NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Quality Volume Data Anytime & Anywhere: A Big Data Success Story

Results from NREL/UMD/I95 Corridor Coalition Research

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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

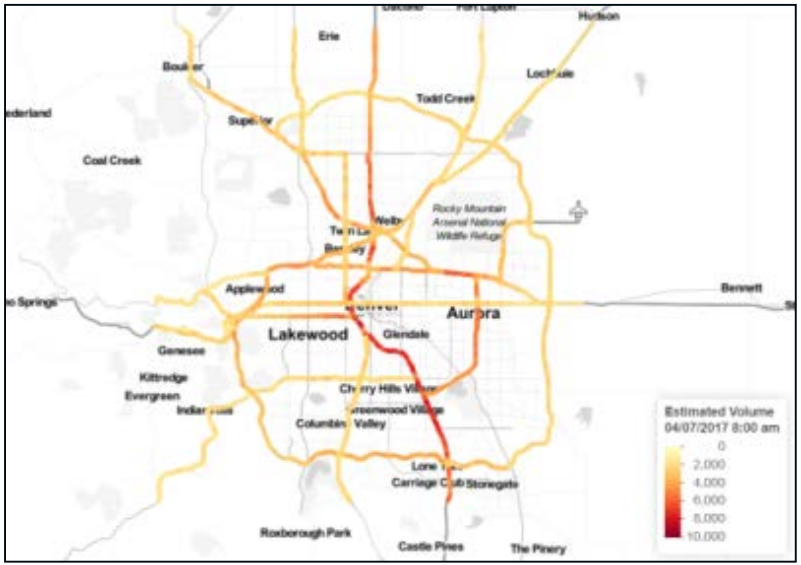

Planning


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

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

How Good is Good Enough?

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

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)

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}

Volume Estimation on Freeways

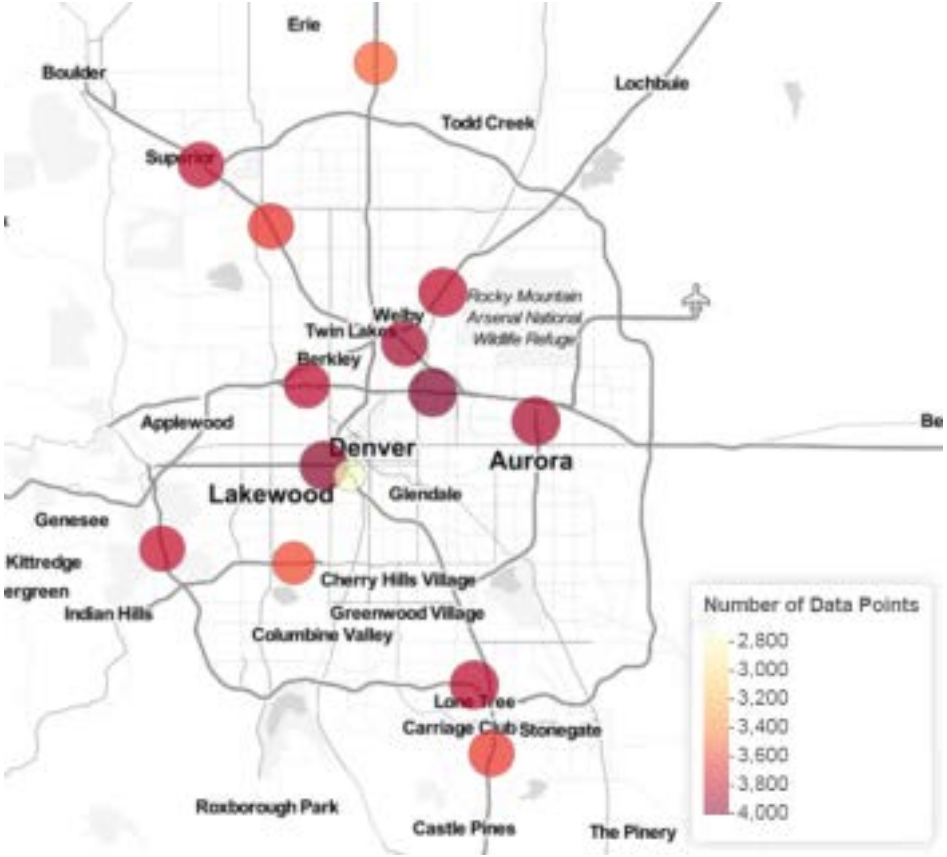
Input Data

- 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

Calibrated to the 14 Continuous Count Stations in Denver region

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
- Percentage of traffic covered by GPS probe data (ranges from 8%-12%)



Estimation Methodology

- Machine Learning: A subfield of computer science that gives computers the ability to learn from data without being explicitly programmed
  - 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 Cross-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)

Volume Estimation Results

- Results exceed the survey expectation: ETCR<10%
- About 18% error relative to observed volume
- Representative results:

Model	MAPE	ETCR	R2	Training Time
XGBoost	17.7%	5.3%	0.91	13s

- Without Probe Data

Without Probe Data	MAPE	ETCR	R^2
	39.4%	12.4%	0.65

Estimation vs. Observation

Denver Police Dept.
@DenverPolice
Follow

#Traffic: Delays possible in area of 6th Ave/Steele St due to a 2-vehicle crash with serious injuries. #Denver

5:37 PM - Feb 23, 2017

1 7 6

DC Sheriff
@dcsheriff
Follow

It's treacherous out! Douglas county is on accident alert. PLEASE slow down and drive carefully! #headsup #dcsotraffic

5:19 PM - Feb 23, 2017

21 28

Volume Estimation on Non-Freeways

Functional Classification of Roadways

FHWA functional classification

Freeways
- Interstates
- Other Freeways

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

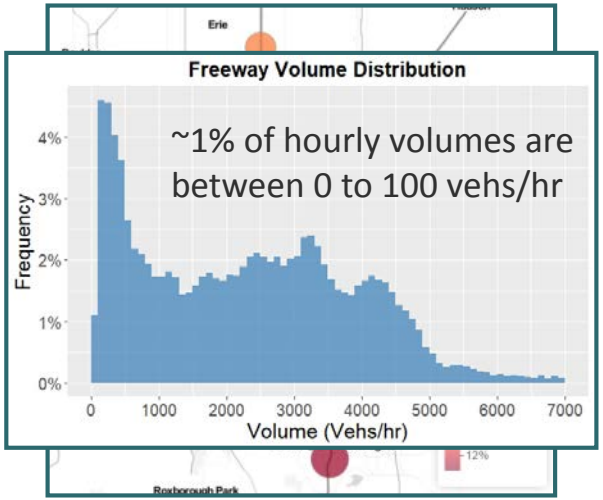
Property	Lower Class Roads	Freeways
Percentage of Miles	98.5%	1.5%
Percentage of Lane Miles	96.7%	3.3%
Percentage of VMT	68.5%	31.5%
Monitoring Method	Short-term counts	Continuous count stations & Short-term counts

Data source: FHWA Highway Statistics 2013

Calibration / Validation Network

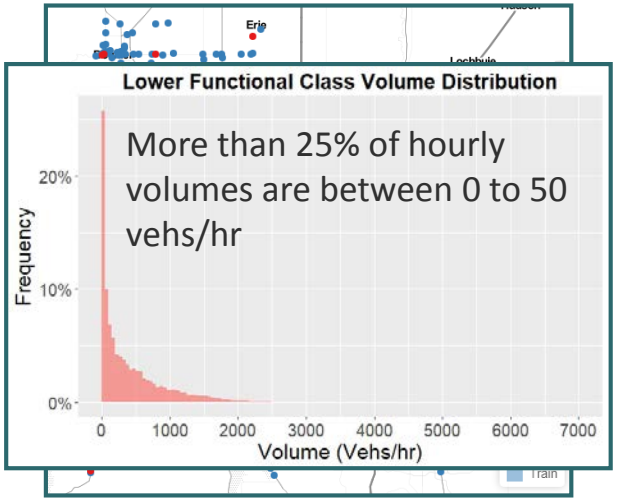
Freeway

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



Off-Freeway

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



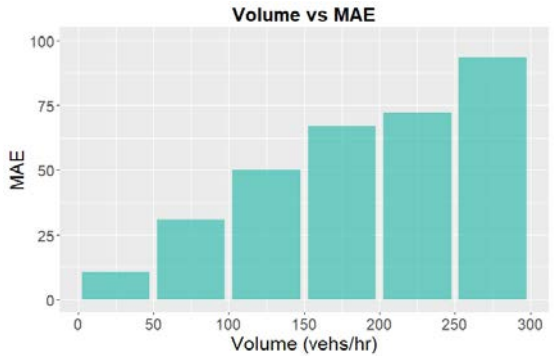
Model Evaluation Criteria

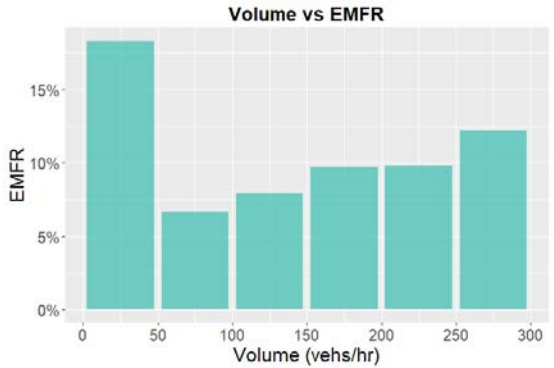
- Mean Absolute Percentage Error (MAPE)
  - Reflect the absolute volume accuracy
- Coefficient of Determination (R^2)
  - Explanatory power of model

New Measures need for Off-Freeway Results

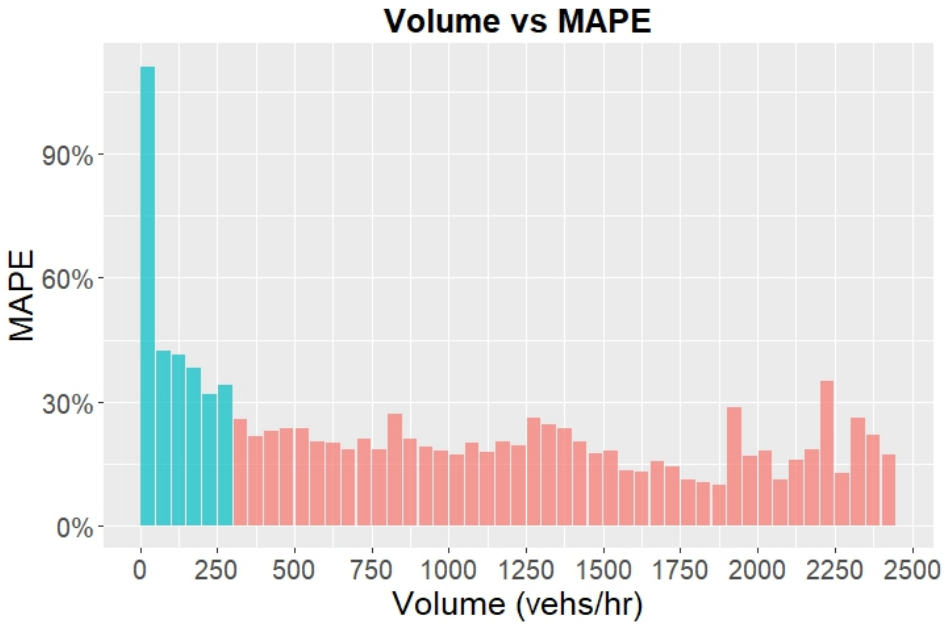
- Error to Maximum Flow Ratio (EMFR)
  - Reflect volume to capacity fidelity
- Mean Absolute Error (MAE)
  - Reflect the absolute error
  - Effective for low volume roads

MAPE of Different Volume Ranges



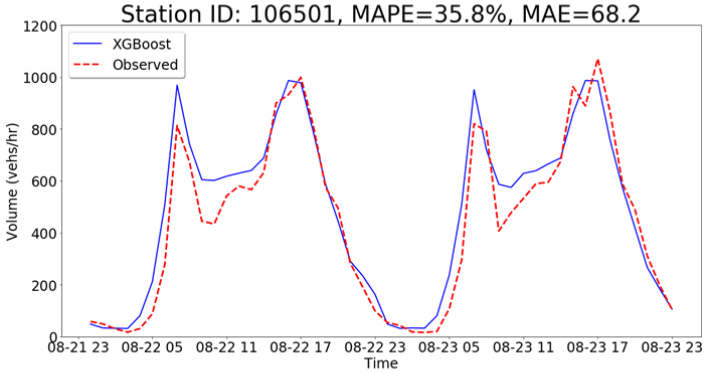


- Volume>300 vehs/hr: MAPE is low and stable
- Volume<300 vehs/hr: MAPE is high, but model is still good

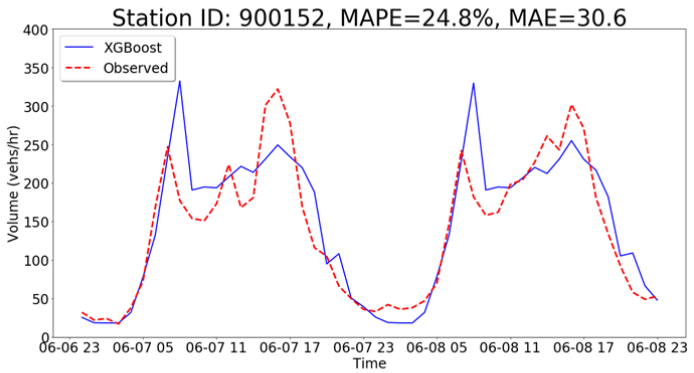


48-Hour Prediction on Test Locations

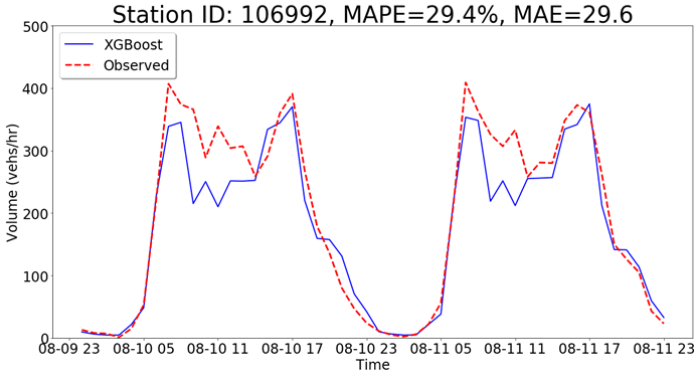
Principal Arterial



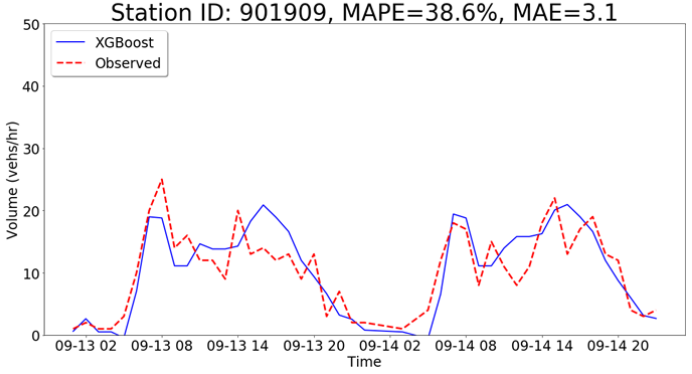
Minor Arterial



Major Collector



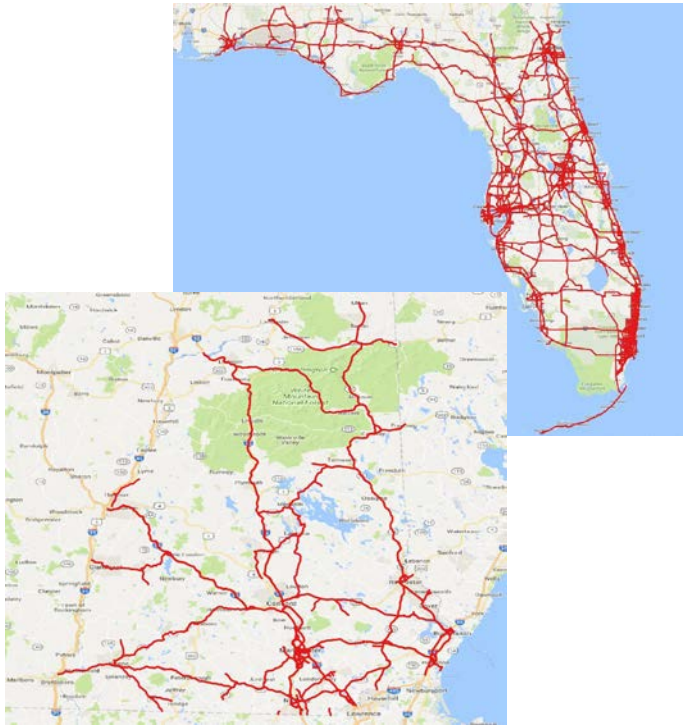
Local Street



Aggregate Volume Measures - AADT

Florida Analysis – UMD Partner

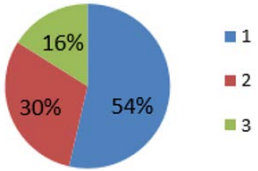
- Overview
  - Objectives
  - Volume estimation approach
- Florida case study
  - Dataset
  - Results
    - Statewide estimates
    - AADT/AAWDT
    - Truck Volumes
    - Flagging unusual behavior
- New Hampshire case study
  - Dataset
  - Results
    - Statewide estimates
    - AADT/AAWDT
    - Model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



Florida Dataset (Q4 2016)

Data needed at all TMCs

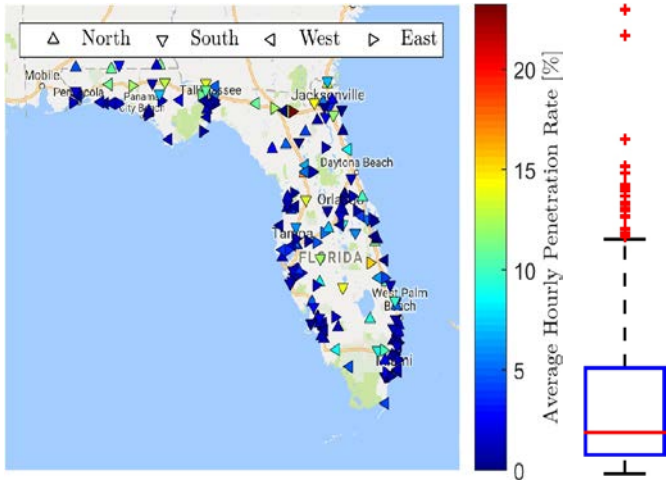
- **GPS probe data** (INRIX)
  - 75M trips, 3.4B pts
  - Penetration rate: 2.1% median
  - Snapped to base map
- **Probe speeds** (HERE)
- **Road characteristics**
  - # lanes, speed limit, facility type, etc.
- **Weather**
- **TTI hourly volume estimates**



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 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

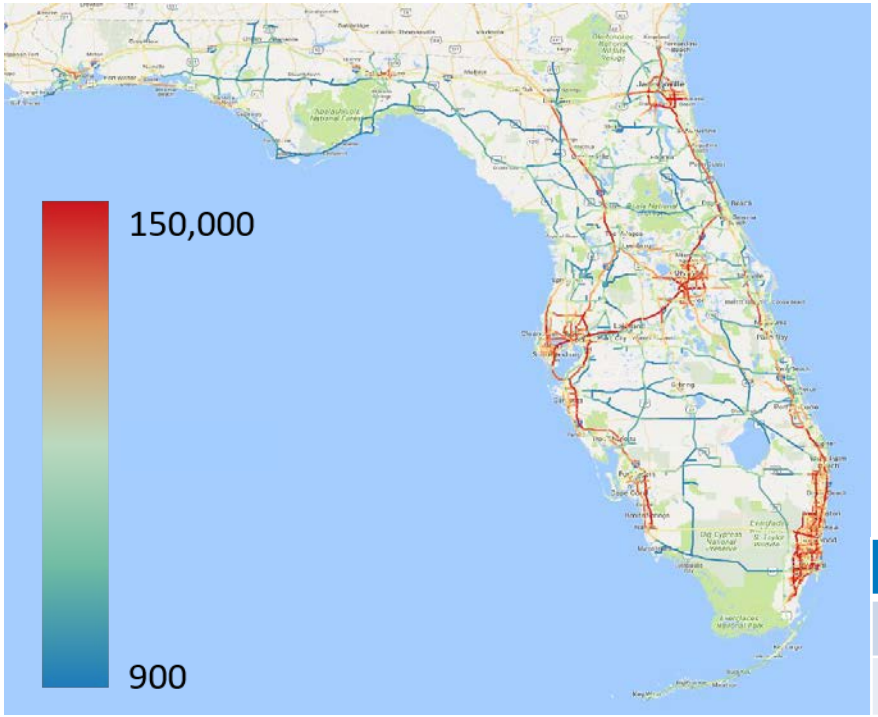
Road Classification	R2	MAPE (%)	EMFR (%)	Obs
FRC 1 (Interstates)	0.86	21	6	195704
Maryland (mostly FRC 1)	0.86	23	7	158040
FRC 2 (Other Freeways & Expressways)	0.82	26	7	370567
FRC 3 & 4 (Other principal & minor arterials)	0.83	33	7	128419

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

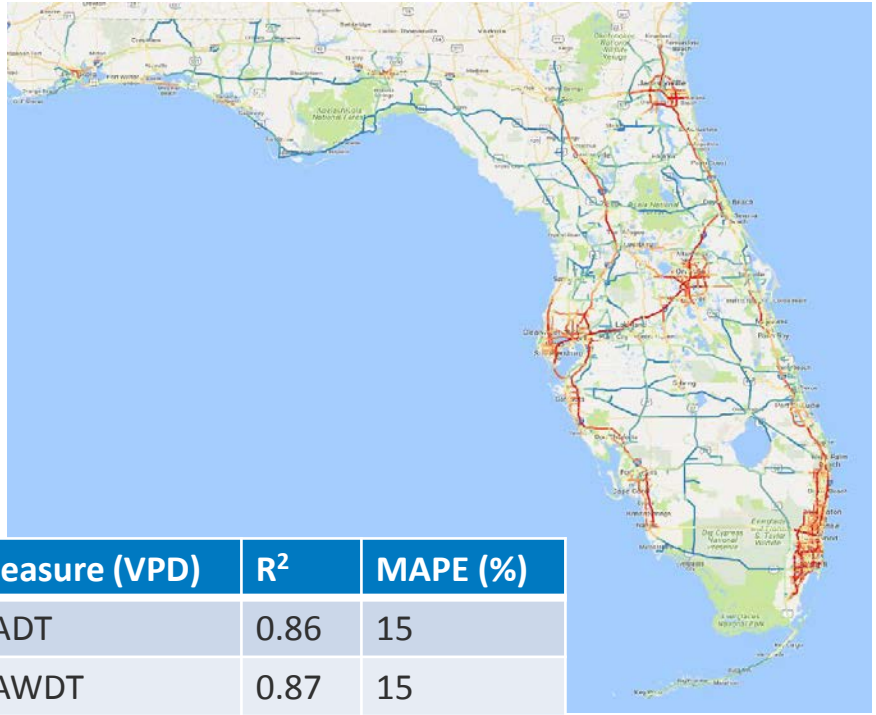
Avg probe counts / hr	R2	MAPE (%)	EMFR (%)	Obs
"Low" [0-6]	0.78	38	8	214557
"Medium" [6-17]	0.84	24	7	249730
"High" [17-145]	0.85	22	6	230403

Florida: AADT & AAWDT Estimation

AADT



AAWDT



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

Summary / Conclusions

- Volume estimation can be supported with a combination of:
  - Commercial Probe Data (Probe count & Speed/Travel Times)
  - Other road attribute data and weather
  - High confidence ground truth sensor for calibration and validation
- Machine learning provides rapid and sustainable calculation methods
- Probe data is key ingredient to accurately estimate traffic volumes
- Can be applied for both historical and real-time

On-going / Future Work

- **Finishing up Phase I – Proof of Concept**
  - Results in CO, MD, FL, NH
  - Established metrics and targets
  - Methods scaled from freeways to local streets
- **Phase II – Prototype – initiating in January 2019**
  - Funded through Dept. of Energy Technology Commercialization
  - Colorado DOT collaborating (lead) state – other states participating TomTom industry partner (possibility of other vendors)
  - Productize to standard specs – and deliver data, real-time and horizontal
- **FHWA/USDOT – Pooled Fund Study – sometime in 2019**
  - Exploring Non-Traditional Methods to Obtain Vehicle Volume and Class Data

Contact us if interested!

Thank You!

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