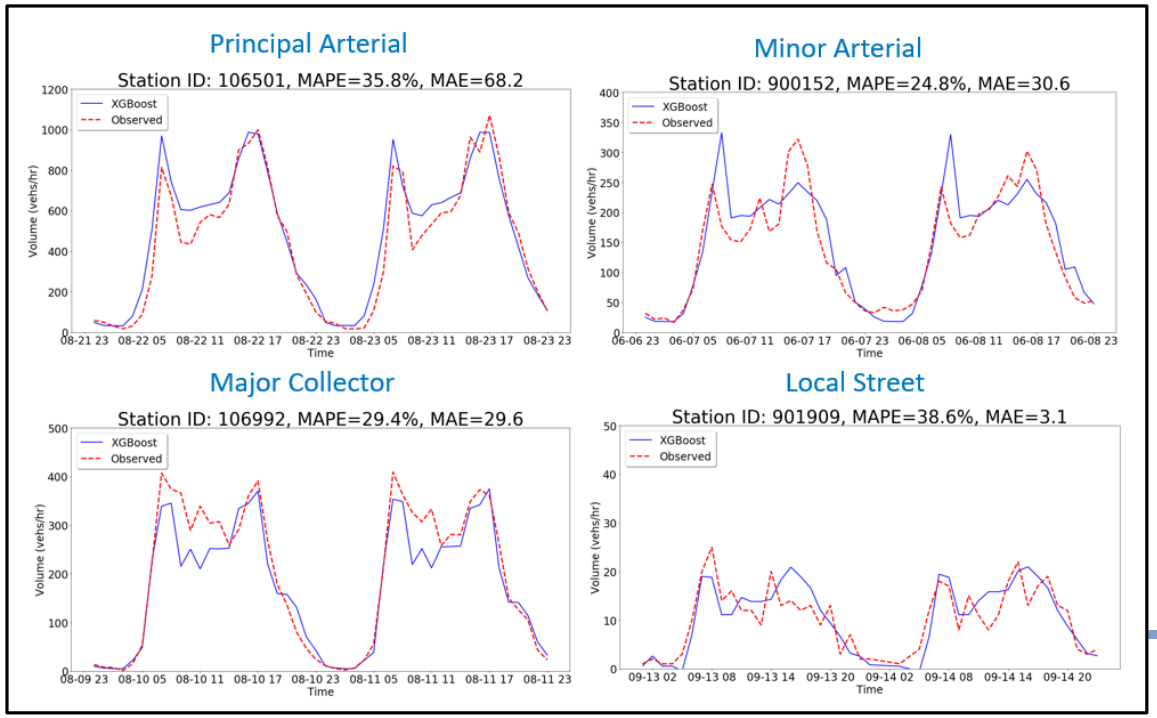


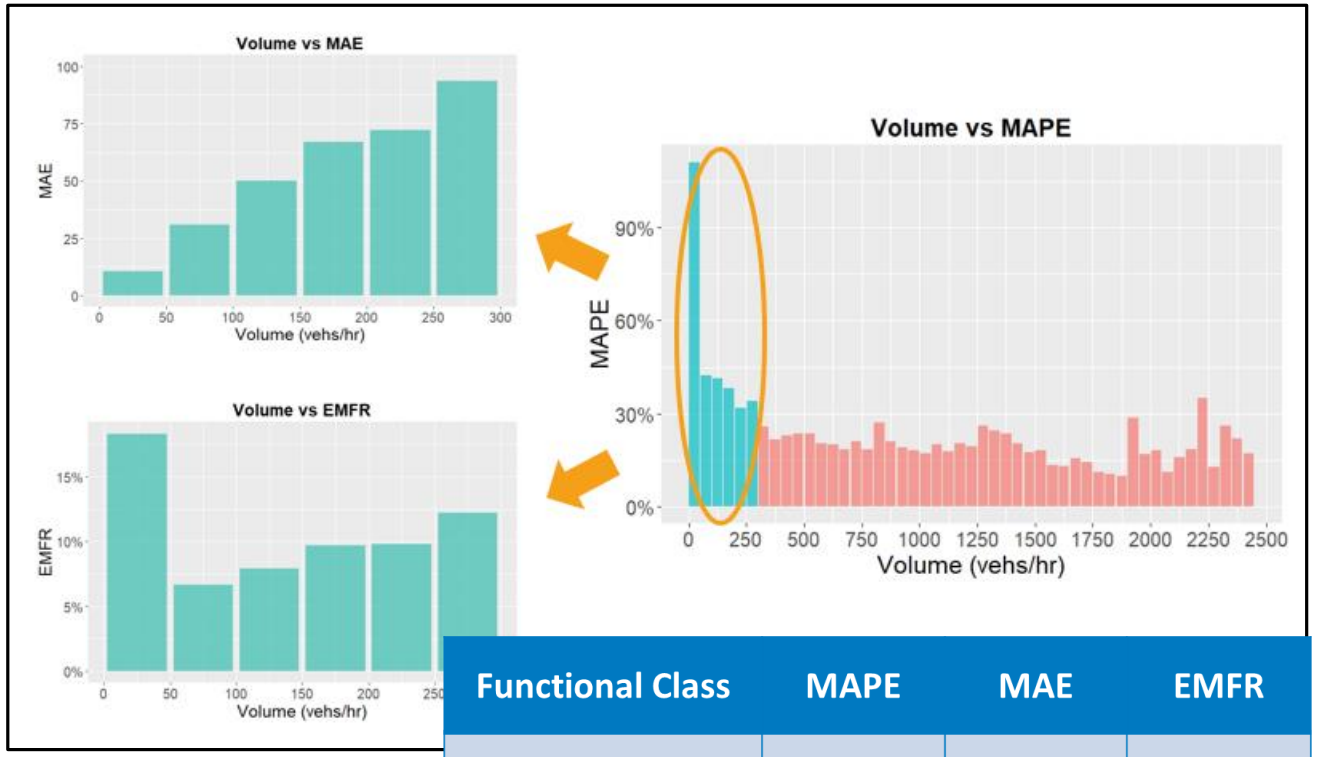


	Overall MAPE	Overall ETCR	Median R^2
Without Probe Data	39.4%	12.4%	0.65
With Probe Data	**17.7%**	**5.3%**	**0.91**

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**

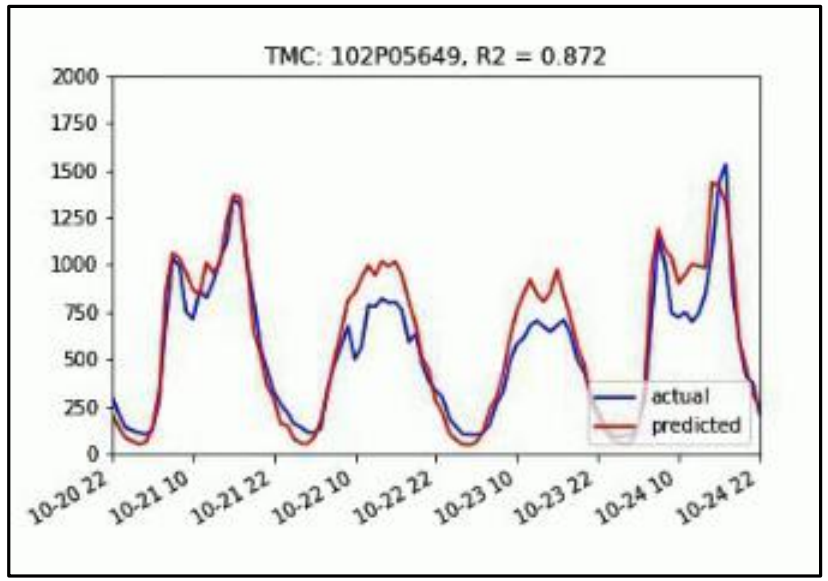




Functional Class	MAPE	MAE	EMFR
Principal Arterial	31.3%	123.3	9.8%
Minor Arterial	44.1%	71.0	9.4%
Major Collector	115.7%	29.4	24.8%
Local Street	101.7%	6.6	26.9%

Florida Results

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

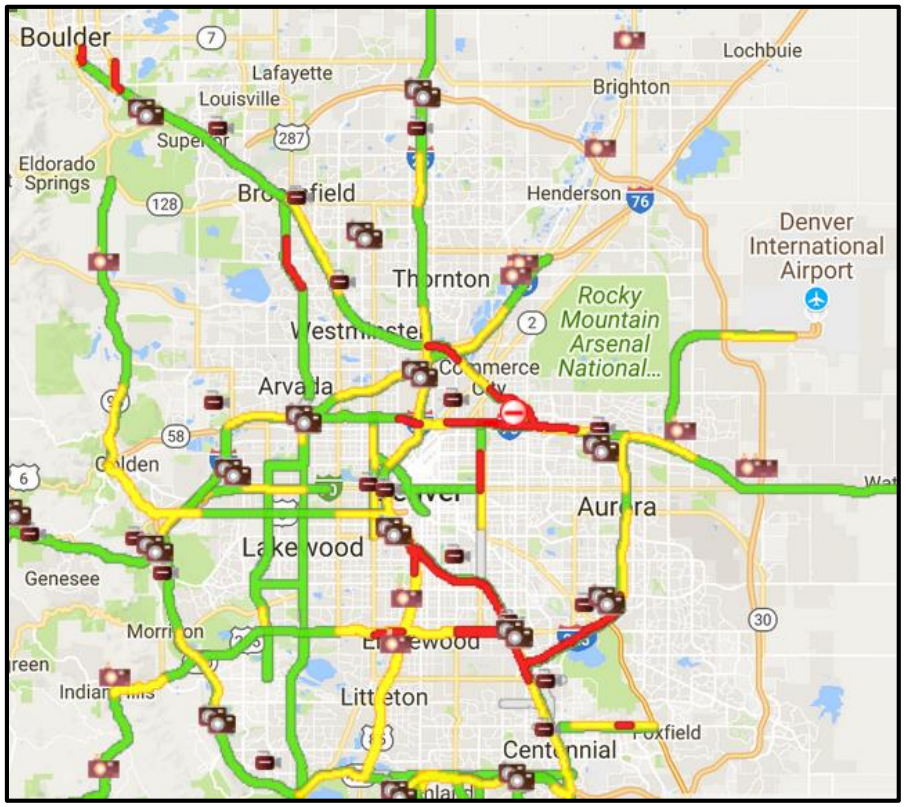


Road Classification	R2	MAPE (%)	EMFR (%)	Obs
Freeways (FRC 1)	0.86	21	6	195704
Maryland (mostly FRC 1)	0.86	23	7	158040
Principal Arterials (FRC 2)	0.82	26	7	370567
Major/Minor Arterials (FRC 3 & 4)	0.83	33	7	128419

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

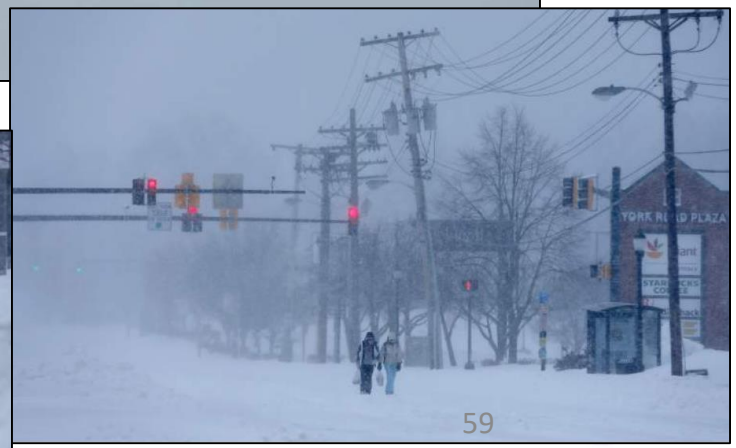
Putting this to work – sample application

- Colorado – calibrate operations sensors
  - Colorado maintain nearly 3000 operations sensors related to ramp metering, signals, speed, etc.
  - Maintaining/calibrating that network is sensor is time and resource intensive. Subject to weather (wind) issues.
  - A tool to identify, prioritize and manage that sensor network could extend already scarce maintenance funds.
  - Exploring with CDOT on how to integrate volume estimation with data systems



Performance Measures for Each Roadway – for Each Hour

- Maryland – Hours of Delay
  - Initial attempt to apply hours of delay resulted in abnormally large delay estimates
  - During winter storms, prevailing methods assumed normal ‘weekday’ traffic
  - Although real-time speed estimates were available, volume data proved inadequate
  - New method allows for 24x7x365 applications of performance metrics, rather than ‘average conditions’



On-going and 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

Seeking Operational Partners:

- **Taking it from the Laboratory to the Streets ….**

  If interested please contact Kaveh, Denise or Stan

Poll Question #1

1 How would you use this volume data in your agency?

___ Planning purposes
___ Operational purposes
___ Management Decisions
___ All of the above

Thank You!

For Questions, please contact:

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- Denise Markow (I-95 Corridor Coalition) 301-789-9088 or dmarkow@i95coalition.org
- Stanley Young (NREL) 301-792-8180 or Stanley.Young@nrel.gov

Thank You!