Volume & Turning Movements Project

Steering Committee Meeting #8

August 18, 2018

Conference call number: 1-719-867-1571 and enter 725437# at the prompt

CATT Center For Advanced Transportation Technology

NREL National Renewable Energy Laboratory

Housekeeping Items

- Please call 484-557-7009 for difficulties with the web or audio application
- This is a virtual meeting experience
  - Please keep your phone muted until asking a question or speaking (press *6 to mute/unmute individual phone lines)
  - 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 and Organizations	
Colorado DOT	New Hampshire DOT
District DOT	North Carolina DOT
Durham MPO (NC)	North Jersey Transportation Planning Authority
FHWA	NREL
Florida DOT	Pennsylvania DOT
Georgia DOT	Port Authority NY & NJ
HERE	StreetLight Data
I-95 Corridor Coalition	Texas A&M Transportation Institute
INRIX	TomTom
Kentucky Transportation Center	UMD CATT
MWCOG	Virginia DOT

Speakers

Denise Markow, PE
TSMO Director
I-95 Corridor Coalition
dmarkow@i95coalition.org

Stanley Young, PhD, PE
National Renewable Energy Laboratory
(NREL)
Stanley.young@nrel.gov

Kaveh Sadabadi, PhD
Center for Advanced Transportation Technology - University of Md.
(UMD CATT)
kfarokhi@umd.edu

Zachary Vander Laan
Center for Advanced Transportation Technology - University of Md.
(UMD CATT)
zvanderl@umd.edu

Please confirm that your line is muted *6

Thank you!

Agenda

	Topic	Speaker
1	Welcome & Project Status Update	Denise Markow, I-95 Corridor Coalition Stan Young, NREL
2	Traffic Volume Estimation using GPS Traces: Florida and New Hampshire Update	Kaveh Sadabadi, UMD CATT Zach Vander Laan, UMD CATT
3	Insights from VTM Error Analysis	Stan Young, NREL
4	Future Work - Next Steps & Wrap Up	Stan Young, NREL Denise Markow, I-95 Corridor Coalition

Why Do We Need More and Better Volume Data?

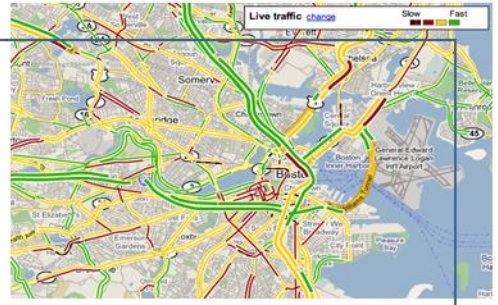
- **Operations**
  - Detect real-time traffic volume in the network
  - Traffic volume during inclement weather and special events

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

- **Economic and energy assessment**
  - Estimate economic impact of congestion
  - Quantify VMT and energy use


Planning

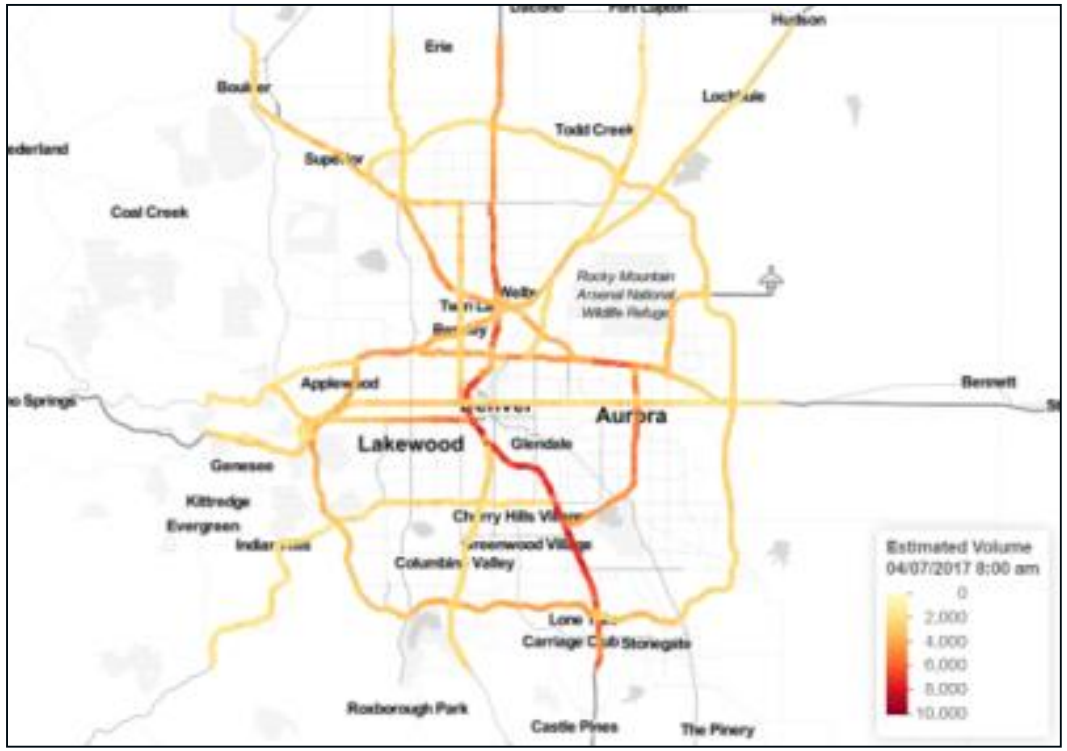

Operations



Performance Measures

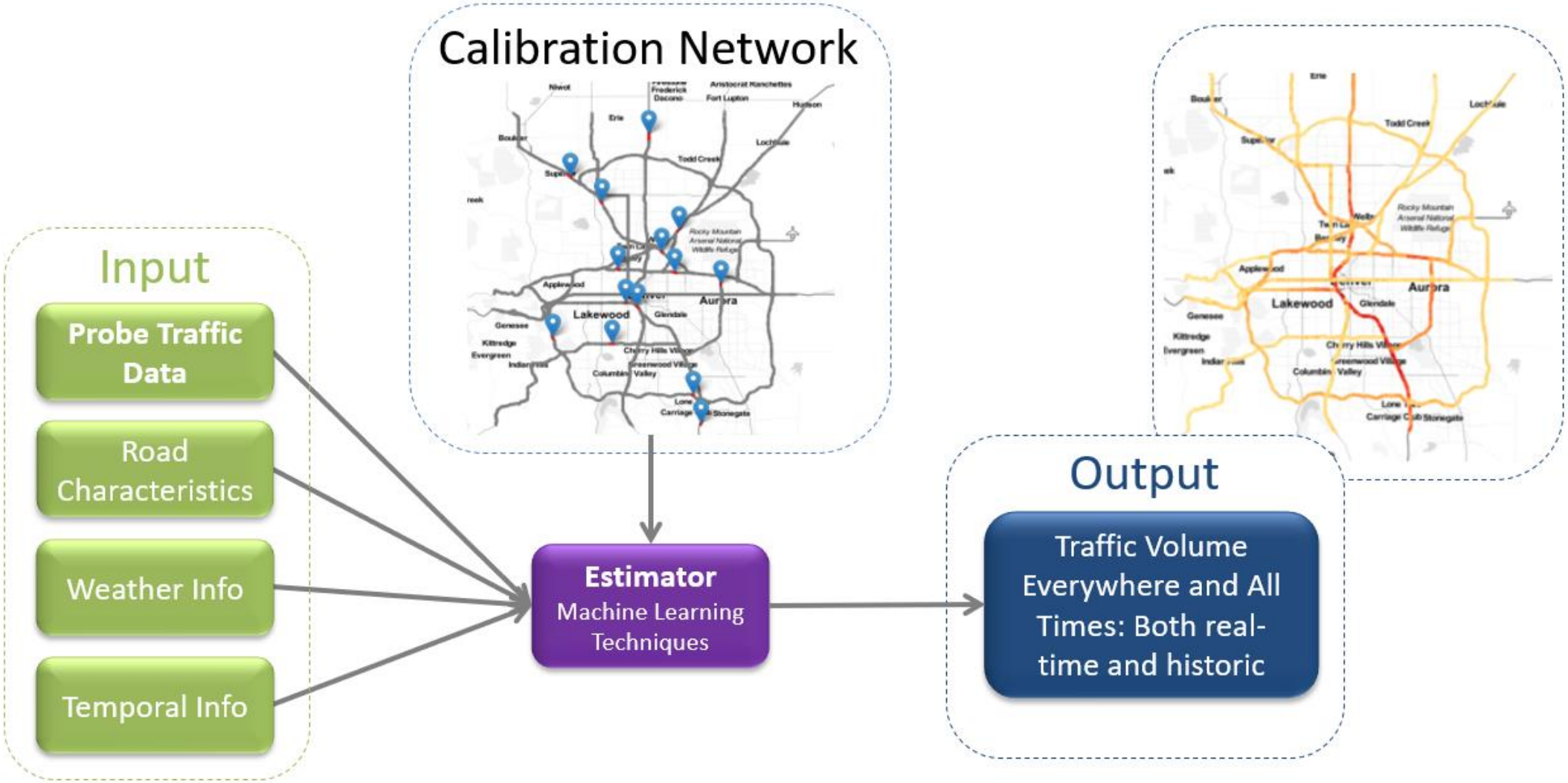
Forecasts (special events)

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



How Good is Good Enough?

Traffic Engineer

- 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)

MAPE is Volume Dependent!

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

Statistician/ Planner

- R^2 Coefficient of Determination
  - >70% good >80% better >90% best

Highway Operations

- Error to Capacity (ETCR) or Max Flow (EMFR)
  - < 10% becomes useful < 5% is target
  - {For highway operations, reflective of capacity constraint situations}

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

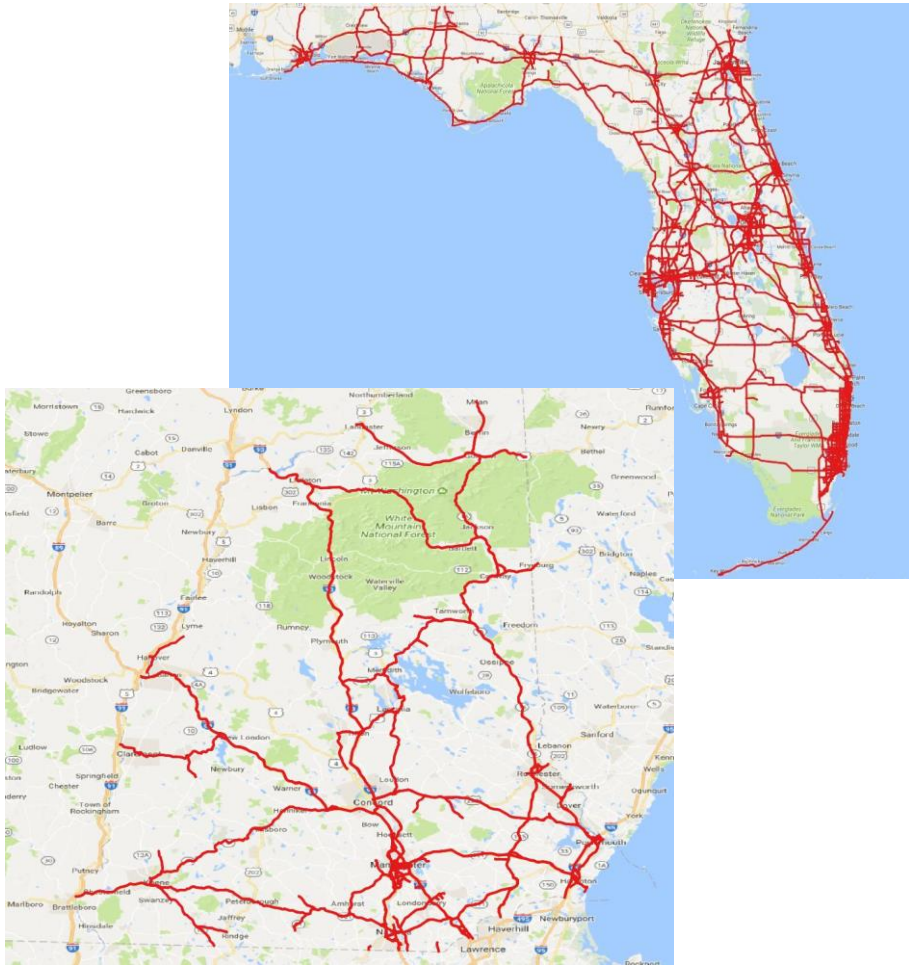
Analysis Performed by:
Przemyslaw Sekula and Zachary Vander Laan

Presented by:
Kaveh Farokhi Sadabadi and Zachary Vander Laan

VTM Steering Committee Meeting
August 16, 2018

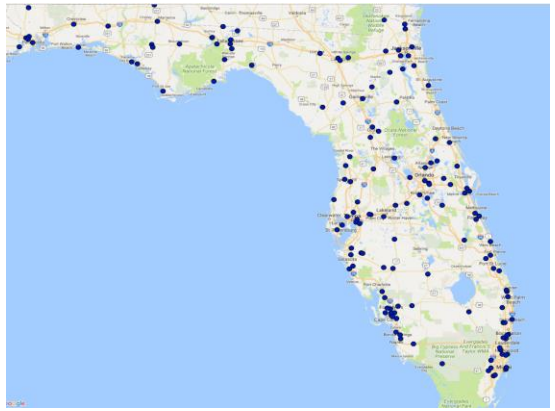
Presentation Outline

- Overview
  - Objectives
  - Volume estimation approach
- Florida case study
  - Dataset
  - Results
    - Statewide estimates
    - AADT/AAWDT
    - Truck Volumes
    - Flagging unusual behavior
- New Hampshire case study
  - Dataset
  - Results
    - Statewide estimates
    - AADT/AAWDT
    - Model transferability
- Summary / Next Steps
- Q & A

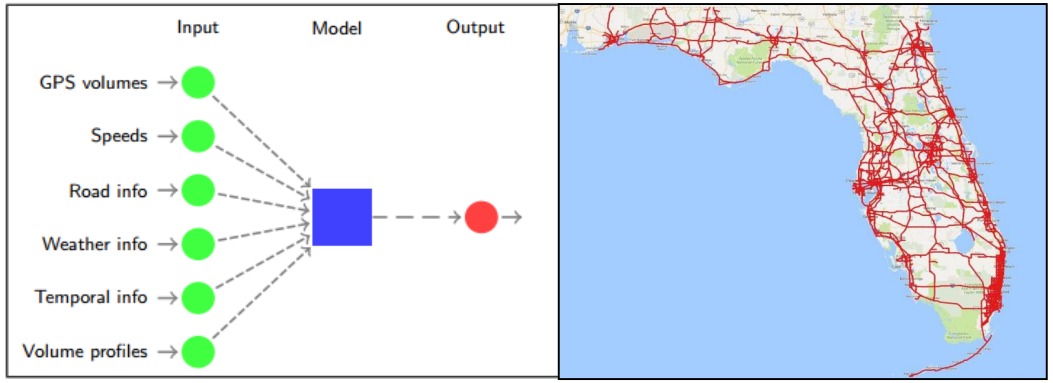


Objectives

- Given the following:
  - Probe volumes (processed from GPS traces of a subset of vehicles),
  - Other archived data (speeds, road geometry, weather, etc.)
  - Continuous count data from select locations



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



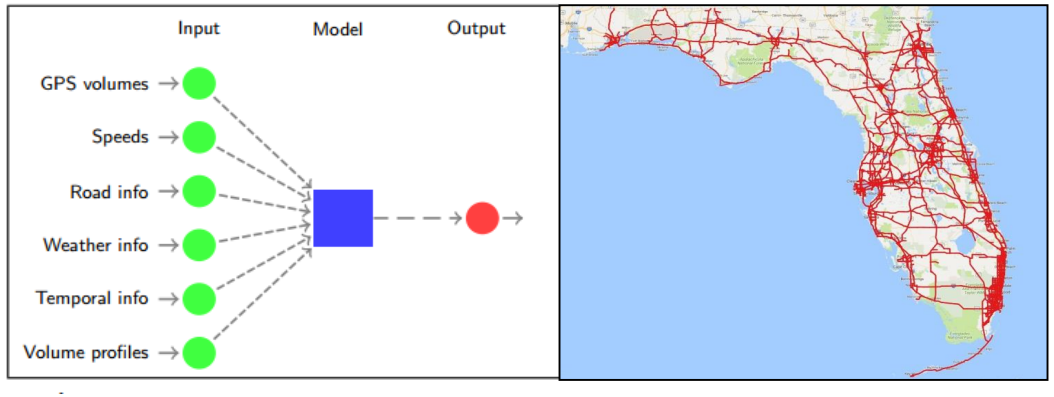
Volume Estimation: General Approach

Develop and Train Model

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

Apply model to state road network

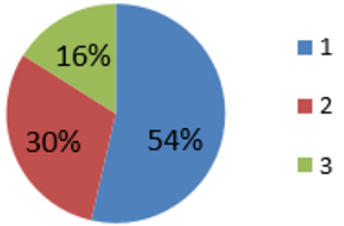
- Where? All TMCs on road network
- How? Apply trained model to input variables from any TMC segment on the network



Florida Dataset (Q4 2016)

Data needed at all TMCs

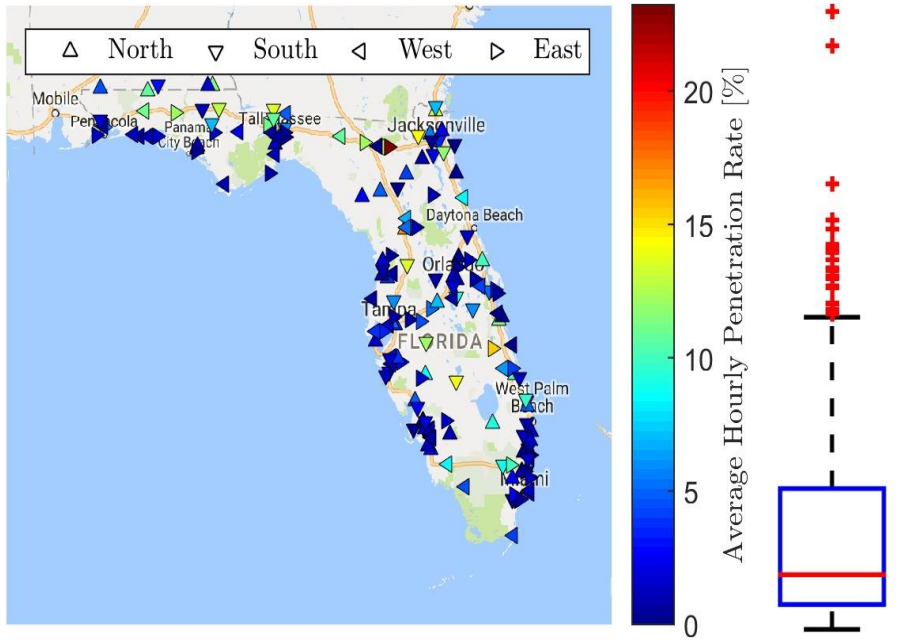
- **GPS probe data** (INRIX)
  - 75M trips, 3.4B pts
  - Penetration rate: 2.1% median
  - Snapped to base map
- **Probe speeds** (HERE)
- **Road characteristics**
  - # lanes, speed limit, facility type, etc.
- **Weather**
- **TTI hourly volume estimates**



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

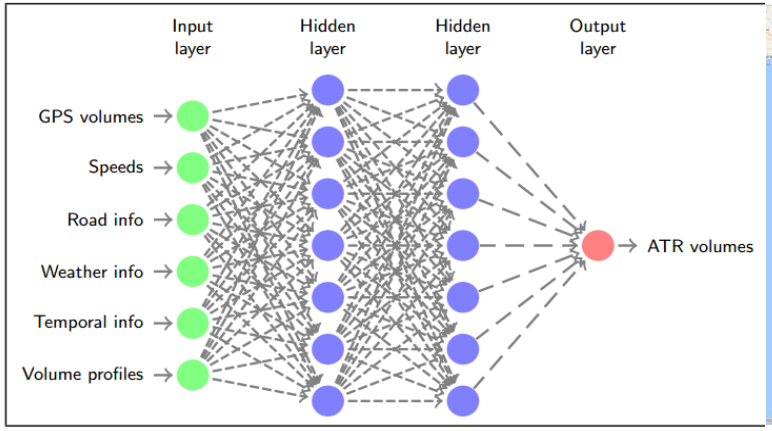
Data needed only at continuous count stations

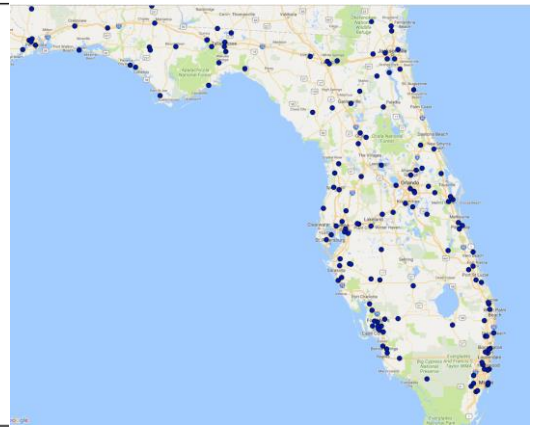
- **Ground truth count data** (FDOT)
  - Used for model training / evaluation
  - Used to estimate probe penetration rate

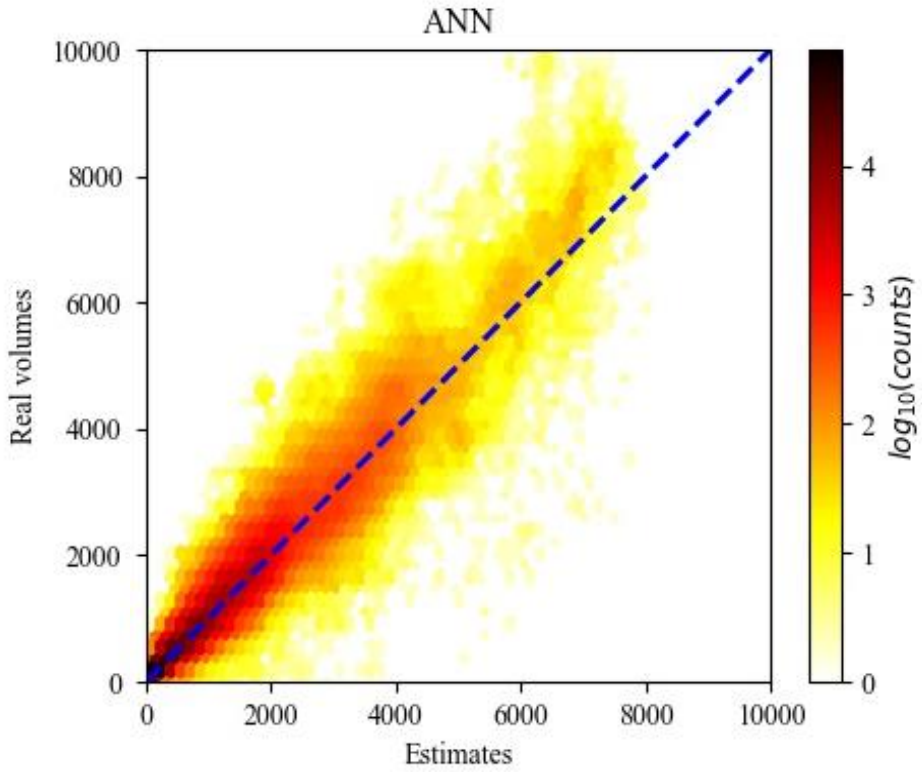


Florida Model Evaluation

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







- Evaluation: Compare estimates with actual volumes & generate metrics

Florida Results: Summary

→ **Overall median error metrics:**

- R2 = 0.83
- MAPE = 25%
- EMFR = 7%

Summary

Promising model performance, even over a variety of scenarios

Observations

- ↑ Road class = ↑ Accuracy
- ↑ Avg. hourly volume = ↑ Accuracy
- ↑ Avg. hourly GPS counts = ↑ Accuracy

Median Error Metrics by Scenario

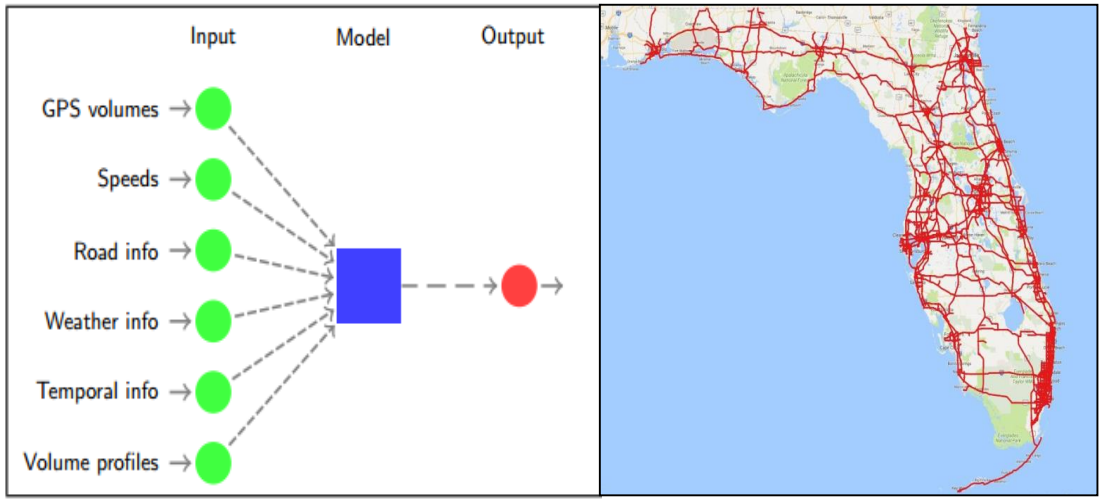
Road Classification	R2	MAPE (%)	EMFR (%)	Obs
FRC 1 (Interstates)	0.86	21	6	195704
Maryland (mostly FRC 1)	0.86	23	7	158040
FRC 2 (Other Freeways & Expressways)	0.82	26	7	370567
FRC 3 & 4 (Other principal & minor arterials)	0.83	33	7	128419

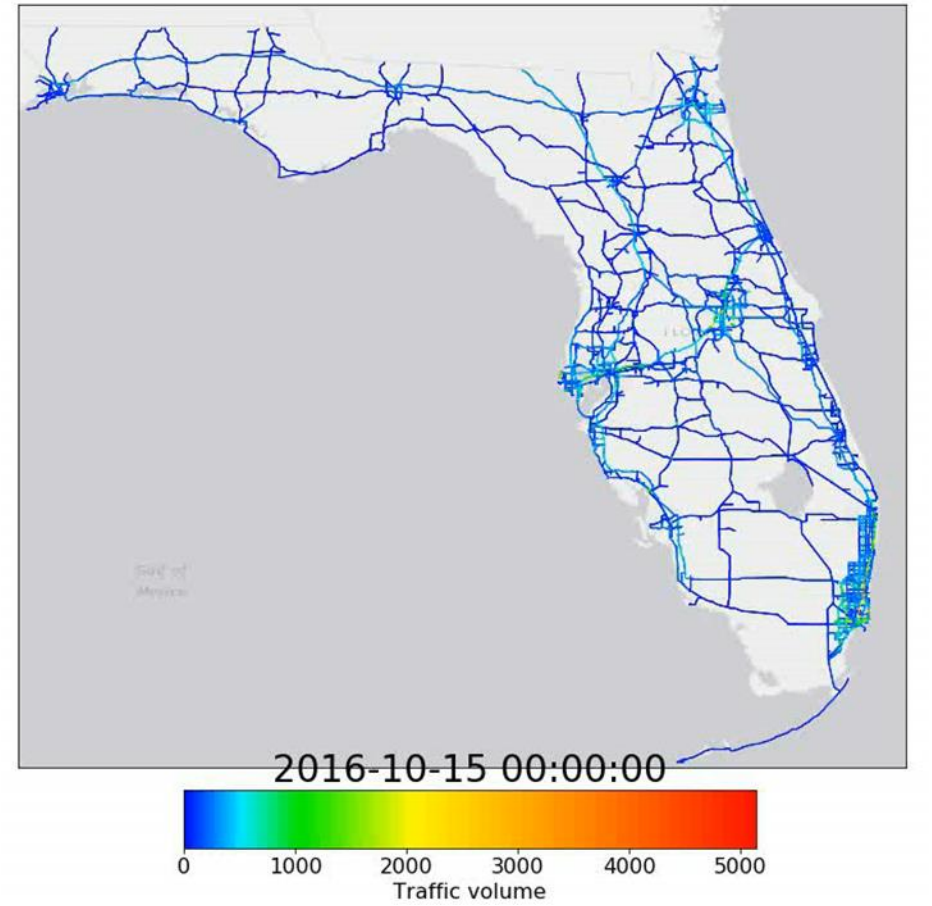
Hourly Volume (vph)	R2	MAPE (%)	EMFR (%)	Obs
0-1k	0.81	29	7	465591
1k-2k	0.86	22	6	164465
2k-3k	0.88	18	6	49221
3k+	0.87	19	6	15413

Avg probe counts / hr	R2	MAPE (%)	EMFR (%)	Obs
"Low" [0-6]	0.78	38	8	214557
"Medium" [6-17]	0.84	24	7	249730
"High" [17-145]	0.85	22	6	230403

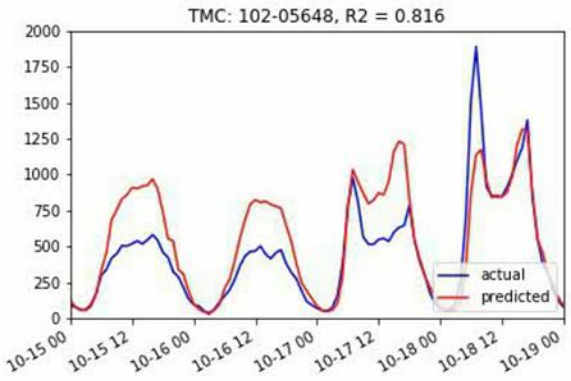
Florida Statewide Model

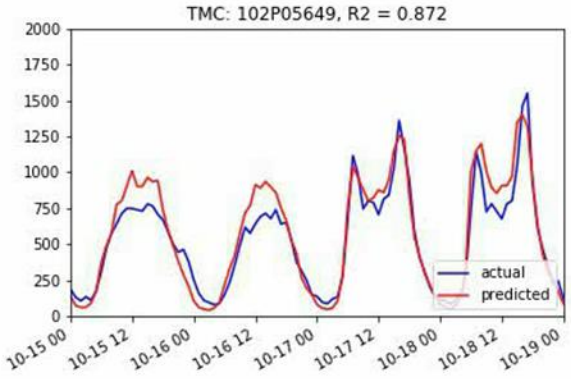
- Apply trained model to entire road network
  - Requires 3 months of hourly input data at ~20k TMCs
  - Generate hourly volume estimates at each input time/location

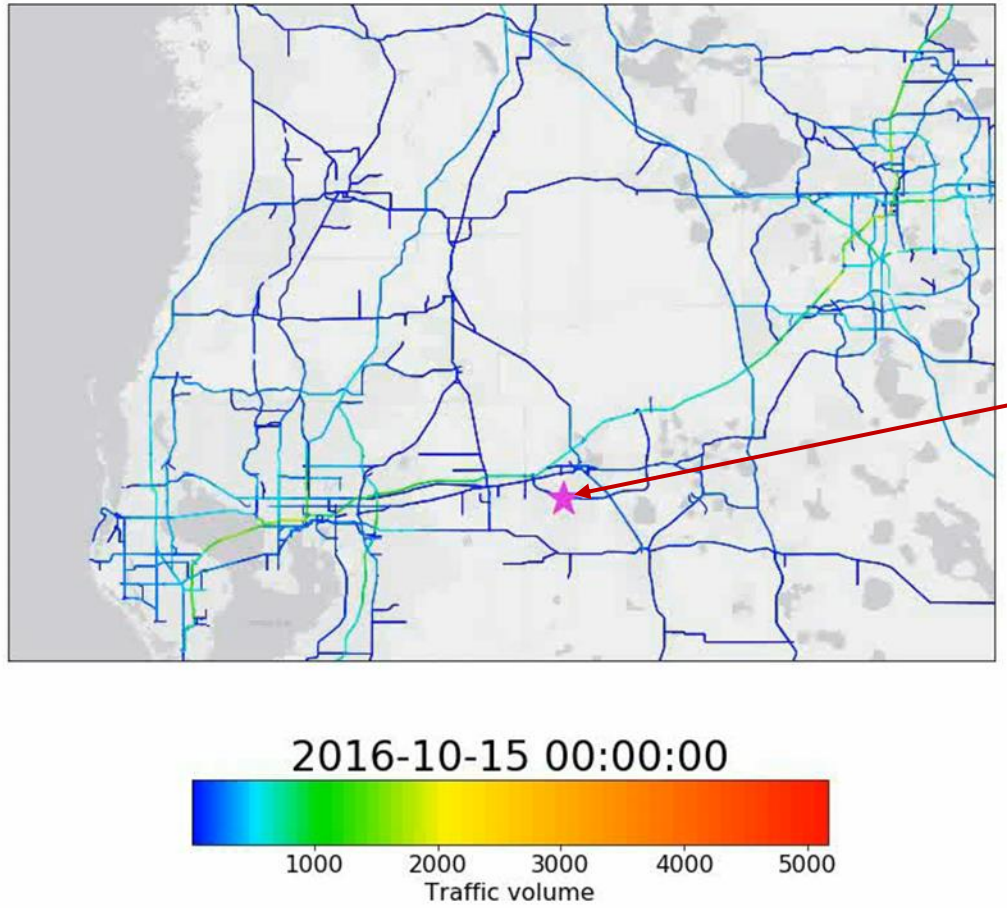




Florida Statewide Model: Tampa Bay Area



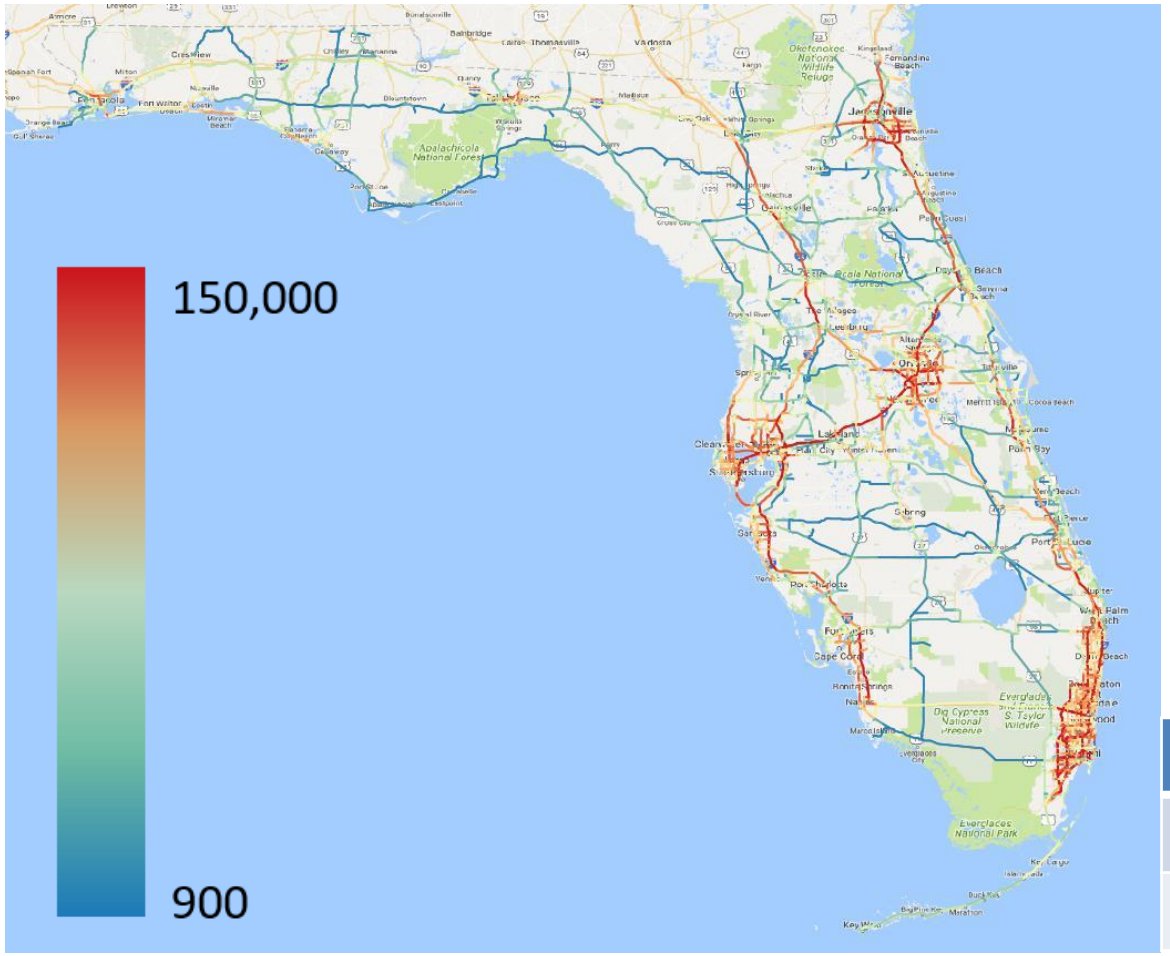




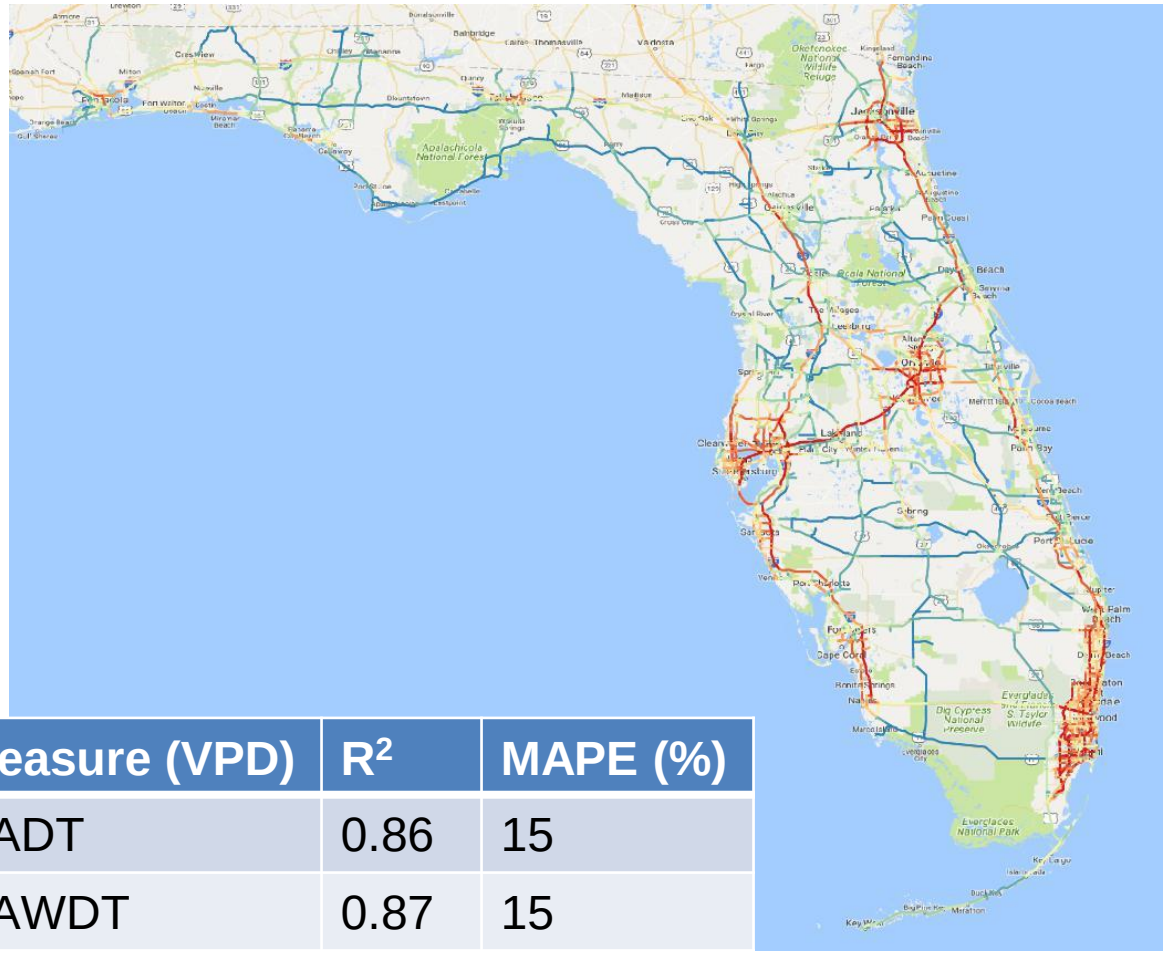
Continuous count station selected that exhibits typical (median) model performance

Florida: AADT & AAWDT Estimation

AADT



AAWDT



Measure (VPD)	R^2	MAPE (%)
AADT	0.86	15
AAWDT	0.87	15

Florida: Freight Volume Estimation

→ Apply model to estimate hourly freight volumes
- Leverage highly-granular FDOT continuous count data

→ Initial freight volume results look promising, particularly on higher functional road classes

All Trucks

FHWA Class 5-13	R^2	MAPE (%)
Overall	0.77	38
FRC 1	0.83	24
FRC 2	0.76	42
FRC 3 & 4	0.65	49

Heavy Trucks

FHWA Class 7-13	R^2	MAPE (%)
Overall	0.66	44
FRC 1	0.80	26
FRC 2	0.62	49
FRC 3 & 4	0.38	54

** Median error metrics*

Florida: Flagging Unusual Behavior

Goal: Develop flags to highlight unusual input data and output model estimates

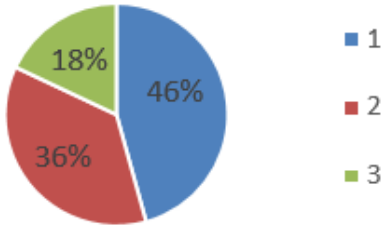
- **Flag 1** - based on GPS input data (key model "ingredient")
  - *Typical*: Observed GPS counts within X std. dev of mean GPS counts during same day of week and hour
  - *Low* : Less than *Typical* range
  - *High:* Greater than *Typical* range

- **Flag 2** - based on output model estimates
  - *Typical*: Observed hourly estimates within X std. dev of mean estimates during same day of week and hour
  - *Low* : Less than *Typical* range
  - *High:* Greater than *Typical* range

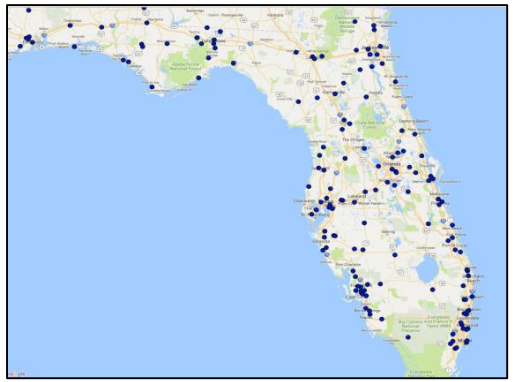
New Hampshire Dataset (Q3 2017)

Data needed at all TMCs

- **GPS probe data** (INRIX)
  - 7M trips, 595M waypoints
  - Penetration rate: 2.3% median
  - Snapped to base map
- **Probe speeds** (RITIS, various vendors)
- **Road characteristics**
  - # lanes, speed limit, facility type, etc.
- **Weather**
- **TTI hourly volume estimates** (Optional)



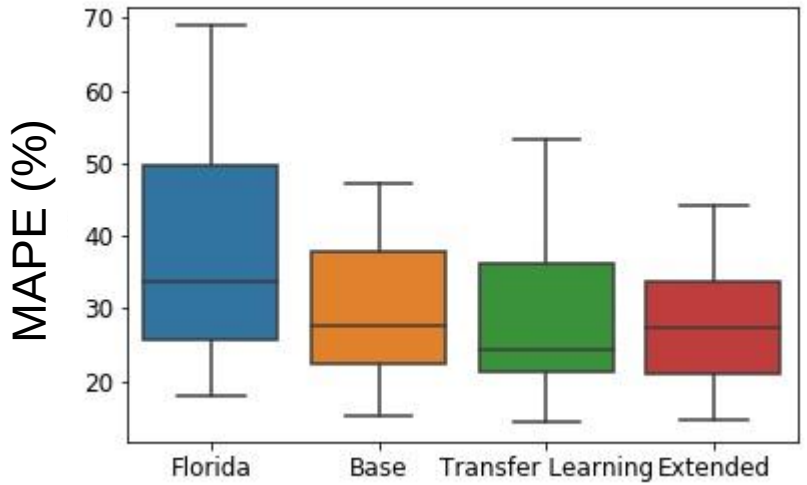
1: cars / light-duty trucks
2: medium-duty trucks
3: heavy-duty trucks



Corresponding Florida dataset (Q4 2016)

- **GPS probe data** (INRIX)
  - 75M trips, 3.4B waypoints
  - Penetration rate: 2.1% median
  - Snapped to base map

New Hampshire: Model Comparisons



Model	R2	MAPE	EMFR
Florida	0.77	34%	8%
Base (trained on NH data only)	0.83	28%	7%
Transfer Learning (FL model fine tuned w/ NH data)	0.83	24%	7%
Extended (trained on NH and FL data combined)	0.84	27%	7%

New Hampshire Results: Summary

→ **Overall median error metrics:**

- R2 = 0.84
- MAPE = 27%
- EMFR = 7%

Summary

Promising model performance, even over a variety of scenarios

Observations

- ↑ Road class = ↑ Accuracy
- ↑ Avg. hourly volume = ↑ Accuracy
- ↑ Avg. hourly GPS counts = ↑ Accuracy

Median Error Metrics by Scenario

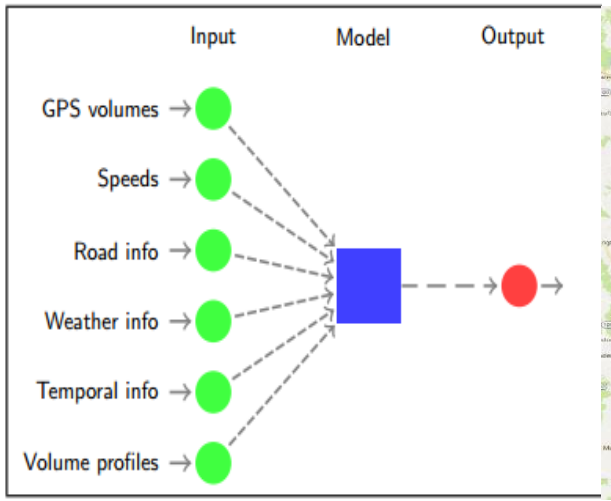
Road Classification	R2	MAPE (%)	EMFR (%)	Obs
FRC 1 (Interstates)	0.84	21	7	65,728
FRC 2 (Other Freeways & Expressways)	0.83	30	7	84,307
FRC 3 & 4 (Other principal & minor arterials)	0.86	29	7	25,369

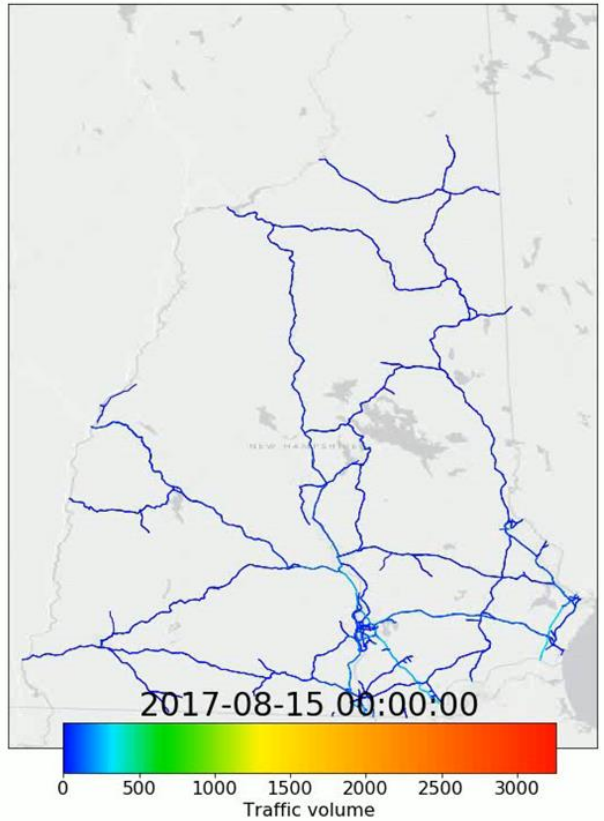
Hourly Volume (vph)	R2	MAPE (%)	EMFR (%)	Obs
0-1k	0.84	30	7	38,771
1k-2k	0.86	20	8	10,394
2k-3k	0.86	18	7	65,728

Avg probe counts / hr	R2	MAPE (%)	EMFR (%)	Obs
Low [0-5]	0.81	32	7	60,182
Medium [6-17]	0.85	25	7	57,524
High [17-145]	0.86	21	6	57,698

New Hampshire Statewide Model

- Apply trained model to entire road network
  - Requires 3 months of hourly input data at ~2k TMCs
  - Generate hourly volume estimates at each input time/location

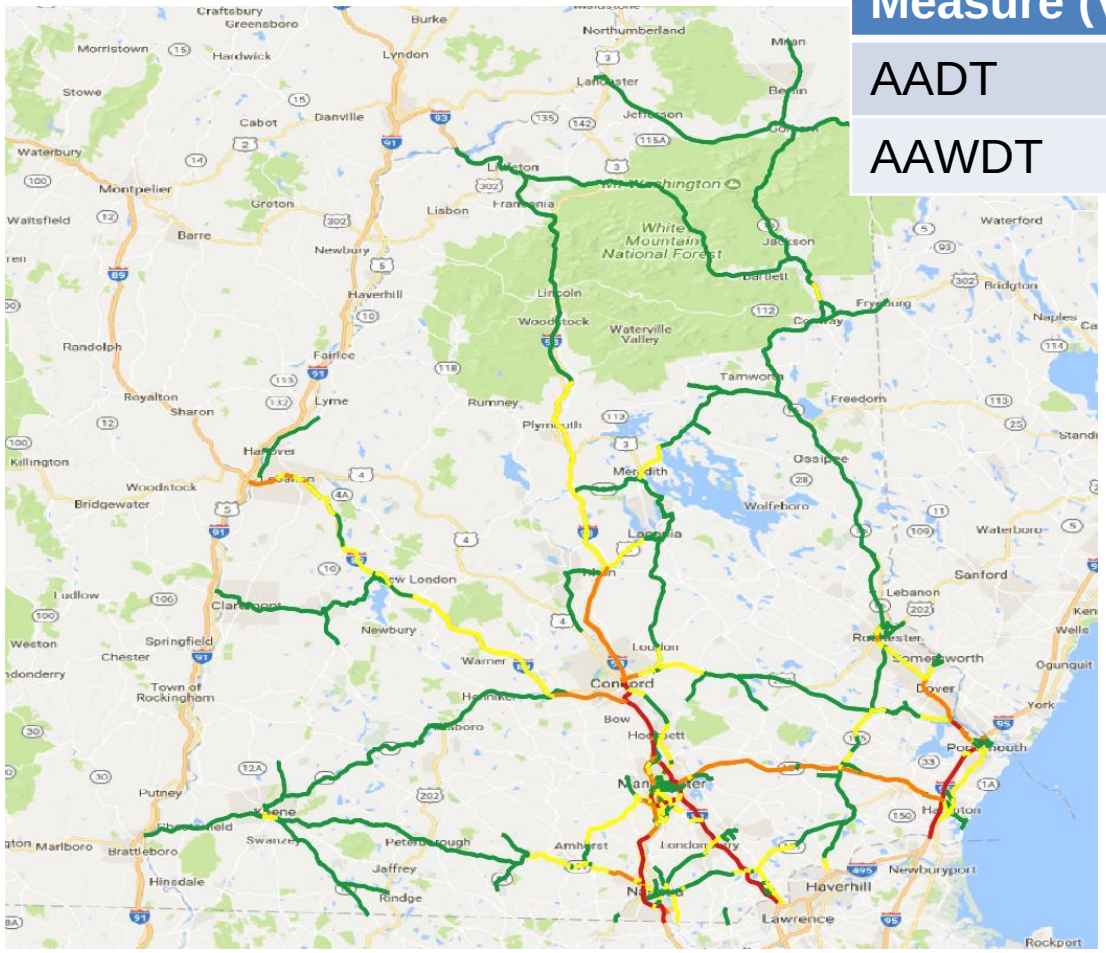




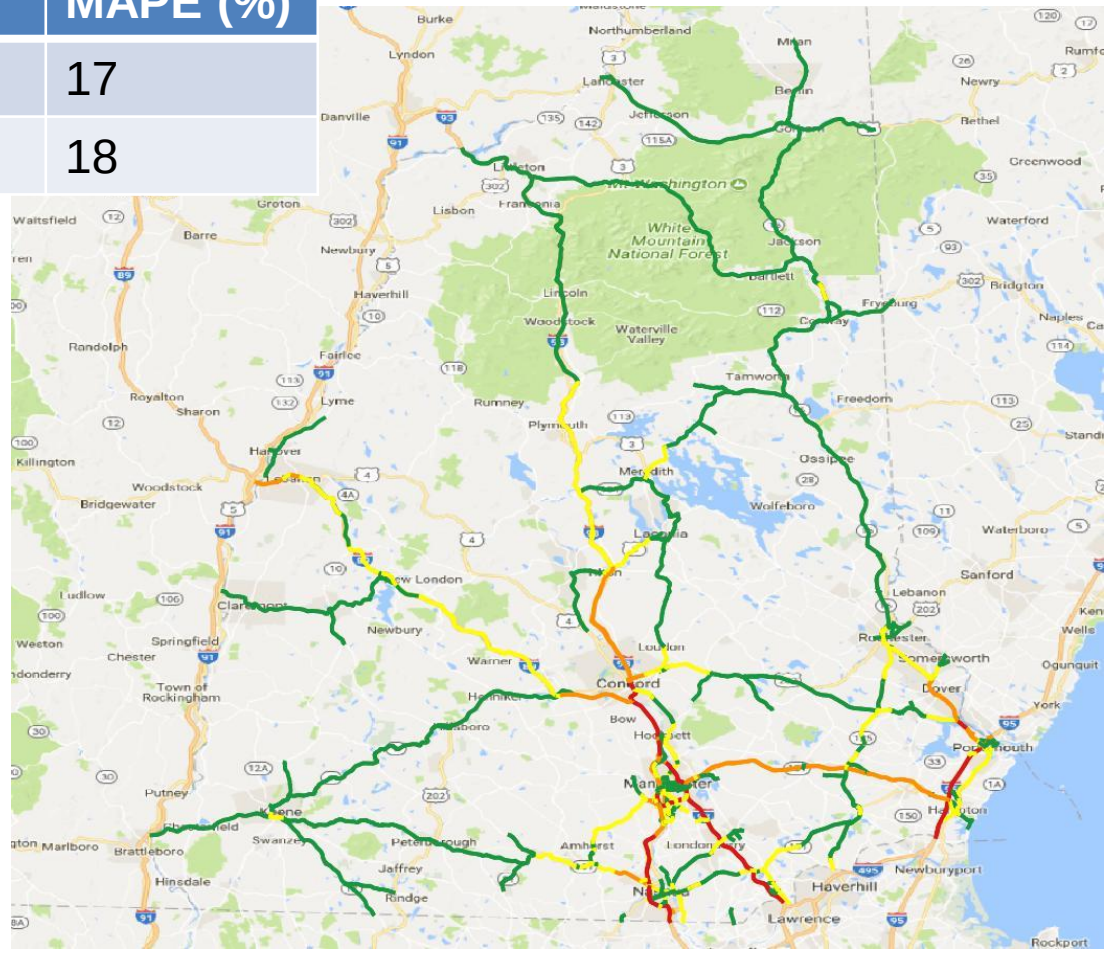
New Hampshire:
AADT & AAWDT Estimation

Measure (VPD)	R^2	MAPE (%)
AADT	0.87	17
AAWDT	0.86	18

AADT

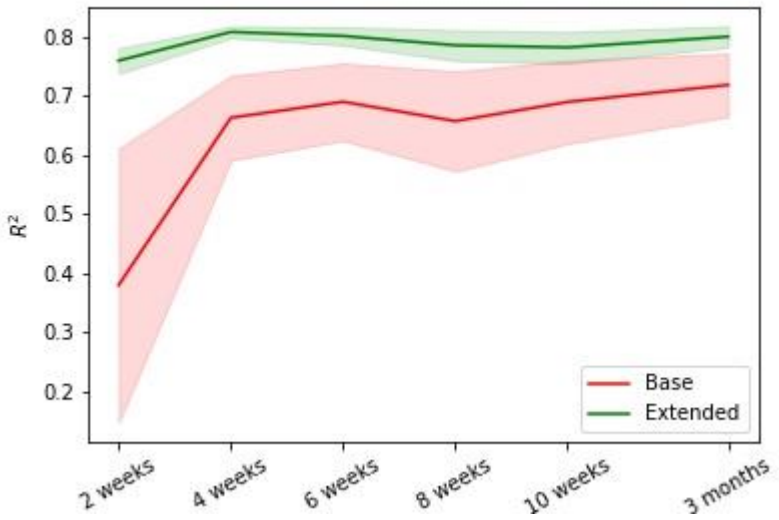


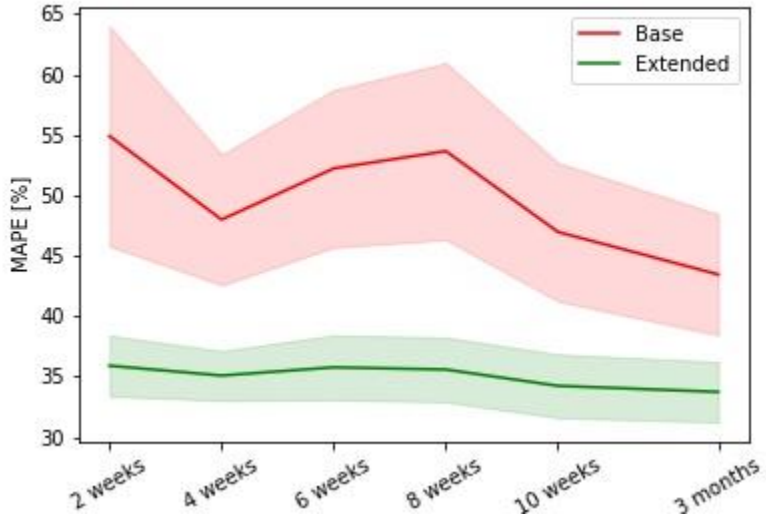
AAWDT



Experiments with Training Dataset

- When Florida dataset is combined with only 2 weeks of New Hampshire data for training, model predictions are reasonably good!
- Over time, only small amount of data for each new geography is needed to create powerful models!
- Potentially, the statewide traffic count data collection (and its associated cost) can be optimized!





		R^2		MAPE	
		2 w.	3 mo.	2 w.	3 mo.
Base	mean	0.38	0.72	54.9	43.4
	median	0.77	0.83	34.3	27.5
Extended	mean	0.76	0.80	35.9	33.7
	median	0.81	0.84	27.8	27.3

Summary & Next Steps

Summary

- Analysis on Florida and New Hampshire datasets are complete
- Hourly volume estimates:
  - Estimates meet requirements for most planning and operational purposes
  - Estimation quality improves with road class and actual volumes (number of probes)
  - Developed sensible flags to identify unusual behavior of input to and output from the models
- AADT and AAWDT estimates:
  - High level of accuracy
  - Consistent with expectations along major highways and urban areas
- Freight volumes
  - Initial results are promising, especially on FRC1 roads
- Model and data transferability
  - It is possible to leverage larger datasets in developing models for smaller geographies

Questions

Contact Information

Kaveh Farokhi Sadabadi (PI)
kfarokhi@umd.edu

Przemyslaw Sekula
psekula@umd.edu

Zachary Vander Laan
zvanderl@umd.edu

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

40
1977 – 2017





NREL
Insights from VTM Error Analysis

August 16, 2018

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Volume Error Analysis
Colorado Roadways
both Freeways and Off-freeways

(a) Symmetric MAPE
(b) Training Bounds & Data Filtering
(c) Performance during unusual events

August 2018
National Renewable Energy Lab
Yi Hou, Venu Garikapati, Stan Young

Symmetric Mean Absolute Percentage Error

- Issues with Mean Absolute Percentage Error (MAPE)
  - Inflates error at small observed values and can not be used if there are zero values
  - No upper limit to the percentage error – can go to infinity
    - Anything averaged with infinity is infinity
- Symmetric MAPE
  - Overcomes the issues with MAPE
  - Provide a result between 0% to 200%

$$\text{SMAPE} = \frac{100\%}{N}\sum_{t=1}^{N}\frac{\left|V_i - \widehat{V}_i\right|}{\left(|V_i| + \left|\widehat{V}_i\right|\right)/2}$$

$$\text{MAPE} = \frac{100\%}{N}\sum_{i=1}^{N}\left|\frac{V_i - \widehat{V}_i}{V_i}\right|$$

Model Results – Colorado Freeway

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

Model	MAPE	SMAPE	ETCR	R2	Training Time
RF	17.8%	16.6%	5.2%	0.92	73s
GBM	18.3%	17.4%	4.8%	0.93	124s
XGBoost	17.7%	17.2%	5.3%	0.91	13s

Model Results Comparison – Colorado Off-Freeways

- Much more accurate than linear regression and AADT based methods

Model	MAPE*	SMAPE	MAE	EMFR	R2
XGBoost	50.6%	34.0%	89.2	13.2%	0.88
Linear	314.7%	68.1%	153.1	29.5%	0.80
AADT Based Method	161.7%	76.0%	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)	SMAPE (Vol>20)	EMFR (Vol>20)
XGBoost	29.7%	27.4%	10.8%
Linear Regression	90.4%	50.4%	20.5%
AADT Based Method	124.9%	63.8%	28.1%

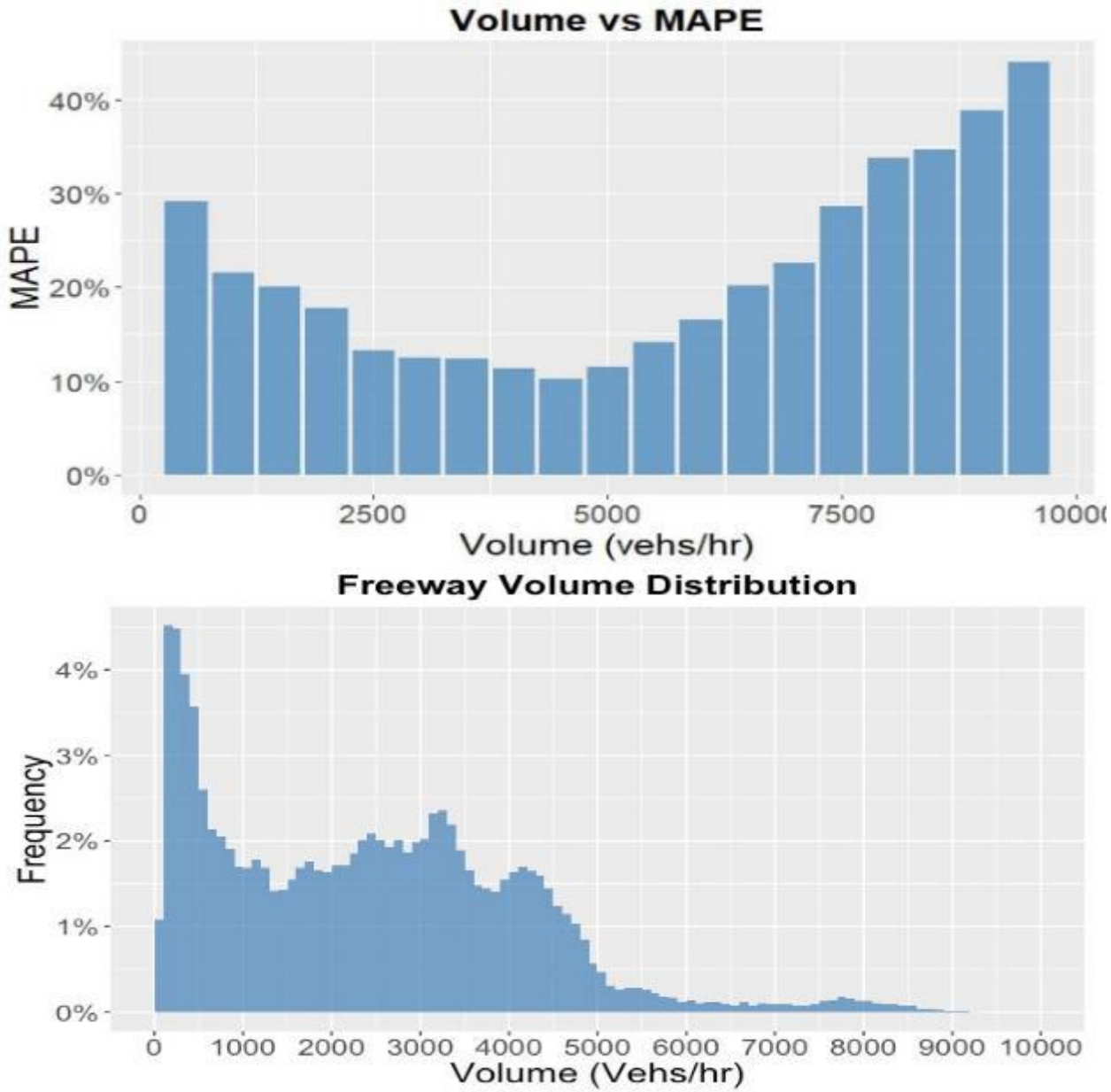
- **Need to look at accuracy in volume ranges**

Volume Error Analysis
Colorado Roadways
both Freeways and Off-freeways

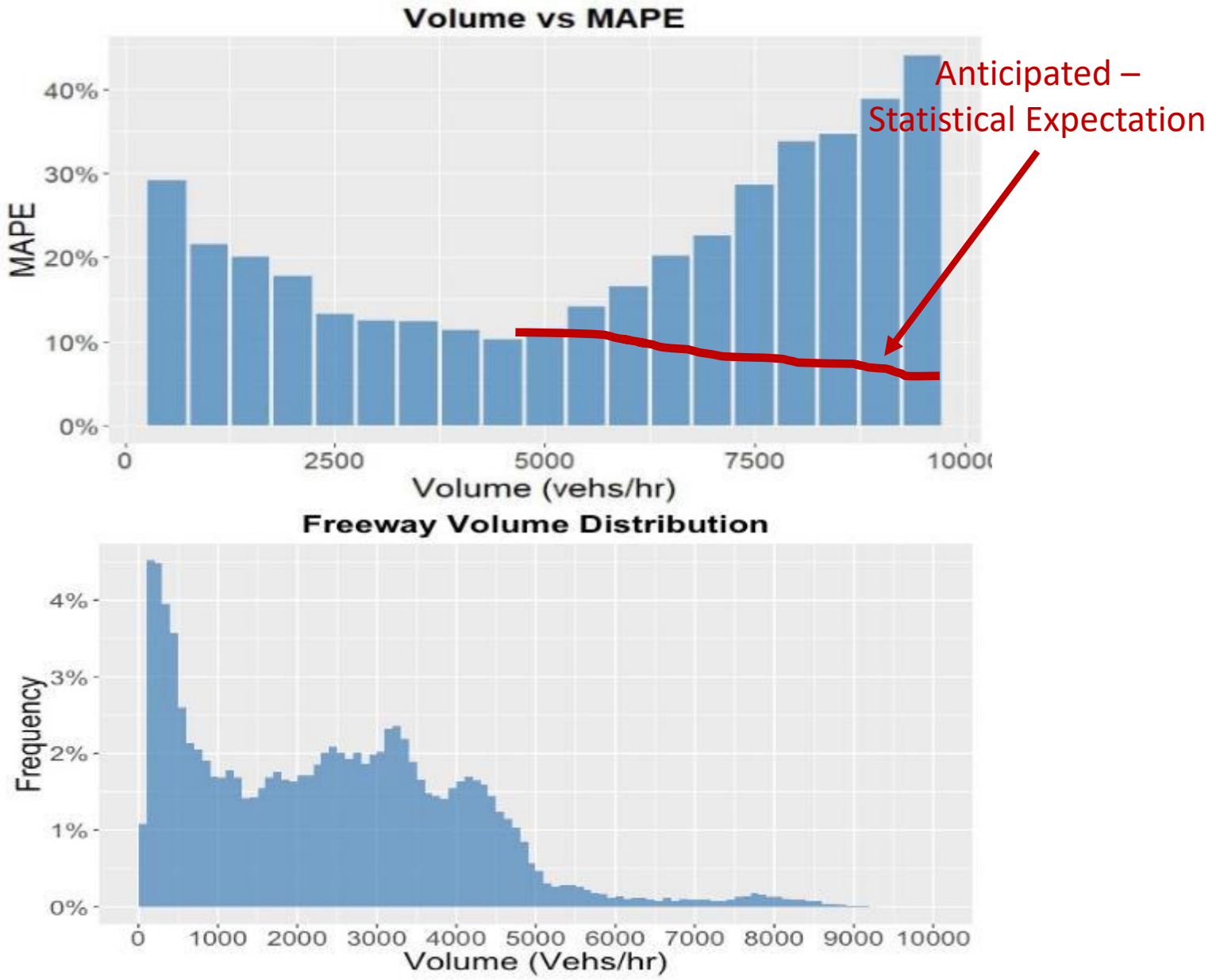
(a) Symmetric MAPE
(b) Training Bounds & Data Filtering
(c) Performance during unusual events

Are the large errors at high volumes due to lack of appropriate training data?

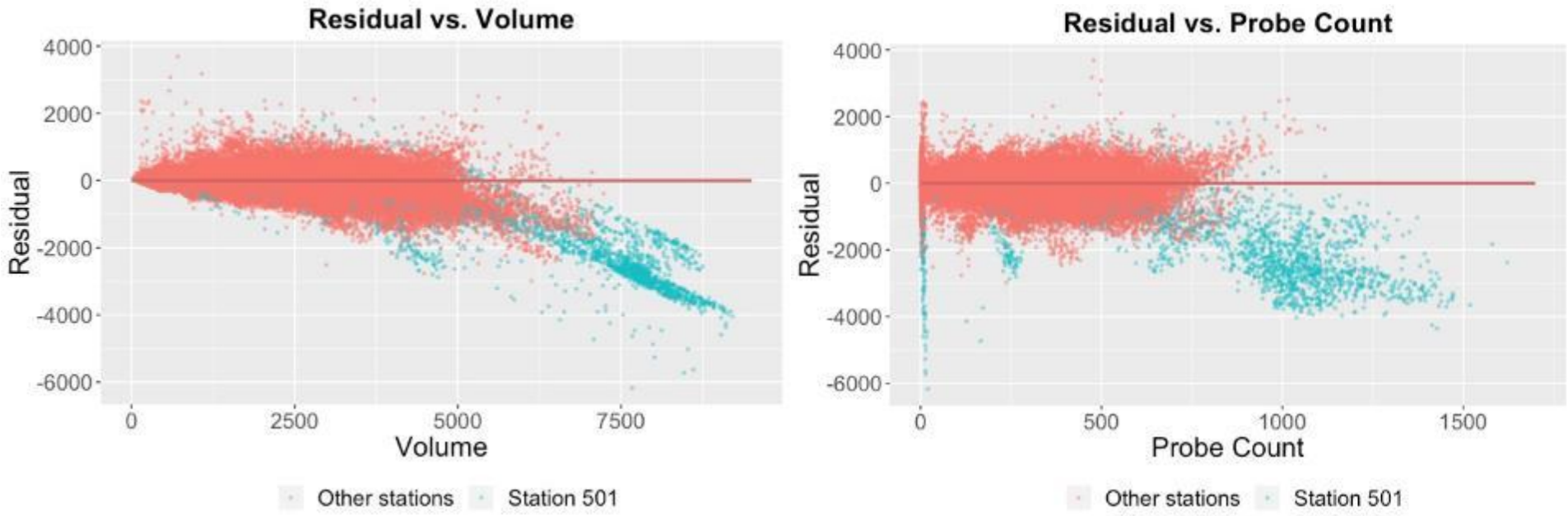
MAPE of Different Volume Range – Colorado Freeways



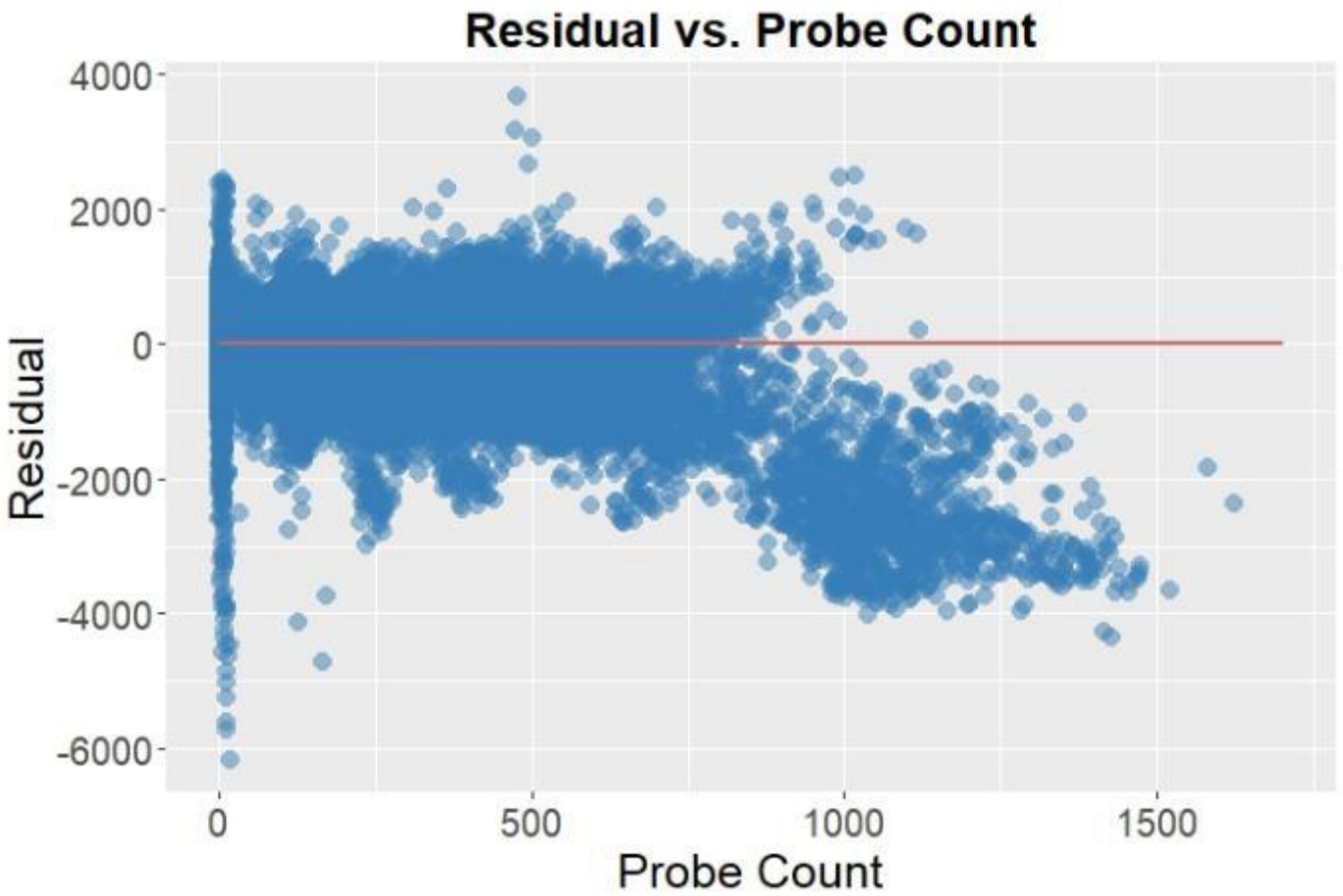
MAPE of Different Volume Range – Colorado Freeways



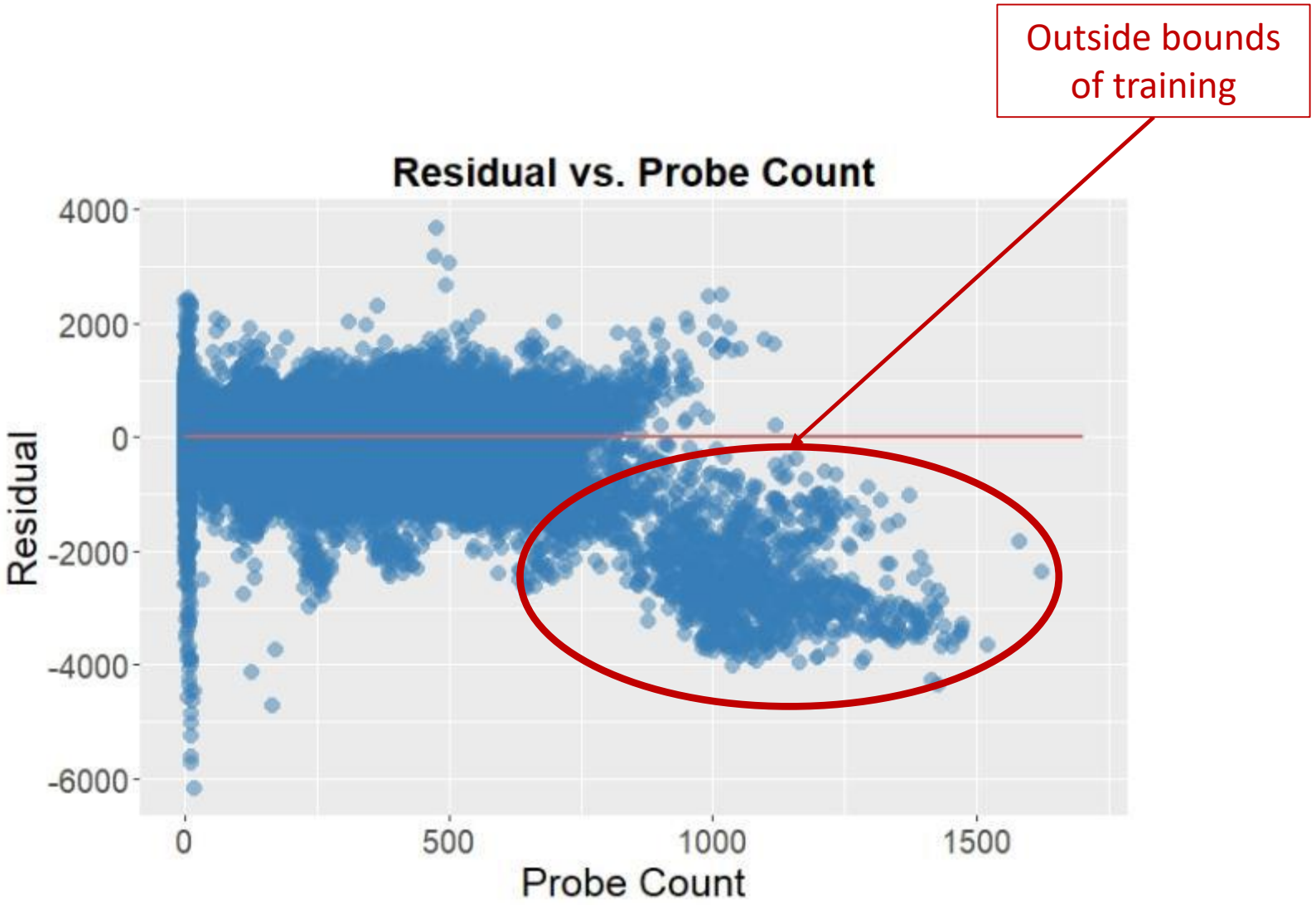
Residual vs. Probe Count



Residual vs. Probe Count – Colorado Freeways

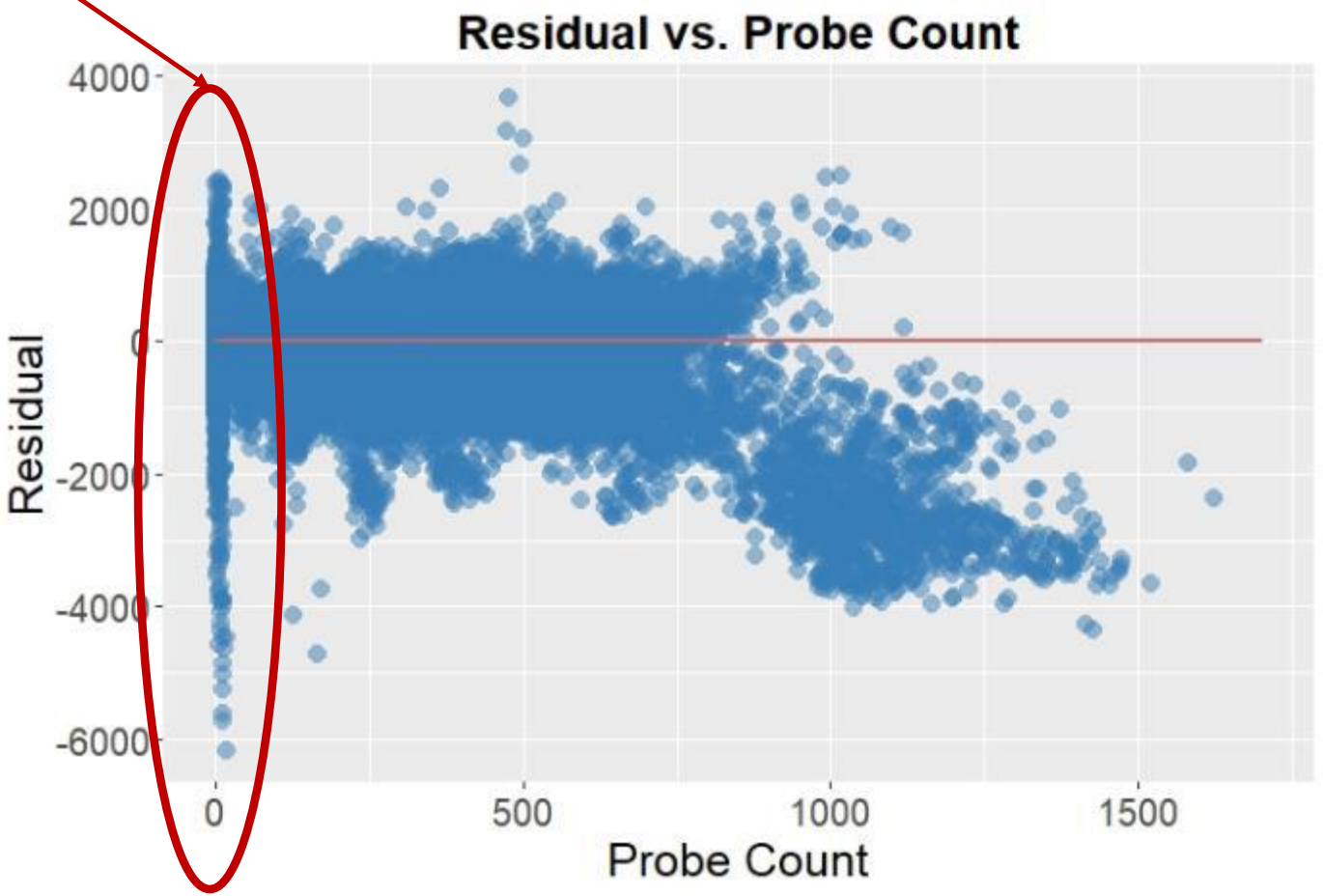


Residual vs. Probe Count

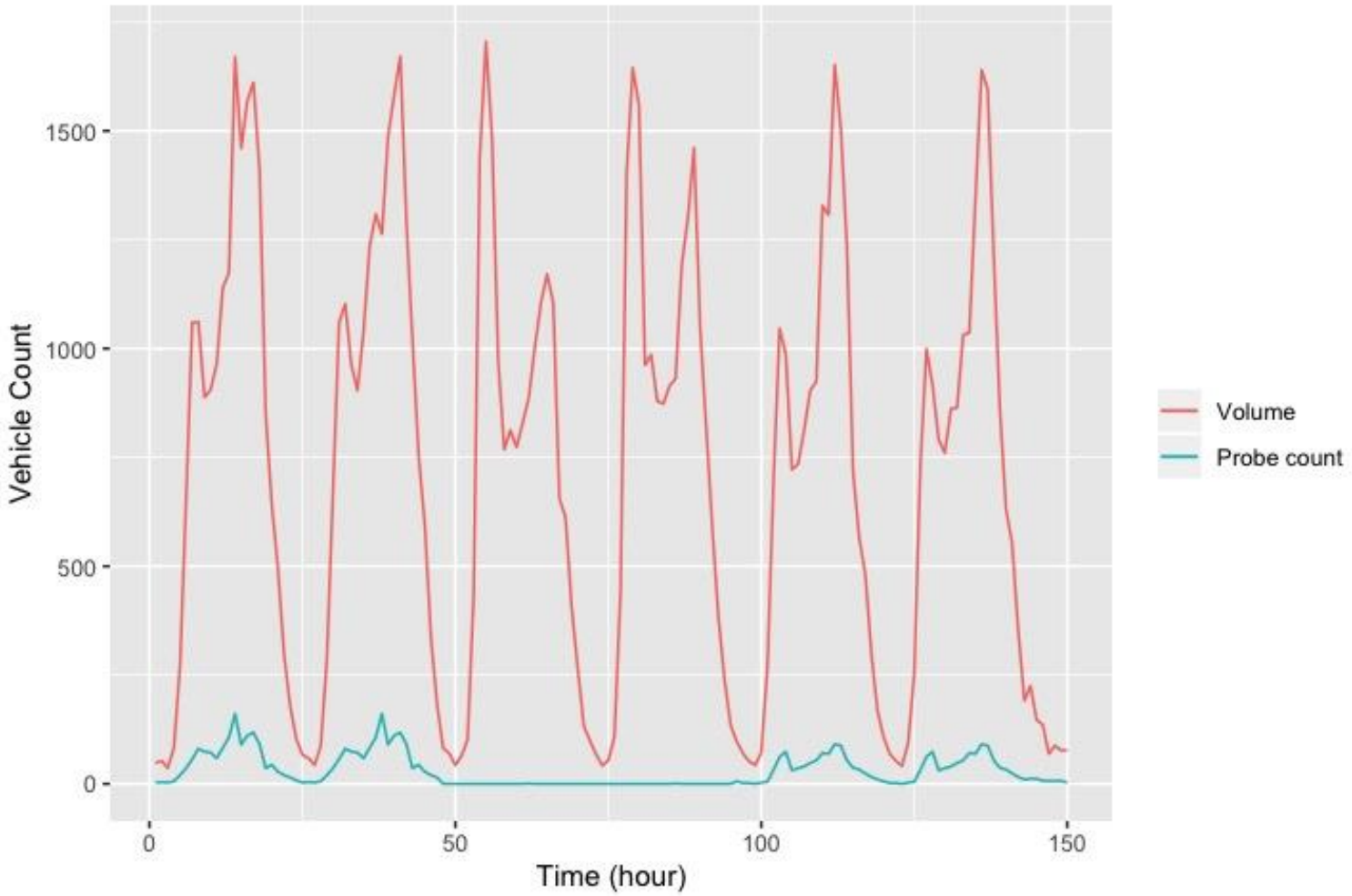


Residual vs. Probe Count

Data issues zero reported probes



Data quality



Volume Error Analysis
Colorado Roadways
both Freeways and Off-freeways

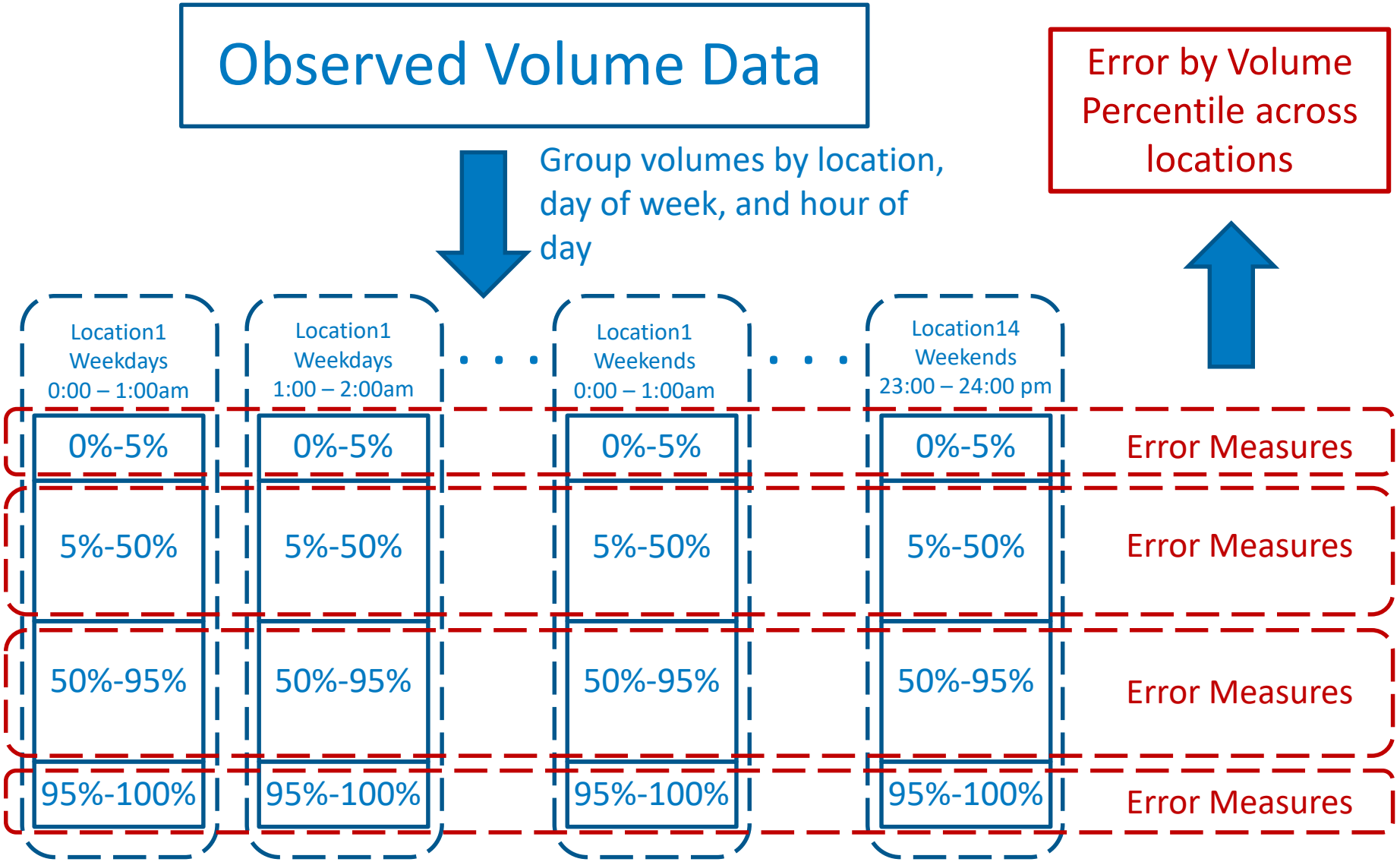
(a) Symmetric MAPE

(b) Training Bounds & Data Filtering

(c) Performance during unusual events

How well does method perform during unusual events and conditions?

Error by Observed Volume Percentile Across Locations

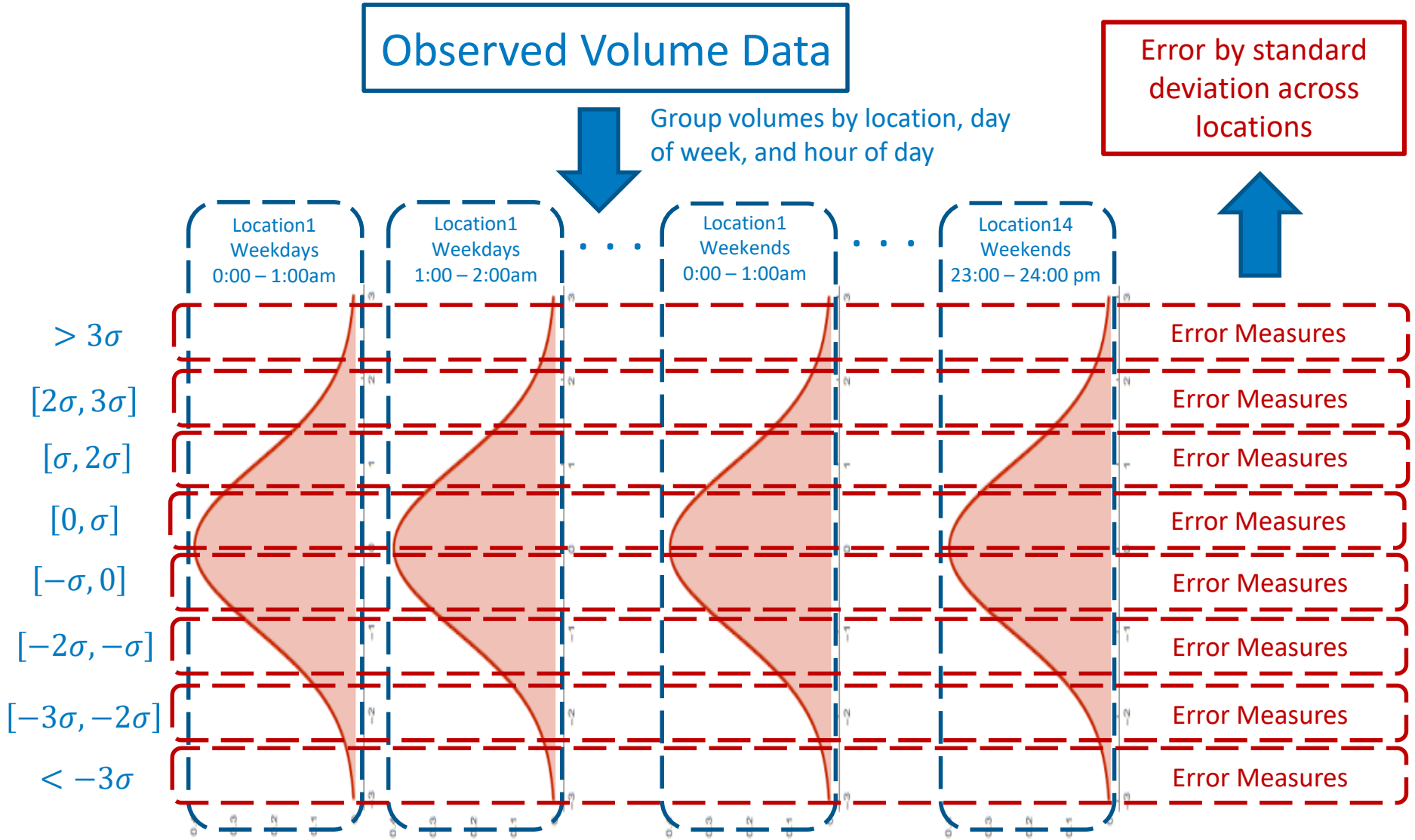


Error by Volume Percentile Across Locations

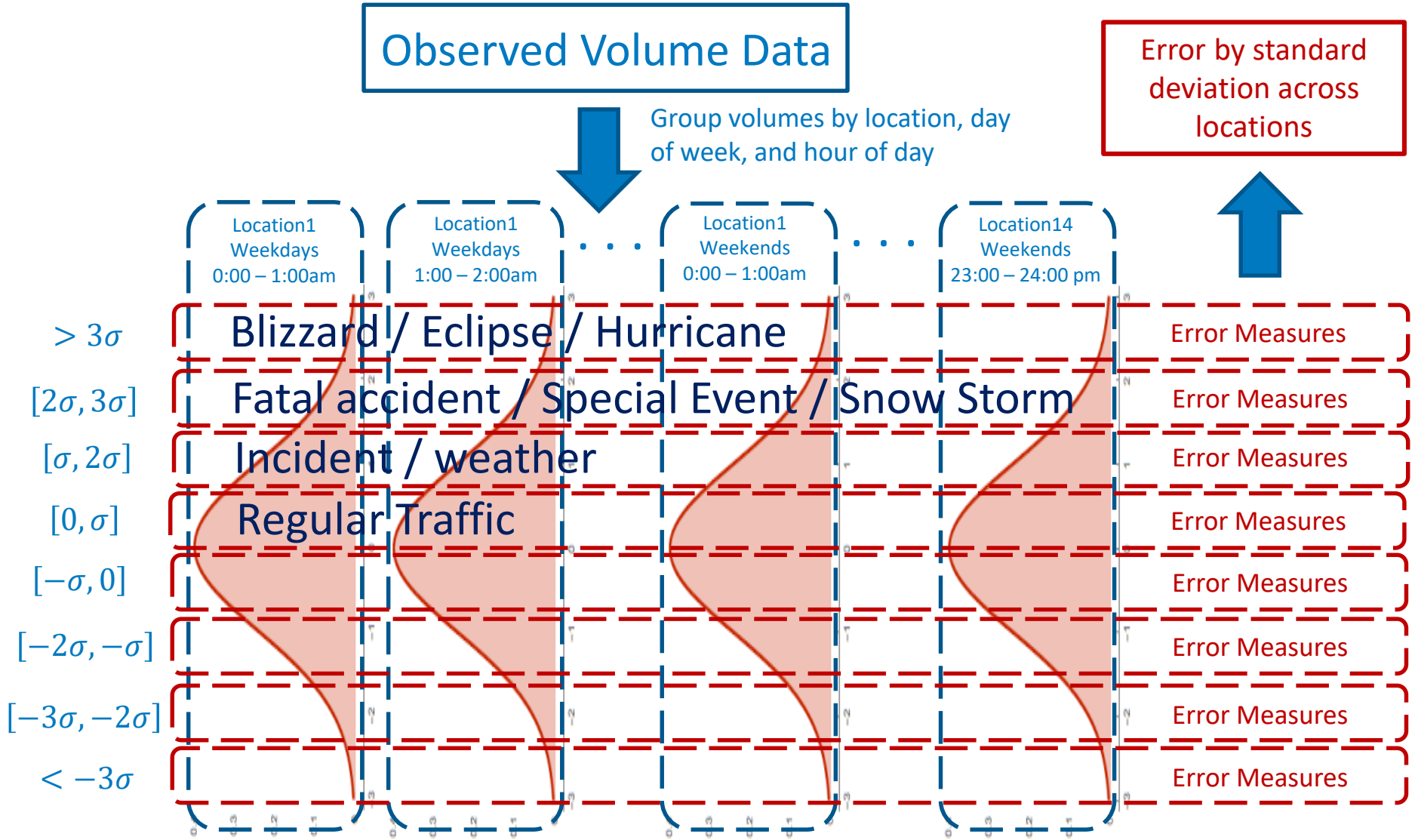
- Model performs as good as normal conditions when observed volume are above 95th percentile.
- For volumes lower than 5th percentile, MAPE and SMAPE are slightly higher than other conditions.

Percentile of Volume	MAPE	SMAPE	MAE	ECR
0% - 5%	25.5%	20.2%	273.9	4.2%
5% - 50%	18.2%	17.4%	326.7	4.9%
50% - 95%	16.2%	16.6%	385.1	5.7%
95% - 100%	16.3%	17.2%	438.9	6.4%

Error by Standard Deviation Across Locations



Error by Standard Deviation Across Locations



Error by Standard Deviation Across Locations

- SMAPE is consistent for both normal and abnormal conditions, except for two 0.1% tails.
- MAPE is between 15.6% and 22.9% for volumes larger than μ-3σ
- Model performs very well for special events and extremely congested conditions.

Std. of Volume	Count	MAPE	SMAPE	MAE	ECR
<-3σ (0.1%)	214	42.9%	25.2%	564.5	8.6%
-3σ to -2σ (2.1%)	1694	22.9%	18.4%	276.0	4.4%
-2σ to –σ (13.6%)	5820	20.9%	18.4%	286.8	4.5%
-1σ to 0 (34.1%)	15896	19.1%	18.0%	278.1	4.2%
0 to σ (34.1%)	22234	15.6%	16.4%	428.6	6.3%
σ to 2σ (13.6%)	5390	15.7%	16.4%	398.8	5.8%
2σ to 3σ (2.1%)	743	17.8%	18.6%	243.9	3.7%
> 3σ (0.1%)	101	21.7%	24.8%	340.1	5.1%

Summary and Future Work

- **Symmetric MAPE Implemented**
- **Error Analysis**
  - Training bounds issue confirmed at large volumes
  - Input data filtering issue discovered
  - Next steps – revised methodology for filtering, flagging and better accuracy
- **Working towards confidence flag / number & identifying information importance**

Future Work – Next Steps

Remaining Analysis Work

- **Status of VTM R&D**
  - In the homestretch – anticipate closeout end of 2018
  - Small additional research funding extended effort
- **Extended work**
  - NREL & UMD
    - Continued Metric / Error Analysis / Confidence
  - NREL Focus
    - Analyze additional Coalition state
  - UMD Focus
    - Truck Volumes and vehicle types analysis

ANNOUNCING - Volumes in VPP V3.0

- **Recall**
  - Original VPP – Single vendor, travel times
  - VPP 2.0 – Travel time and speeds
    - Multiple vendor
    - Ancillary products (maps, trace data, etc.)
- **Preparing VPP 3.0 (everything in VPP 2.0)**
  - Include volume estimates
  - Other emerging capabilities – OD & trace data
- **Recommended specs for volume estimates in VPP 3.0 is product/deliverable in VTM research**

Moving Forward – From the Lab to the Streets

- Results of call for interest to go ‘from Lab to the Streets’
  - Discussion with several states
    - FL, GA, MD, PA, NH, CO, AL, PANYNJ and others
  - Vendors are responding with custom data packages/services to support volume estimates
- USDOT/FHWA – Pooled fund study
  - New sources of volume data for HPMS
- Other ….

- Contact Denise, Stan, or Kaveh if interested

Final Questions

Thank You!

For Questions, please contact:

- PI – Kaveh Sadabadi (UMD-CATT) 301-405-1352 or kfarokhi@umd.edu
- Co-PI – Denise Markow (I-95 Corridor Coalition) 301-789-9088 or dmarkow@i95coalition.org
- Co-PI – Stanley Young (NREL) 301-792-8180 or Stanley.Young@nrel.gov
- Logistics –Justin Ferri (KMJ Consulting, Inc.) 610.228.0759 or jferri@kmjinc.com