Volume & Turning Movements Project

Steering Committee Meeting #5

July 27, 2017

Housekeeping Items

- Please call xxx-xxx-xxxx 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

WELCOME!

Denise Markow, I-95 Corridor Coalition

Speakers

Denise Markow, PE
TSMO Director
I-95 Corridor Coalition
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Stanley Young, PhD, PE
National Renewable Energy Laboratory (NREL)
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Kaveh Sadabadi, PhD
Center for Advanced Transportation Technology - University of Md. (UMD CATT)
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Yi Hou, PhD
National Renewable Energy Laboratory (NREL)
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Shawn Turner, PE
Texas A&M Transportation Institute (TTI)
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Attendees

Agencies	
Colorado DOT	HERE
District DOT	INRIX
FHWA	TomTom
Maryland DOT/MdSHA	Texas A&M Transportation Institute
MWCOG	NREL
NJTPA	I-95 Corridor Coalition
Pennsylvania DOT	UMD CATT
South Carolina DOT	UMD CATT Lab
Virginia DOT	

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	Spotlight Presentation: Real-time Volume Estimation with TomTom Probe Data – Denver Area	Yi Hou, NREL
3	Polling Questions for Steering Committee Input	Steering Committee members
4	Validation Framework	Shawn Turner, TTI
5	Next Steps & Wrap Up	Stan Young, NREL Denise Markow, I-95 Corridor Coalition

Project – Year in Review

- User Survey - Completed
- Preliminary Data Analyses
  - Maryland
  - Rhode Island
  - Florida
  - Colorado
- Calibration (FHWA TMAS)
- Validation (TTI)

Getting Things Done.

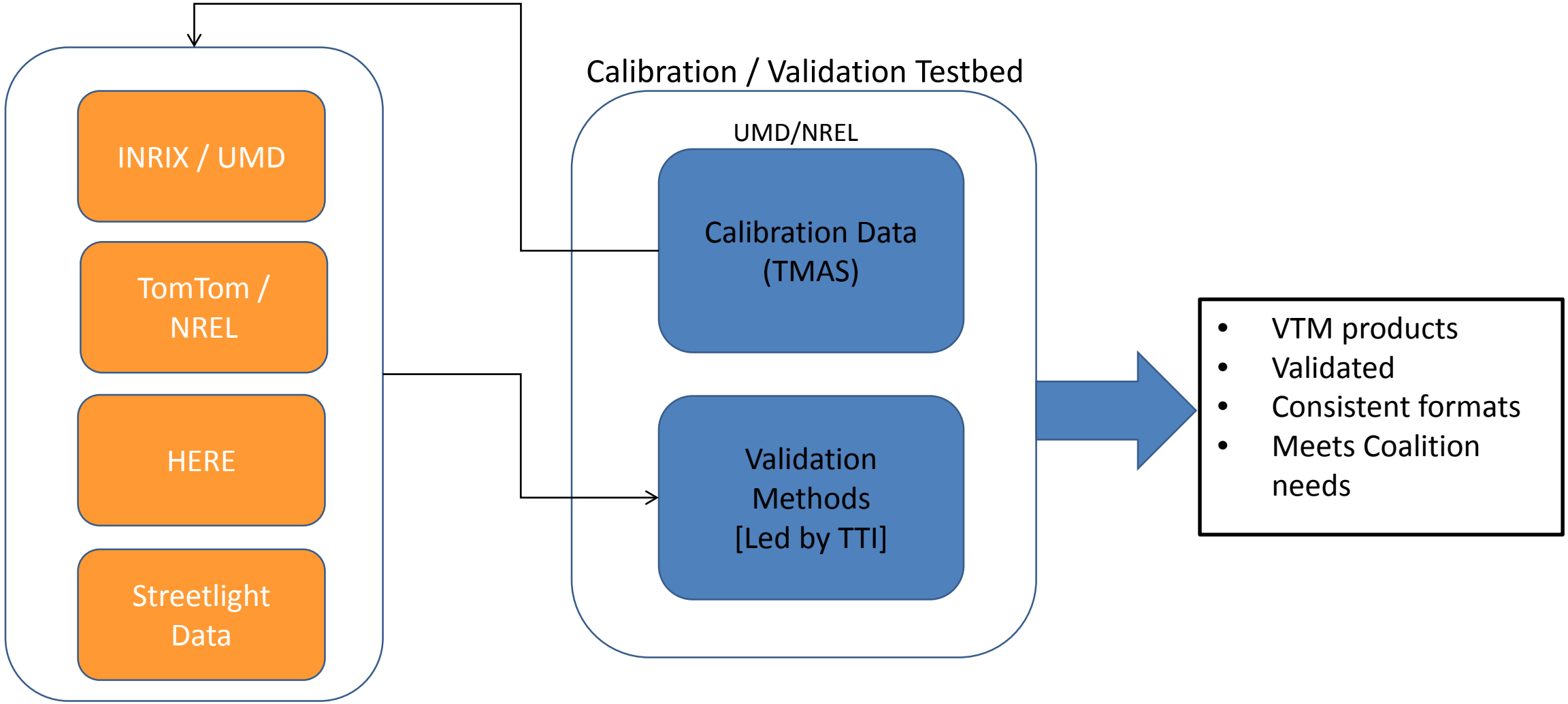
Project Goal

- Accelerate the timeframe to a viable volume and turning movement data feed ---
  - Anywhere/anytime on the network
  - Archive and real-time
- Ensure that initial data products meet the I-95 Corridor Coalition members' information needs for operations, performance measurement, and planning.

Objectives - Original

- Define a *practical and logistical framework* for the delivery of probe-based volume and turning movement data
- Understand, document, and share *data requirement needs for a variety of DOT applications* requiring such data
- Create a *calibration and validation testbed* to assist vendors' initial development efforts
- Provide *representative data products and set appropriate expectations* for data fidelity, form, granularity, and usability
- Anticipating the need for an ongoing calibration network, estimate *resources needed to maintain/operate* a national calibration/validation testbed

Status of Project



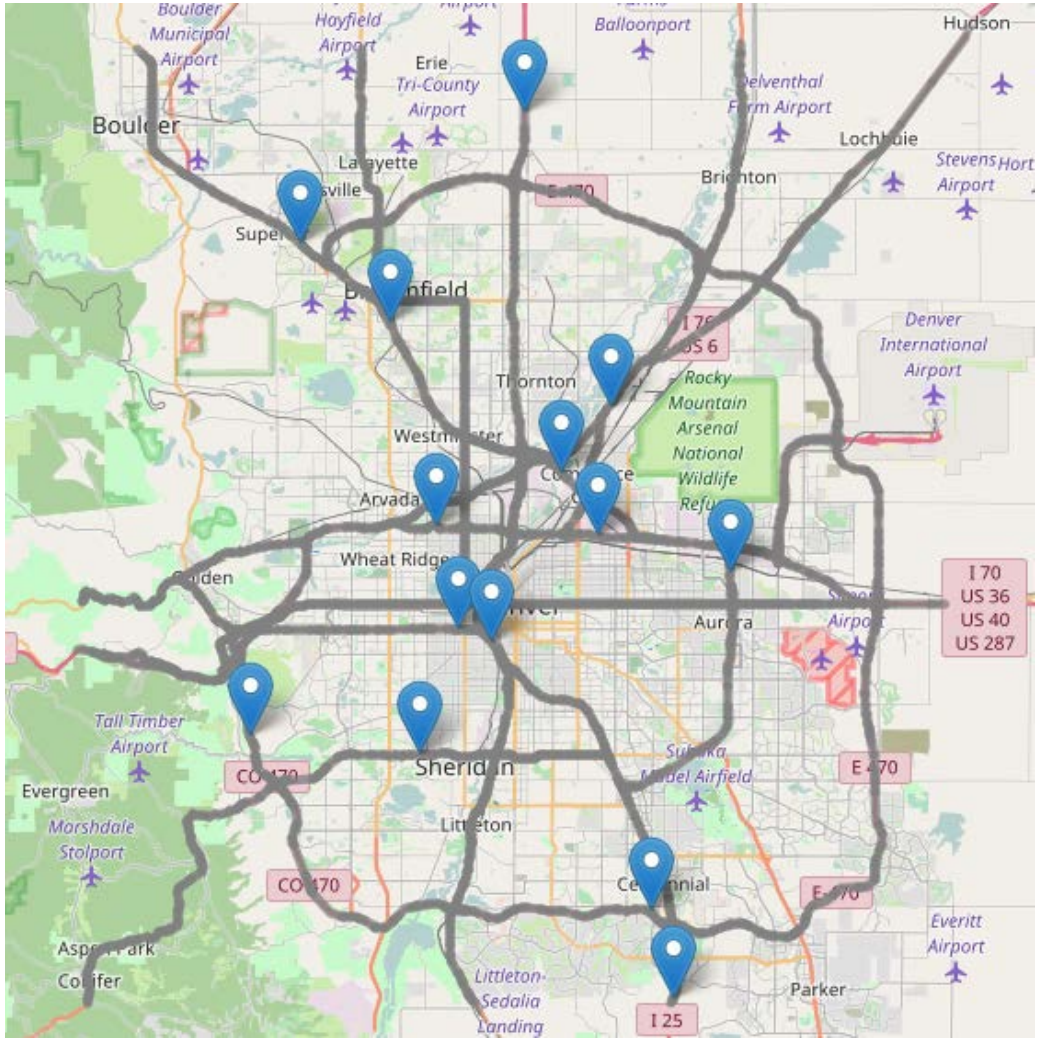
Status

- INRIX/UMD Data – Maryland analysis complete
  - Rhode Island and Florida are the target areas for next analysis
  - Base data: Trips, Origin & Destination, and intervening waypoints
- TomTom/NREL – Archive analysis complete Colorado (presented today)
  - In discussion with TomTom and CDOT for real-time analysis
  - Base data: Probe vehicle counts on segments
- HERE – sample data sets being reviewed
  - Base data: Trips, Origin & Destination
- Streetlight Data – sample data sets being reviewed
  - Base data: AADT estimate for a roadway

ALL DATA SETS ARE DIFFERENT!!

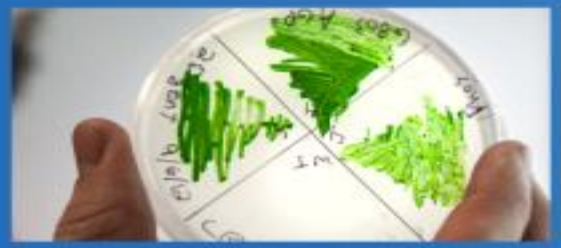
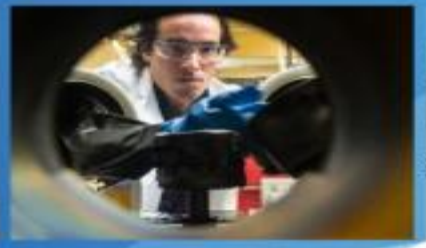
Today's Agenda

- TomTom/NREL analysis of volume estimates in CO
  - Yi Hou, NREL
  - Parallels the approach used in initial Maryland analysis
- Validation overview/thoughts –
  - Shawn Turner, TTI



Questions

NREL
NATIONAL RENEWABLE ENERGY LABORATORY
40
1977 – 2017

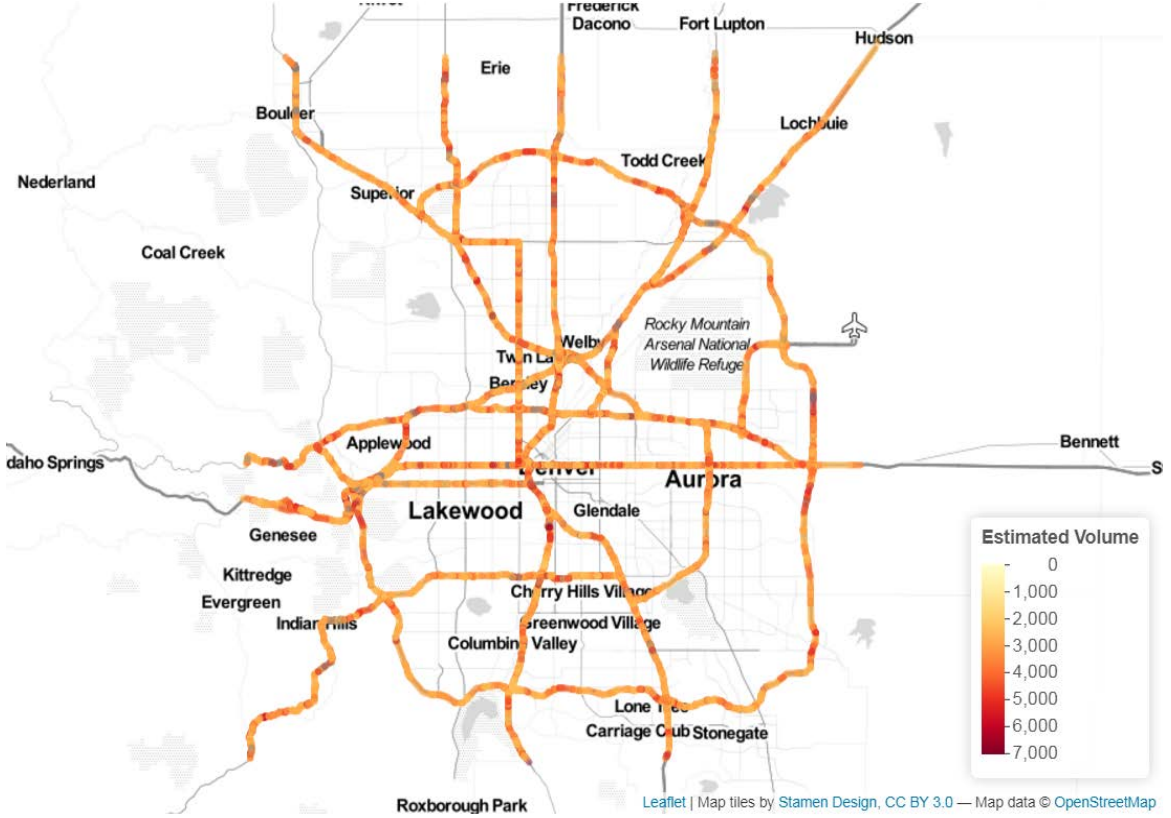

Real-time Volume Estimation with TomTom Probe Data – Denver Area

Yi Hou

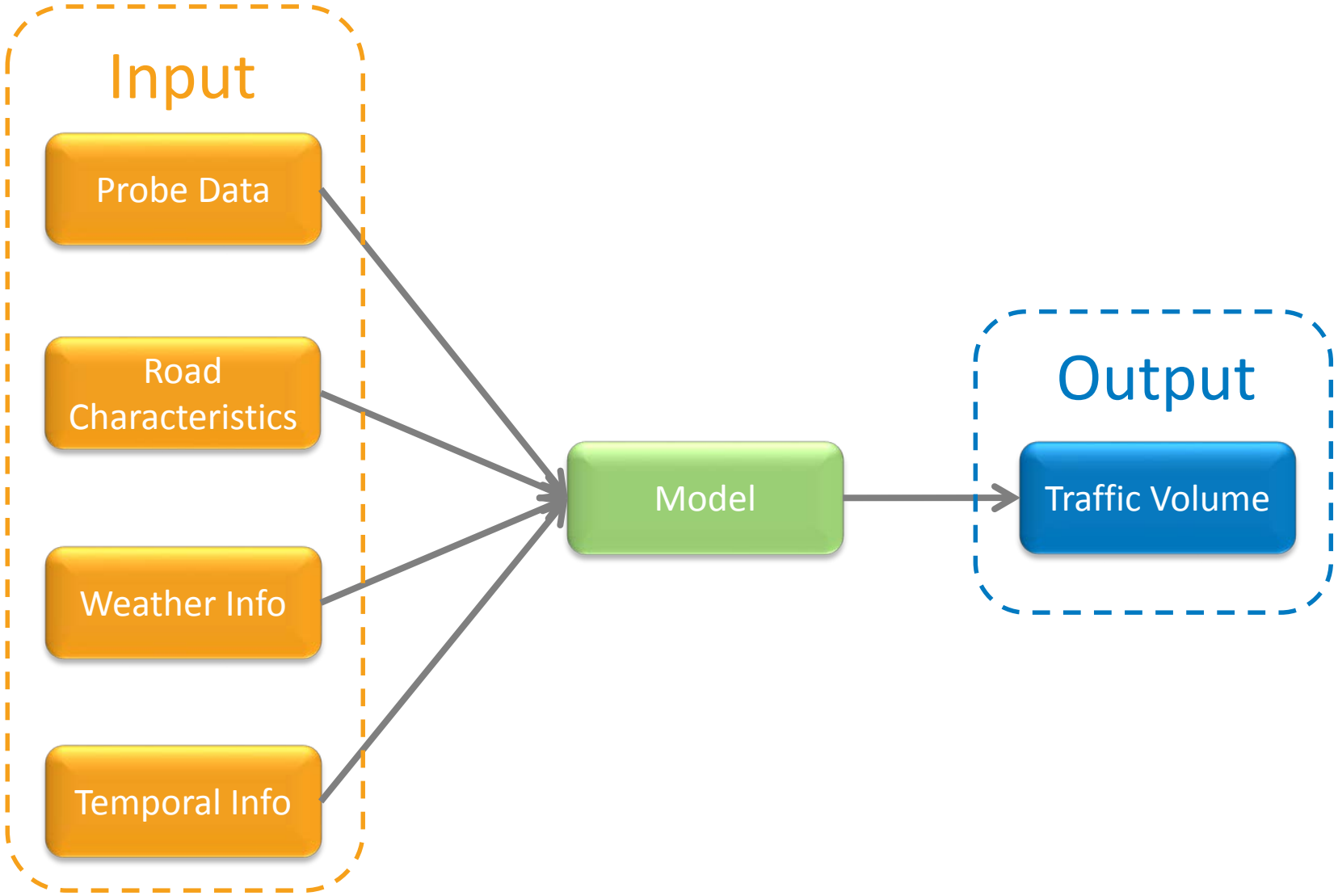
July 27, 2017

Problem Statement

- How to obtain accurate estimate of ubiquitous real-time traffic volume in road networks?



Proposed Solution



Outline

- Data Sources
  - FHWA TMAS
  - CDOT ATR Counts
  - Weather
  - TomTom Probe Data
- Model Development
- Summary
- Web App Framework

Data Sources

- FHWA TMAS
- CDOT ATR Counts
- Weather
- TomTom Probe Data

- ATR station information and road characteristics
  - State
  - Station ID
  - Direction
  - Urban/Rural
  - Number of lanes
  - Road sign (interstate, US, state)
  - Road number
  - Latitude
  - Longitude

Data Sources

- FHWA TMAS
- CDOT ATR Counts
- Weather
- TomTom Probe Data

- Temporal and volume information
  - Year
  - Month
  - Day
  - Weekday
  - Hour of day
  - Hourly volume

Data Sources

- FHWA TMAS
- CDOT ATR Counts
- Weather
- TomTom Probe Data

- Weather information
  - Average temperature
  - Visibility
  - Wind
  - Precipitation
  - Snow
  - Fog
  - Rain
  - Thunderstorm

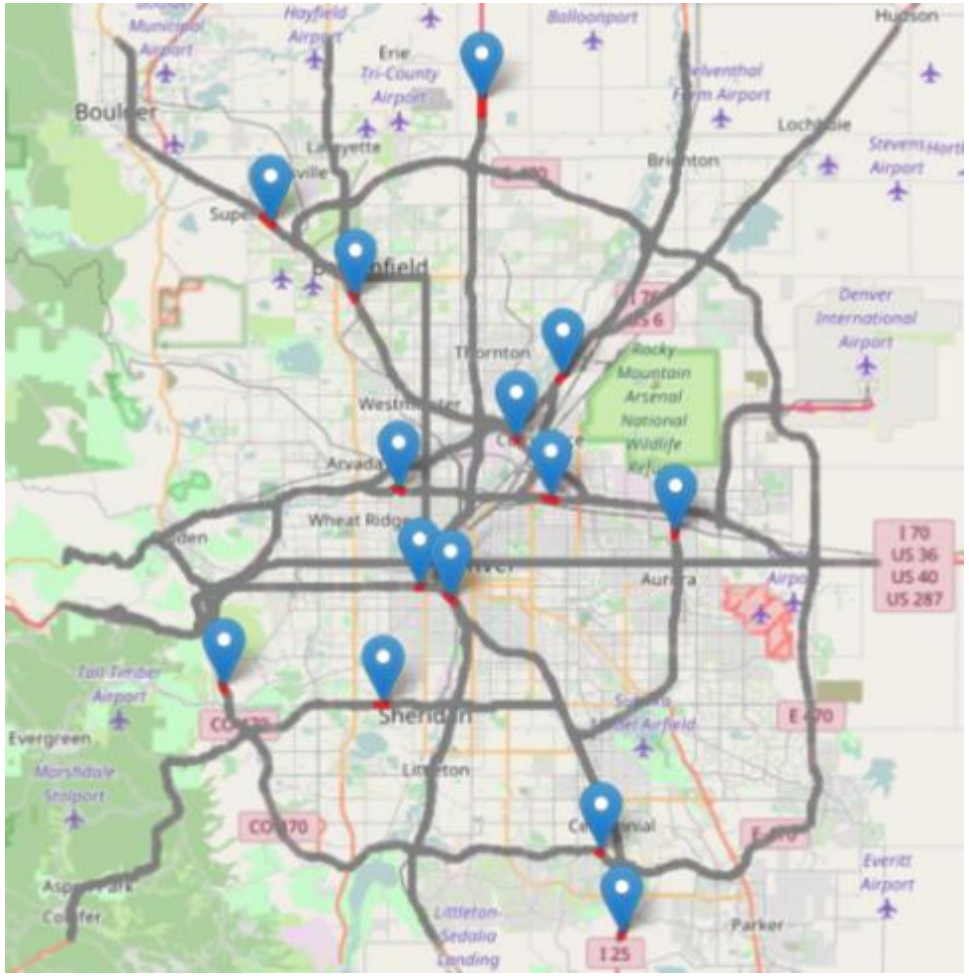
Data Sources

- FHWA TMAS
- CDOT ATR Counts
- Weather
- TomTom Probe Data

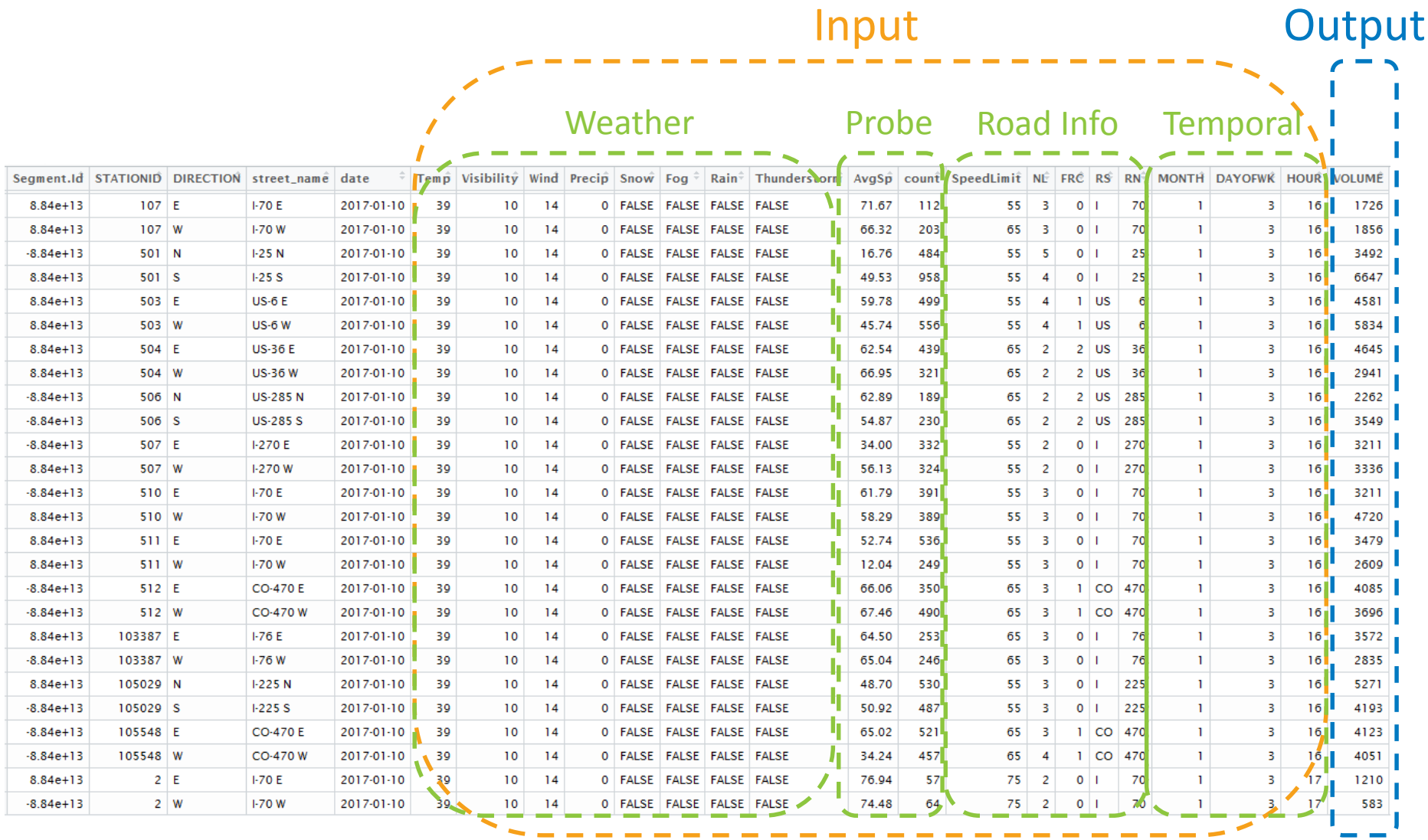
- Probe vehicle data
  - Travel time
  - Speed
  - Probe vehicle count
  - Speed limit
  - Street name
  - Segment ID

Denver Road Network

- Match ATR locations with TomTom segments



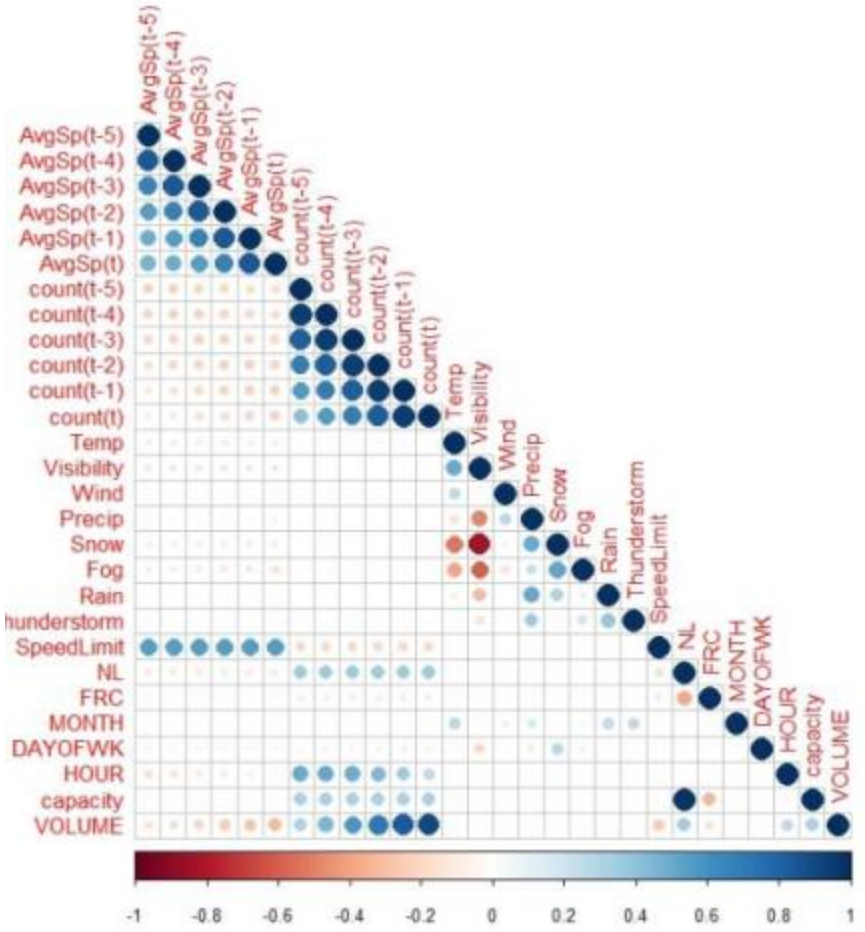
Snapshot of Merged data



Segment.Id	STATIONID	DIRECTION	street_name	date	Temp	Visibility	Wind	Precip	Snow	Fog	Rain	Thunderstorm	AvgSp	count	SpeedLimit	NL	FRC	RS	RN	MONTH	DAYOFWK	HOUR	VOLUME
8.84e+13	107	E	I-70 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	71.67	112	55	3	0	I	70	1	3	16	1726
8.84e+13	107	W	I-70 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	66.32	203	65	3	0	I	70	1	3	16	1856
-8.84e+13	501	N	I-25 N	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	16.76	484	55	5	0	I	25	1	3	16	3492
8.84e+13	501	S	I-25 S	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	49.53	958	55	4	0	I	25	1	3	16	6647
8.84e+13	503	E	US-6 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	59.78	499	55	4	1	US	6	1	3	16	4581
8.84e+13	503	W	US-6 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	45.74	556	55	4	1	US	6	1	3	16	5834
8.84e+13	504	E	US-36 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	62.54	439	65	2	2	US	36	1	3	16	4645
8.84e+13	504	W	US-36 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	66.95	321	65	2	2	US	36	1	3	16	2941
-8.84e+13	506	N	US-285 N	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	62.89	189	65	2	2	US	285	1	3	16	2262
-8.84e+13	506	S	US-285 S	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	54.87	230	65	2	2	US	285	1	3	16	3549
-8.84e+13	507	E	I-270 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	34.00	332	55	2	0	I	270	1	3	16	3211
8.84e+13	507	W	I-270 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	56.13	324	55	2	0	I	270	1	3	16	3336
-8.84e+13	510	E	I-70 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	61.79	391	55	3	0	I	70	1	3	16	3211
8.84e+13	510	W	I-70 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	58.29	389	55	3	0	I	70	1	3	16	4720
8.84e+13	511	E	I-70 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	52.74	536	55	3	0	I	70	1	3	16	3479
8.84e+13	511	W	I-70 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	12.04	249	55	3	0	I	70	1	3	16	2609
-8.84e+13	512	E	CO-470 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	66.06	350	65	3	1	CO	470	1	3	16	4085
-8.84e+13	512	W	CO-470 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	67.46	490	65	3	1	CO	470	1	3	16	3696
8.84e+13	103387	E	I-76 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	64.50	253	65	3	0	I	76	1	3	16	3572
-8.84e+13	103387	W	I-76 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	65.04	246	65	3	0	I	76	1	3	16	2835
8.84e+13	105029	N	I-225 N	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	48.70	530	55	3	0	I	225	1	3	16	5271
-8.84e+13	105029	S	I-225 S	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	50.92	487	55	3	0	I	225	1	3	16	4193
-8.84e+13	105548	E	CO-470 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	65.02	521	65	3	1	CO	470	1	3	16	4123
-8.84e+13	105548	W	CO-470 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	34.24	457	65	4	1	CO	470	1	3	16	4051
8.84e+13	2	E	I-70 E	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	76.94	57	75	2	0	I	70	1	3	17	1210
-8.84e+13	2	W	I-70 W	2017-01-10	39	10	14	0	FALSE	FALSE	FALSE	FALSE	74.48	64	75	2	0	I	70	1	3	17	583

Variable Correlations

- Positively correlated with volume
  - Average hourly probe counts of past 6 hours
  - Number of lanes
  - Capacity
- Negatively correlated with volume
  - Average hourly average speed of past 6 hours
  - Speed limit

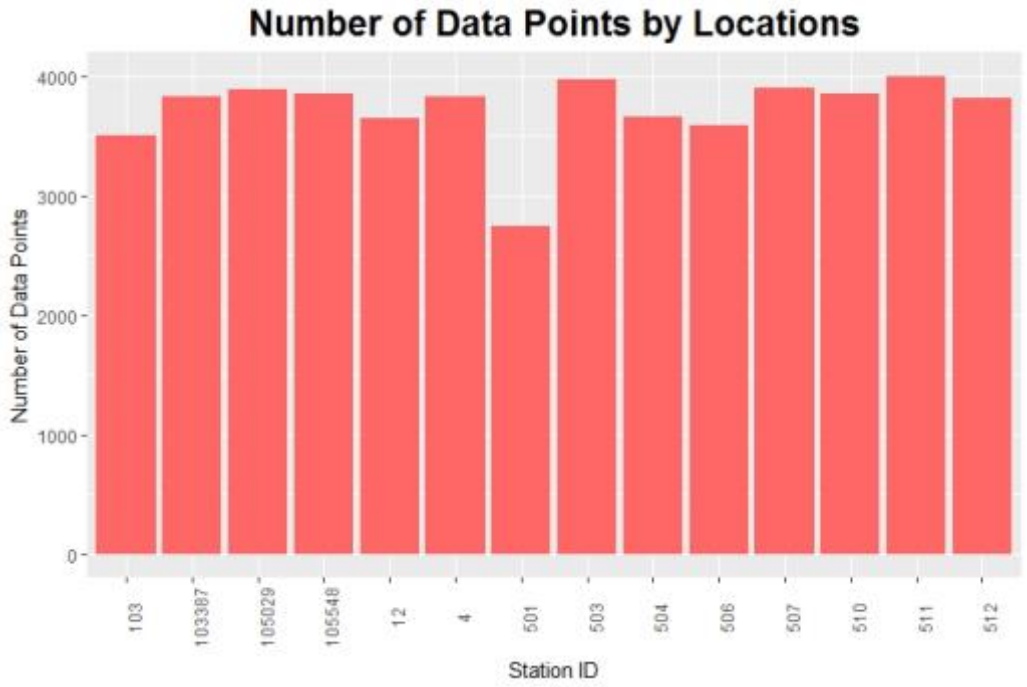


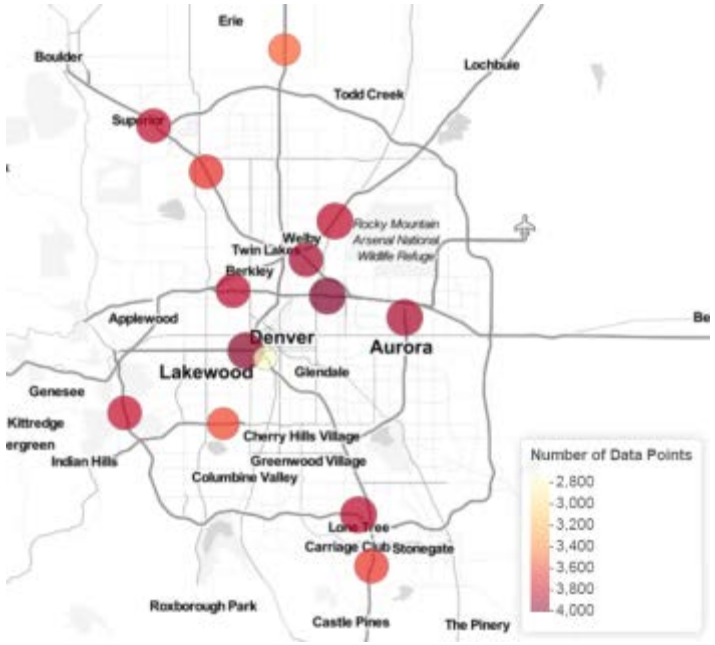
Input Variables

- TomTom GPS data
  - Average speed: average hourly speed of past 6 hours
  - Probe count: average hourly probe counts of past 6 hours
- Weather
  - temperature, visibility
- Road characteristics
  - road type, speed limit, number of lanes, capacity
- Temporal information
  - month, day of week, hour of day

Data Points

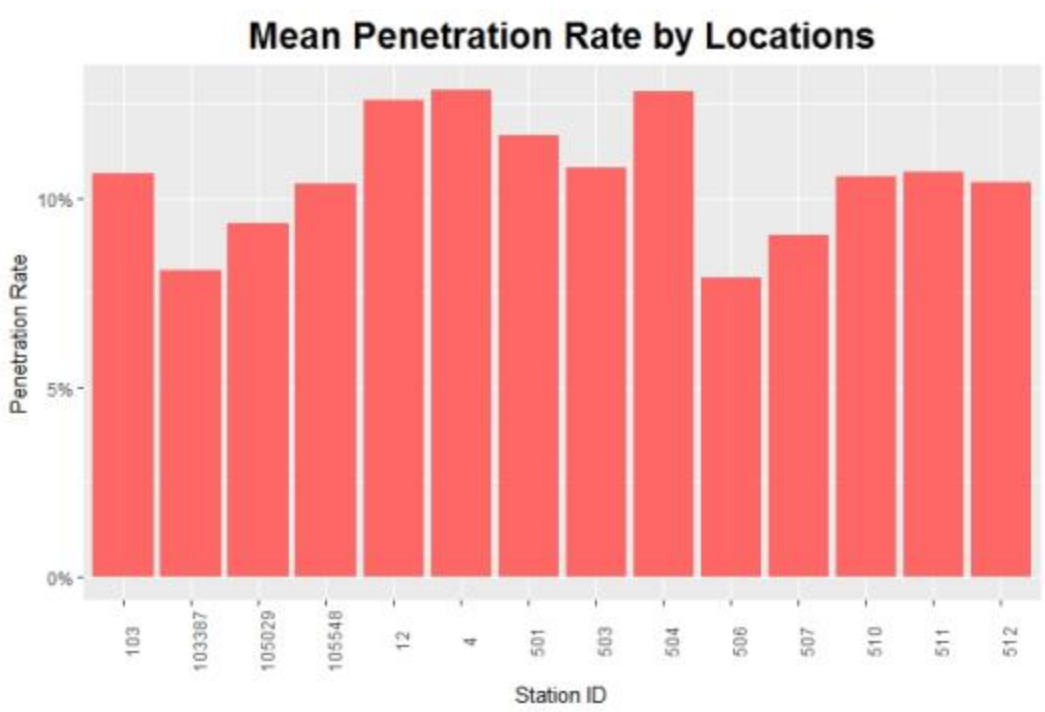
- Feb 1, 2017 – April 30, 2017
- Total of 52,092 data points
- Ranges from 2800-4000

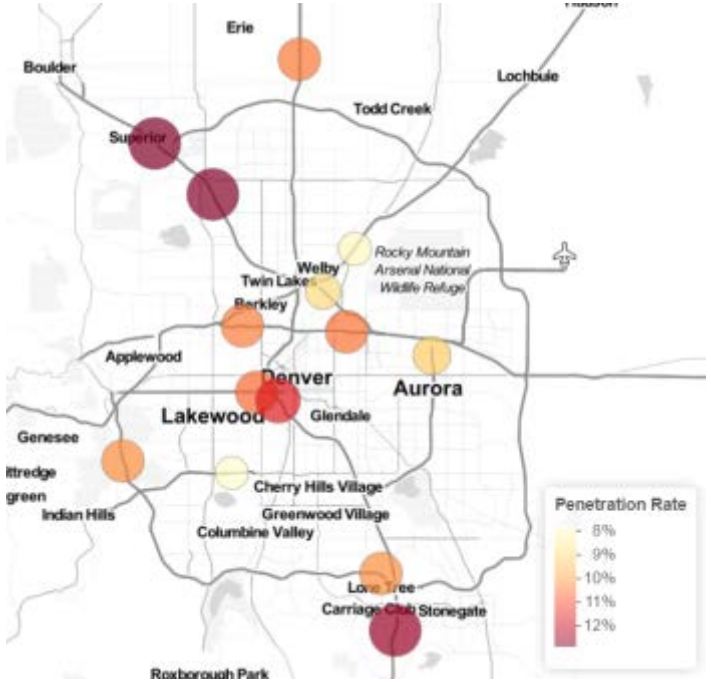




Penetration Rates

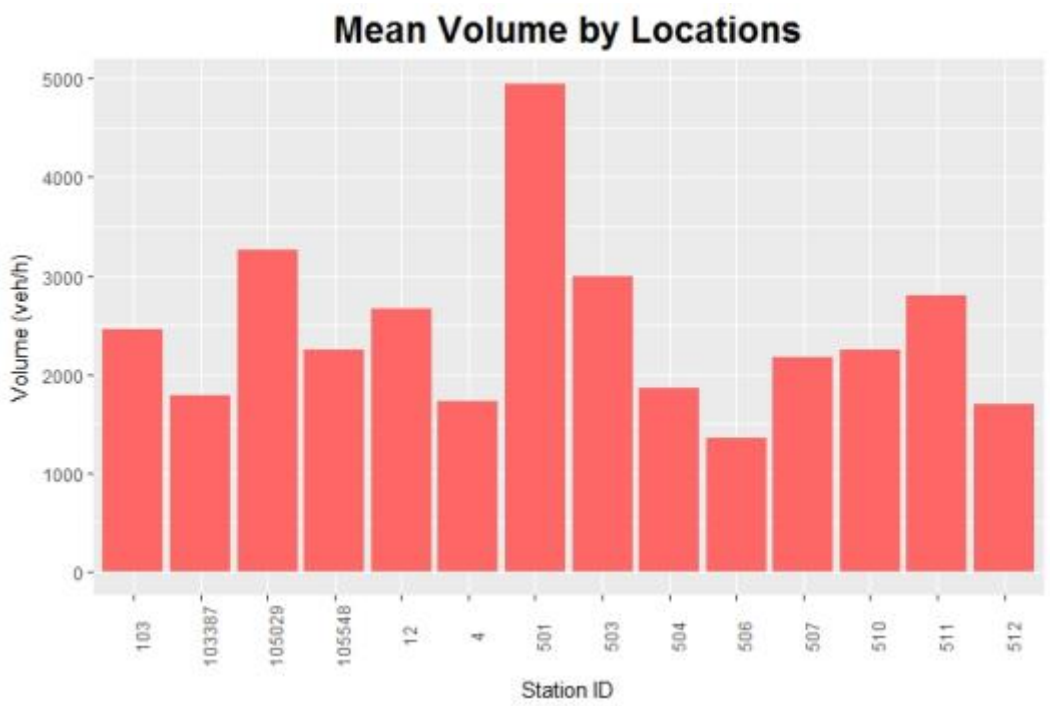
- Ranges from 8%-12%

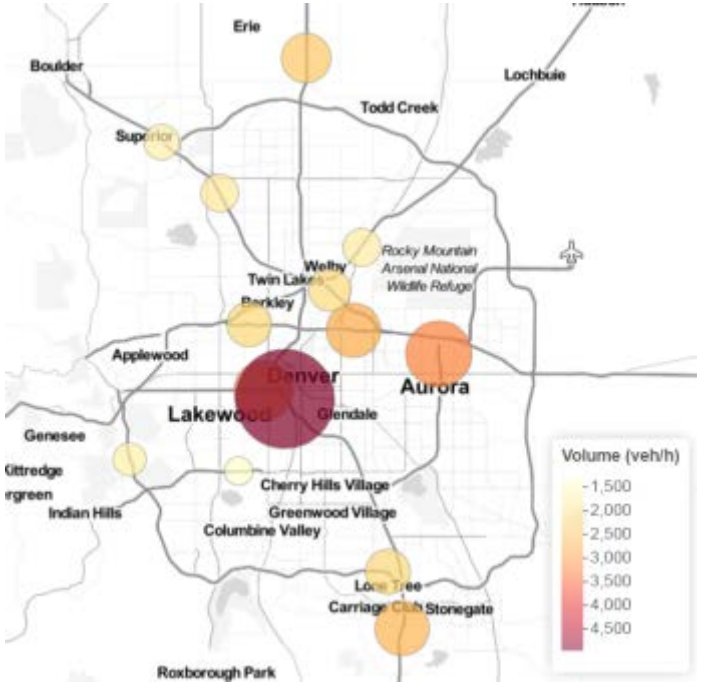




Average Volume

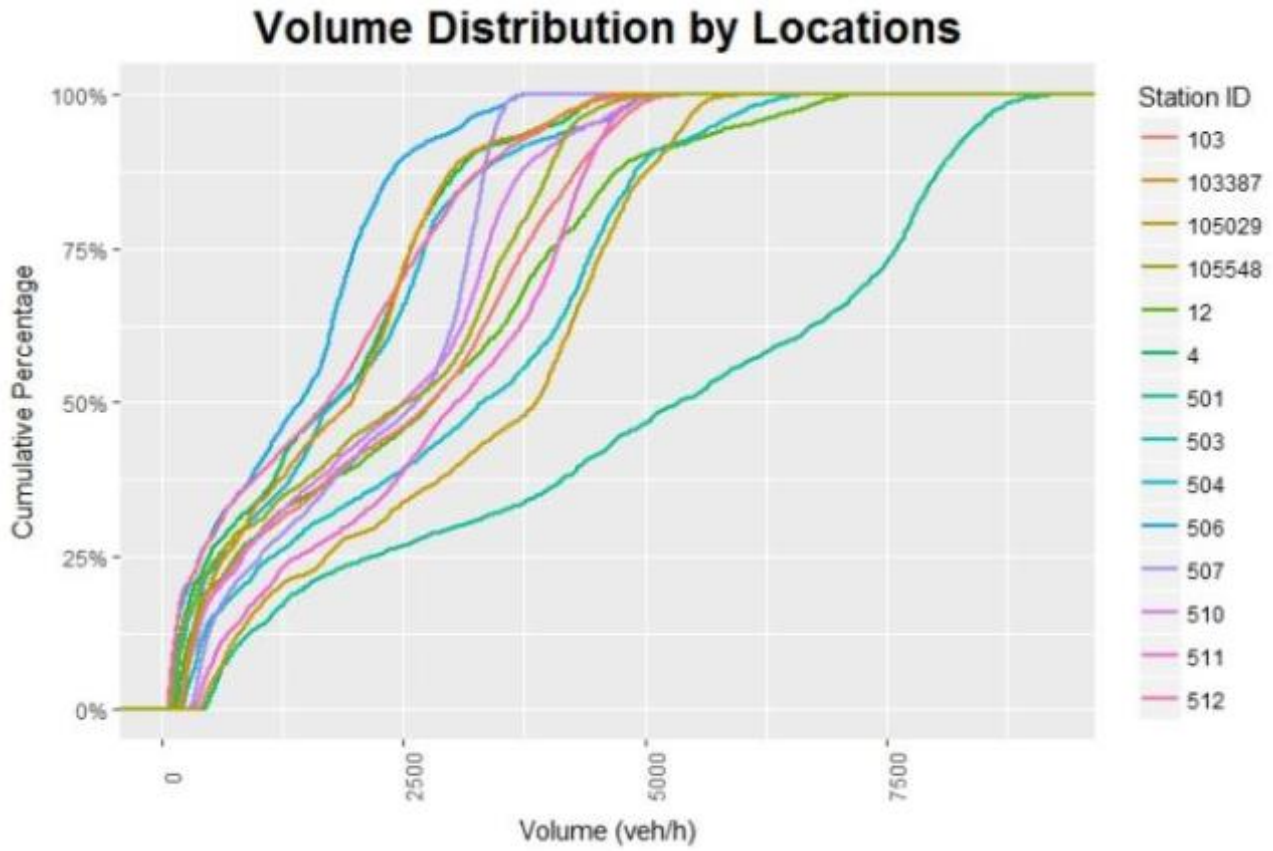
- All Ranges from 1500-3500 veh/hr except station 501
- 501 is an unique case





Volume Distribution by Location

- All ATR stations have similar volume distribution except station 501



Model Development

- Machine Learning Models
  - Random Forest (RF)
  - Gradient Boost Machine (GBM)
  - Extreme Gradient Boost (XGBoost)
- Advantages of these models
  - 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
  - Fewer parameters to tune and easy to implement

Model Validation

- All 14 ATR stations were used for modeling
  - At 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

Model Evaluation Criteria

- Coefficient of Determination: $R^2 = 1 - \frac{(\widehat{V_i} - V_i)^2}{(V_i - \bar{V})^2}$
  - A measure of how well the model can explain data variance
- Mean Absolute Percentage Error: $\mathrm{MAPE} = \frac{1}{N}\sum_{i=1}^{N} \frac{|V_i - \widehat{V_i}|}{V_i}$
  - An error measure when comparing estimated volume with ground truth
- Error to Theoretical Capacity Ratio: $\mathrm{ETCR} = \frac{1}{N}\sum_{i=1}^{N} \frac{|V_i - \widehat{V_i}|}{C_i}$
  - An error measure when comparing estimated volume with roadway capacity

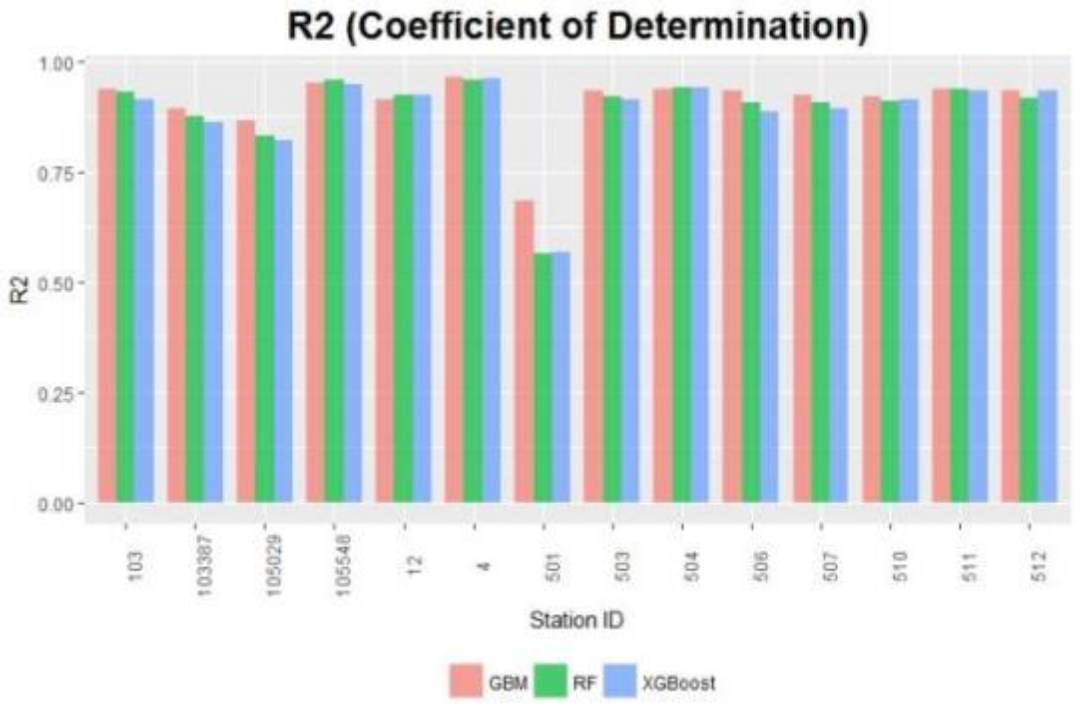
Model Results

- Results exceed the survey expectation: ETCR<10%
- When compared with linear regression:
  - Reduced MAPE by almost 60%
  - Reduced ETCR by almost 30%
  - Increased median R^2 by more than 10%

Model	Overall MAPE	Overall ETCR	Median R2
RF	17.8%	5.2%	0.92
GBM	18.3%	4.8%	0.93
XGBoost	17.7%	5.3%	0.91
Linear Regression	41.8%	7.2%	0.83

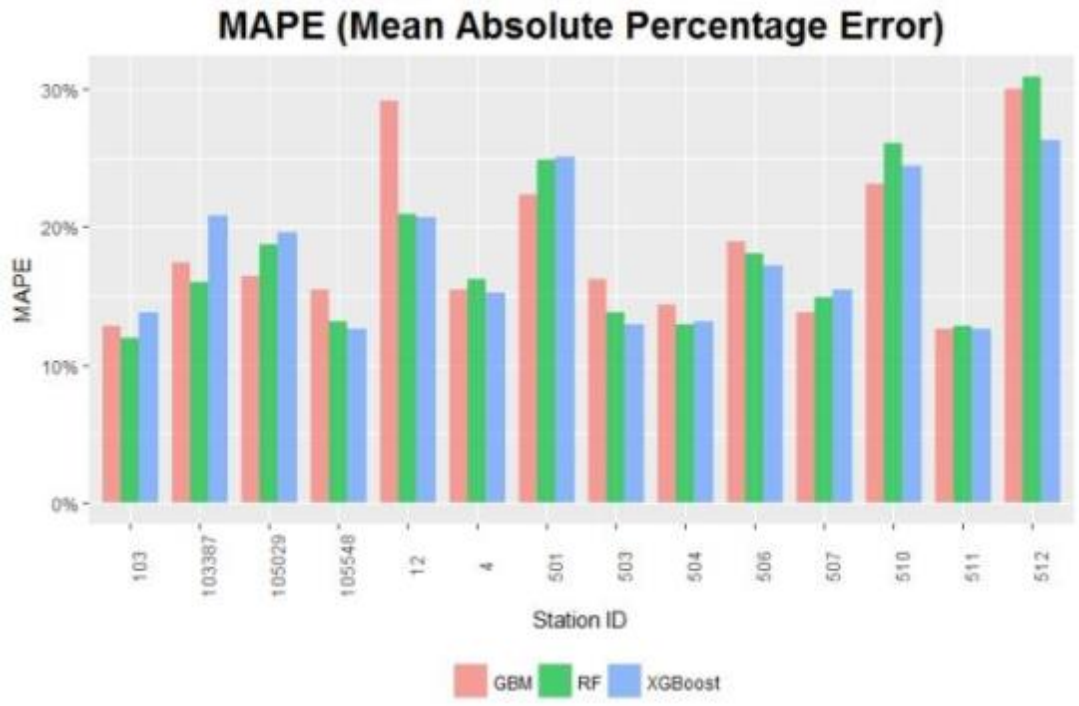
Coefficient of Determination (R^2)

- RF
  - Range: 0.57-0.96
  - Median: **0.92**
- GBM
  - Range: 0.69-0.96
  - Median: **0.93**
- XGBoost
  - Range: 0.57-0.96
  - Median: **0.91**



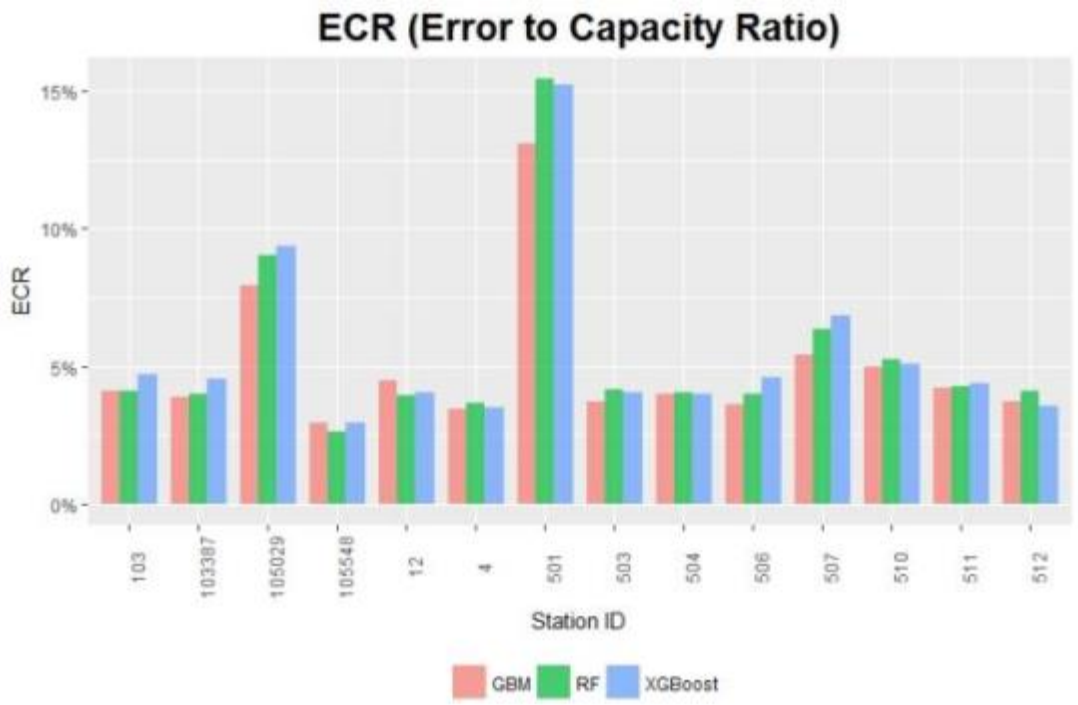
Mean Absolute Percentage Error (MAPE)

- RF
  - Range: 12%-31%
  - Median: **16.1%**
- GBM
  - Range: 13%-29%
  - Median: **16.3%**
- XGBoost
  - Range: 13%-25%
  - Median: **16.3%**



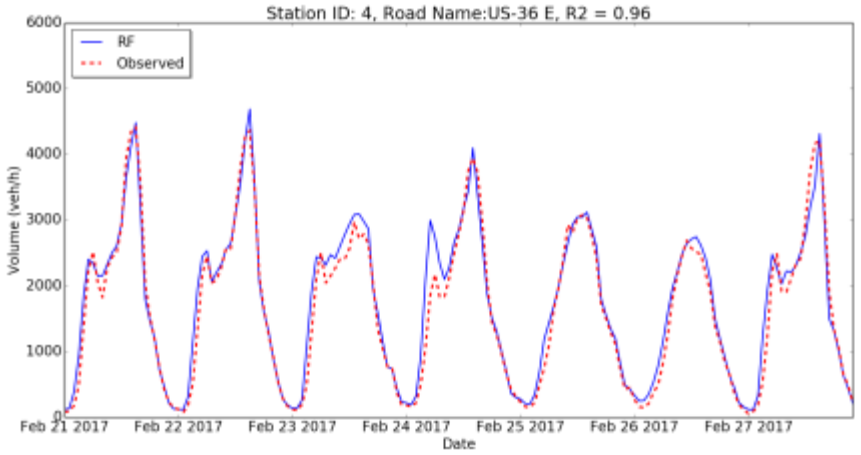
Error to Theoretical Capacity Ratio (ETCR)

- RF
  - Range: 2.6%-15.4%
  - Median: **4.1%**
- GBM
  - Range: 2.9%-13.0%
  - Median: **4.0%**
- XGBoost
  - Range: 3.0%-15.2%
  - Median: **4.5%**

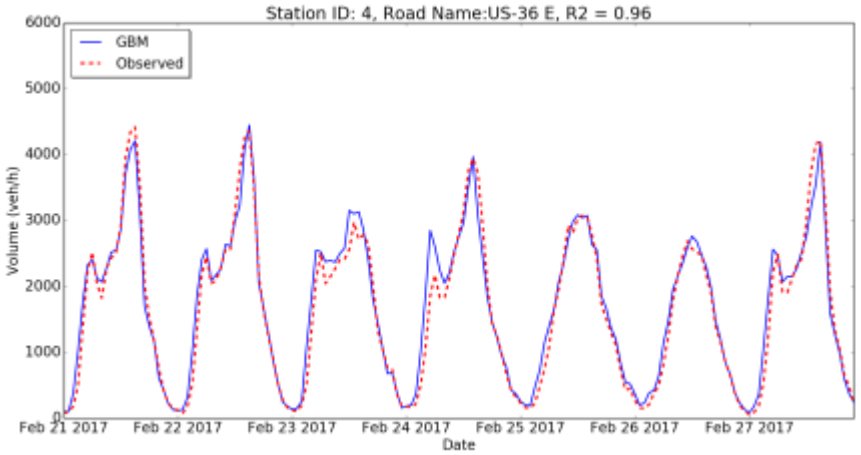


Prediction vs. Observation (Highest R^2)

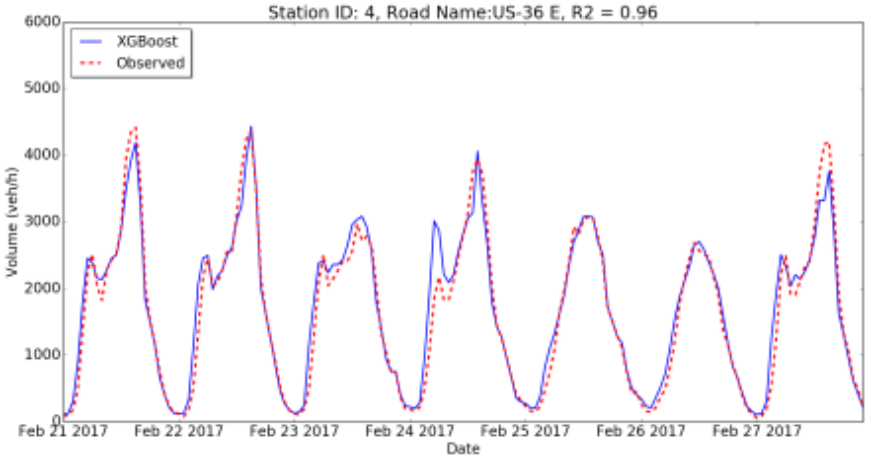
RF



GBM

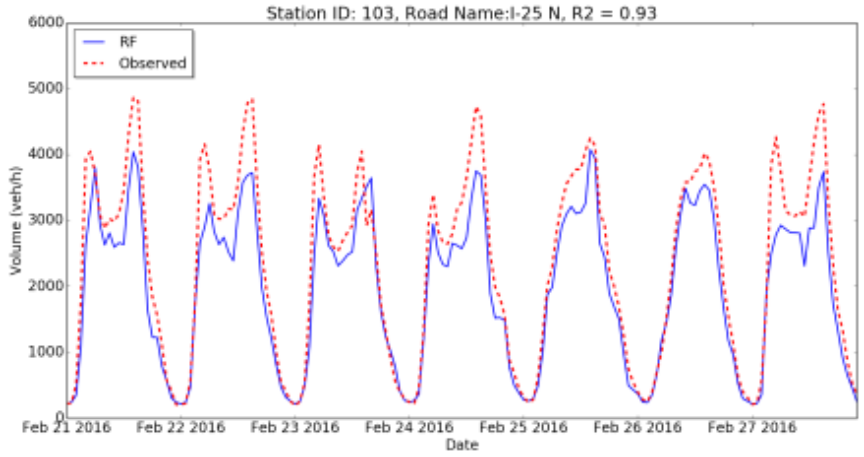


XGBoost

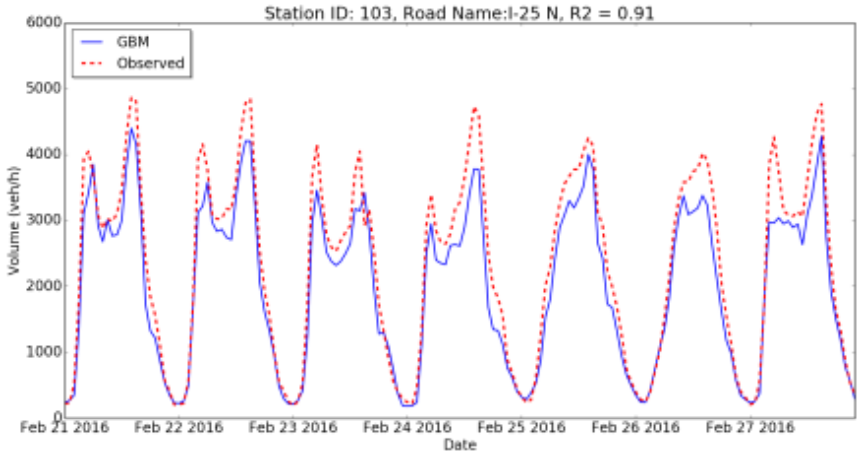


Prediction vs. Observation (Median R^2)

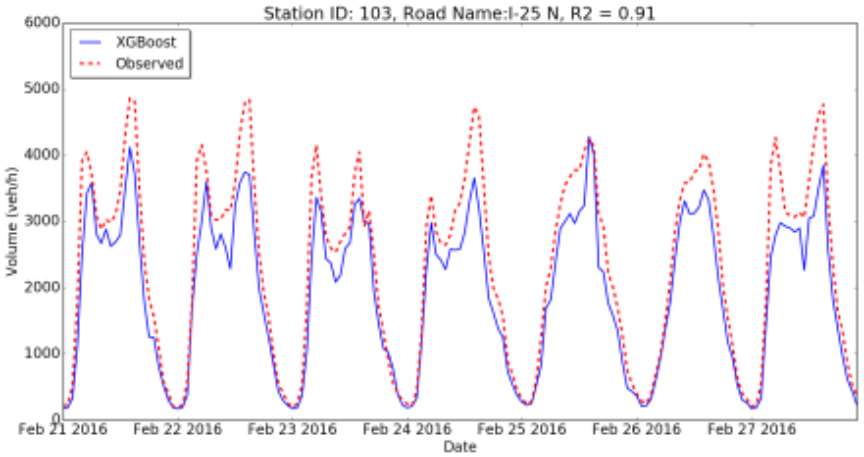
RF



GBM

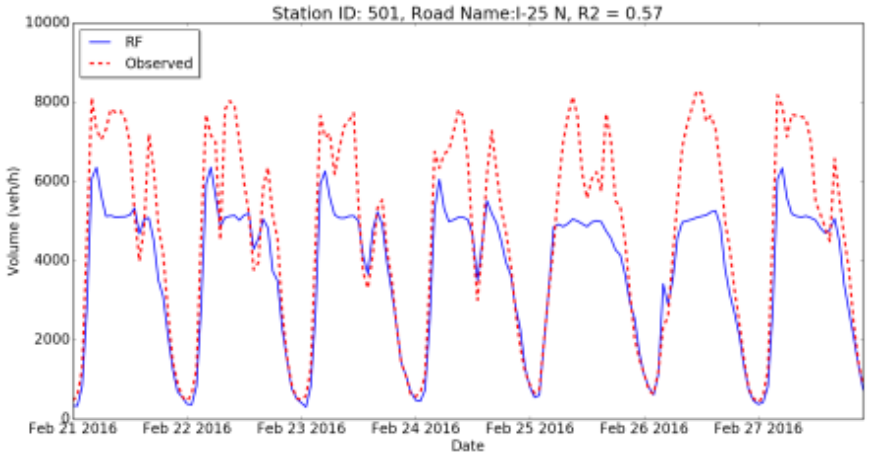


XGBoost

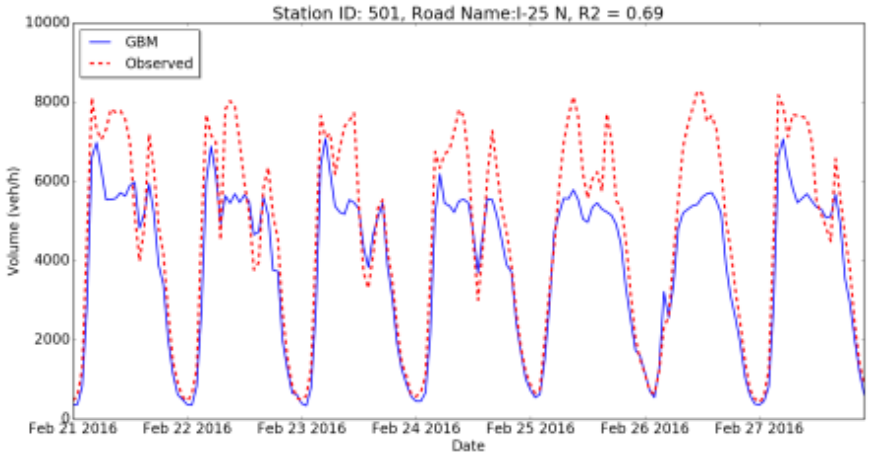


Prediction vs. Observation (Lowest R^2)

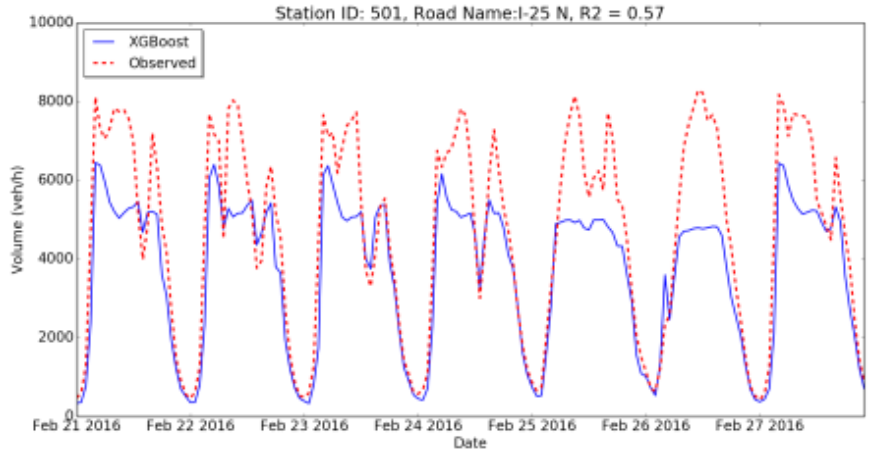
RF



GBM



XGBoost



Contribution of Probe Vehicle Data

- Probe vehicle data has significant impact on volume estimation accuracy

RF

	Overall MAPE	Overall ETCR	Median R^2
All data included	**17.8%**	**5.2%**	**0.92**
With only Probe Data	25.5%	6.4%	0.90
Without Probe Data	35.2%	10.7%	0.70

GBM

	Overall MAPE	Overall ETCR	Median R^2
All data included	**18.3%**	**4.8%**	**0.93**
With only Probe Data	25.7%	6.4%	0.89
Without Probe Data	40.5%	12.1%	0.64

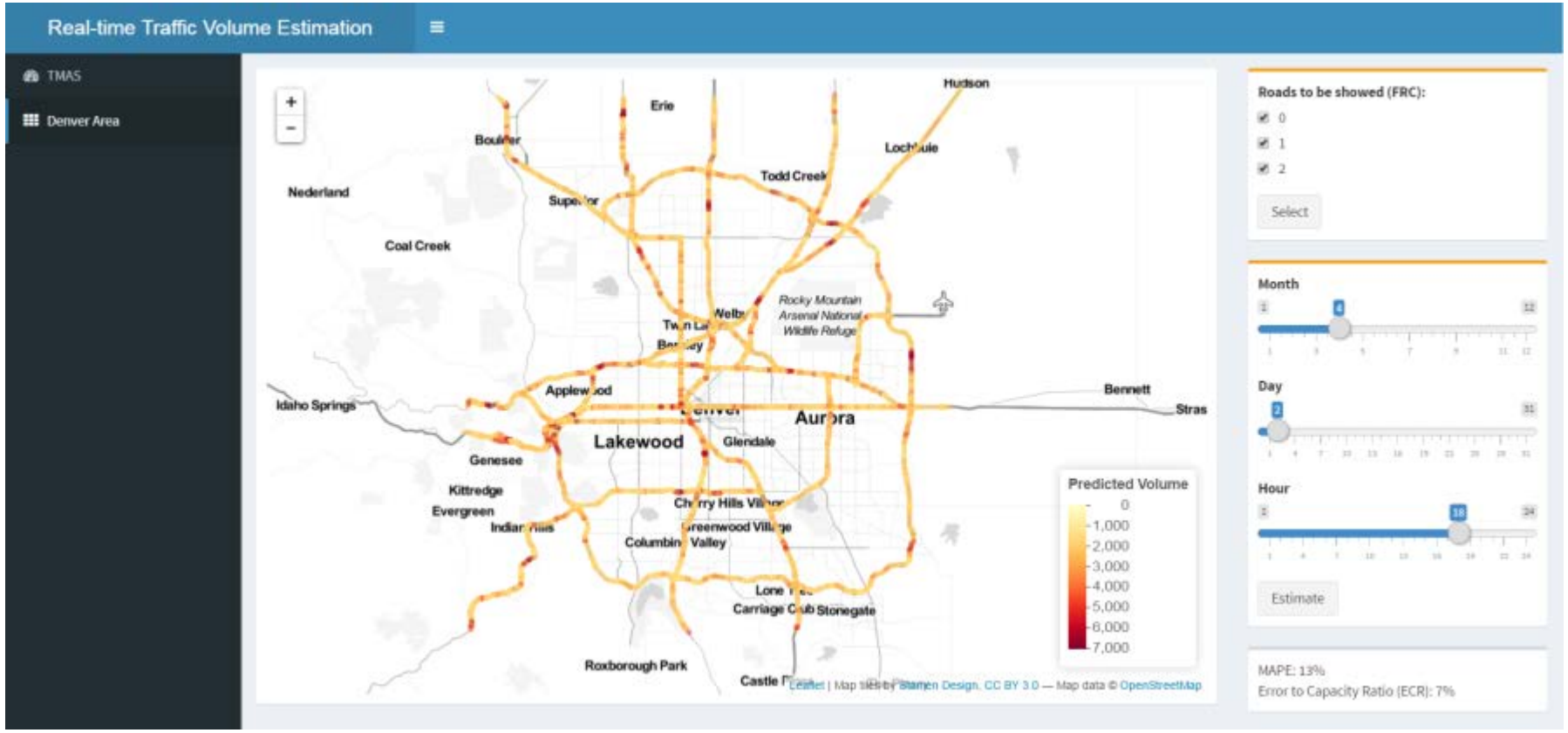
XGBoost

	Overall MAPE	Overall ETCR	Median R^2
All data included	**17.7%**	**5.3%**	**0.91**
With only Probe Data	24.2%	6.4%	0.89
Without Probe Data	39.4%	12.4%	0.65

Summary

- Results satisfy the survey expectation: ETCR<10%
- Improved MAPE by almost 60% when compared with linear regression
- Probe vehicle data has significant impact on volume estimation accuracy
- Has poor performance on unique cases or outlier
- Accuracy can be further improved with more cases or data
- Next step
  - Will scale up to state level with more data
  - Further improve accuracy by trying deep learning

Web App Framework Prototype



Thank You!

Questions?

www.nrel.gov

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.

Poll

1 Having heard the descriptions of the error measures below, which is the most meaningful to you? (select all that apply)

- ❑ R^2 – Coefficient of Determination
- ❑ MAPE – Mean Absolute Percentage Error
- ❑ ETCR - Error to Theoretical Capacity Ratio, where error is calculated with respect to maximum theoretical/observed capacity
- ❑ None of the above

Poll

2 Having heard the descriptions of the error measures below, should the research team consider other error measures?

- R^2 – Coefficient of Determination
- MAPE – Mean Absolute Percentage Error
- ETCR - Error to Theoretical Capacity Ratio, where error is calculated with respect to maximum theoretical/observed capacity

❑ Yes

❑ No

Validation Framework

- Shawn Turner, Texas A&M Transportation Institute (TTI)
  - (979) 845-8829, s-turner@tti.tamu.edu
- Why TTI involvement?
  - Provide 3rd party independent validation of groups that are producing traffic volume estimates (which now include UMD & NREL)
- Smaller-scale MnDOT/TTI research project now finishing up

Validation Framework:
Two-pronged approach - Trust, but Verify

- TRUST
- Self-reported info about model calibration process and results

- High-level description of sample scaling approach (must be non-proprietary and freely distributable)

- Goodness-of-fit or other model calibration statistics (try to standardize)

- VERIFY
- 3rd party independent validation similar to I-95CC travel time validation

- Use existing DOT continuous count stations for benchmark data (that is not yet publicly available)

- Standardized accuracy measures and measure categories (bins in which error results are grouped), similar to I-95CC travel time validation

Trust: Self-Reported Information

- High-level description of sample scaling approach
  - 1-2 pages of text that explains how samples are scaled
  - Build confidence in approach to avoid “black box” perception
  - Avoid overly simplistic marketing text
  - Recognize that details are typically proprietary
- Model calibration information (if applicable)
  - Number of calibration sites
  - Duration/season of calibration data
  - Functional class and geographic representation
  - Frequency distribution of volumes used in calibration
  - Goodness-of-fit statistics (R2, others)

Verify: Benchmark Volume Data

- Similar to I-95CC travel time validation, but no extra collection of benchmark data
- DOTs provide most recent volume data that has not yet been made publicly available
  - Ideally, continuous count location from well-maintained site
  - Ideally, location not used in model calibration

- Need to identify DOTs who can provide benchmark volume data shortly after data has been collected (before it's made public through DOT web site or TMAS)

Verify: Accuracy Measures

- Accuracy when it matters:
  - 10% error at high volume is much different than 10% error at low volume
  - For example:
    - 10% error at 200 vphpl = 20 veh
    - 10% error at 2000 vphpl = 200 veh

- Sliding scale – higher % error acceptable at lower volumes
  - MnDOT planning example

AADT Range	Acceptable % Change	
	Decreasing (-)	Increasing (+)
300 - 999	-20%	+25%
1,000 - 4,999	-15%	+20%
5,000 – 49,999	-10%	+15%
50,000+	-10%	+10%

Verify: Accuracy Measures

- Standardized accuracy measures and measure categories
- Comparing notes with UMD/NREL and assessing best approach
- A possibility:

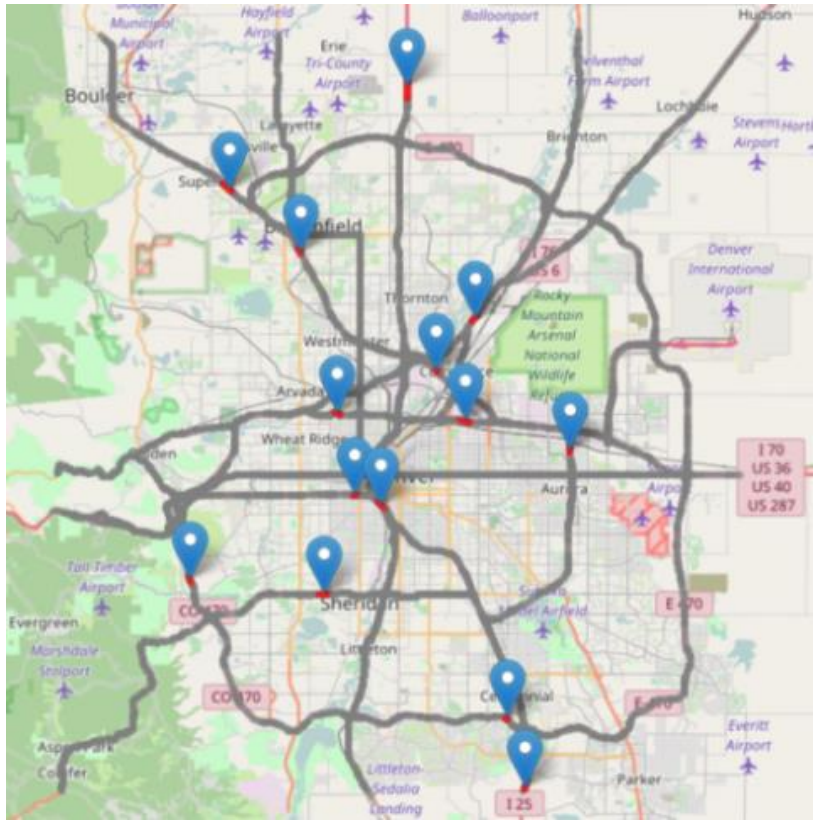
Category	Accuracy Measure #1	Accuracy Measure #2	Accuracy Measure #3
Volume categories (Low, Med, High)	Mean Absolute Percent Error, MAPE (%)	Error-to-Theoretical-Capacity Ratio, ETCR (%)	Mean Signed Error - Bias (Number of Vehicles)
or		or	
% of capacity categories (L, M, H)		Error-to-Maximum-Flow Ratio, EMFR (%)	

Next Steps

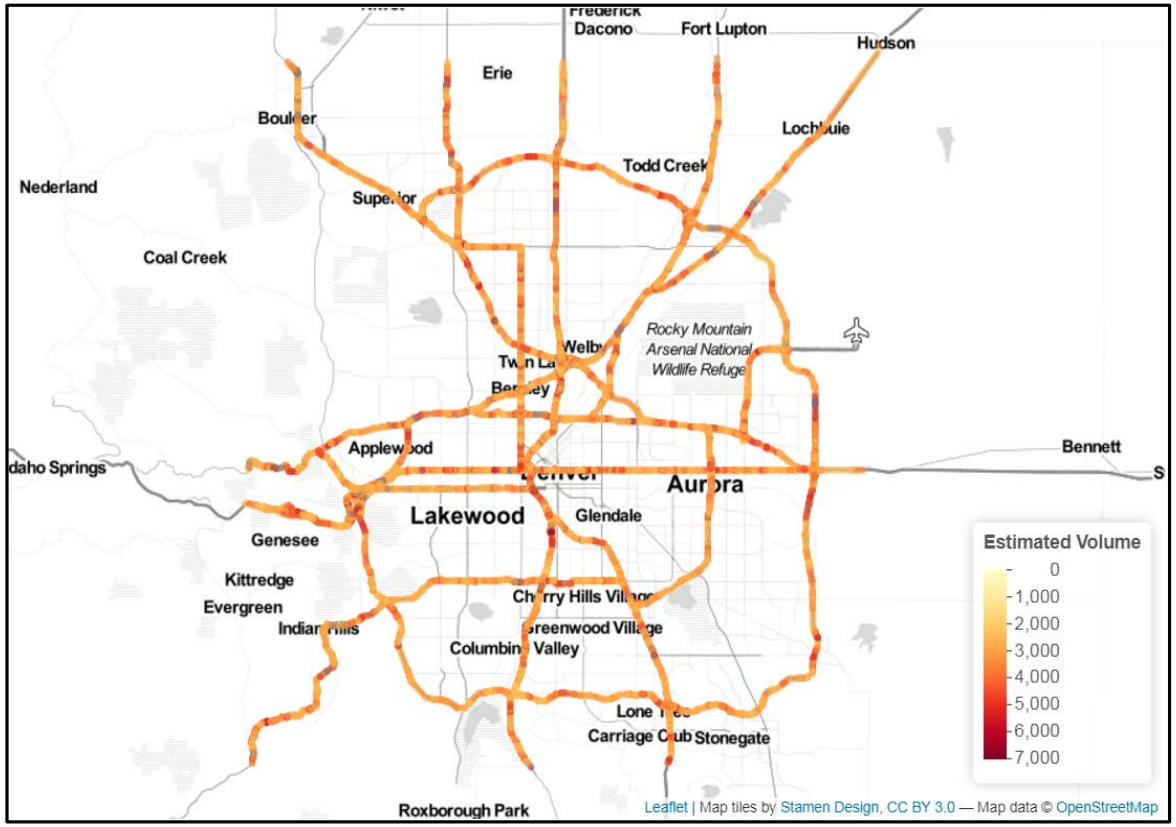
- Gather initial feedback (today)
- Identify available benchmark DOT continuous count data
  - Must be provided to TTI before being made publicly available
- Develop more detail in concept paper
- Gather feedback on concept paper from I-95CC and volume data producers in Sept/Oct
- Develop consensus on validation framework by November

Questions

Wrapping Up



Limited locations, hourly, latent



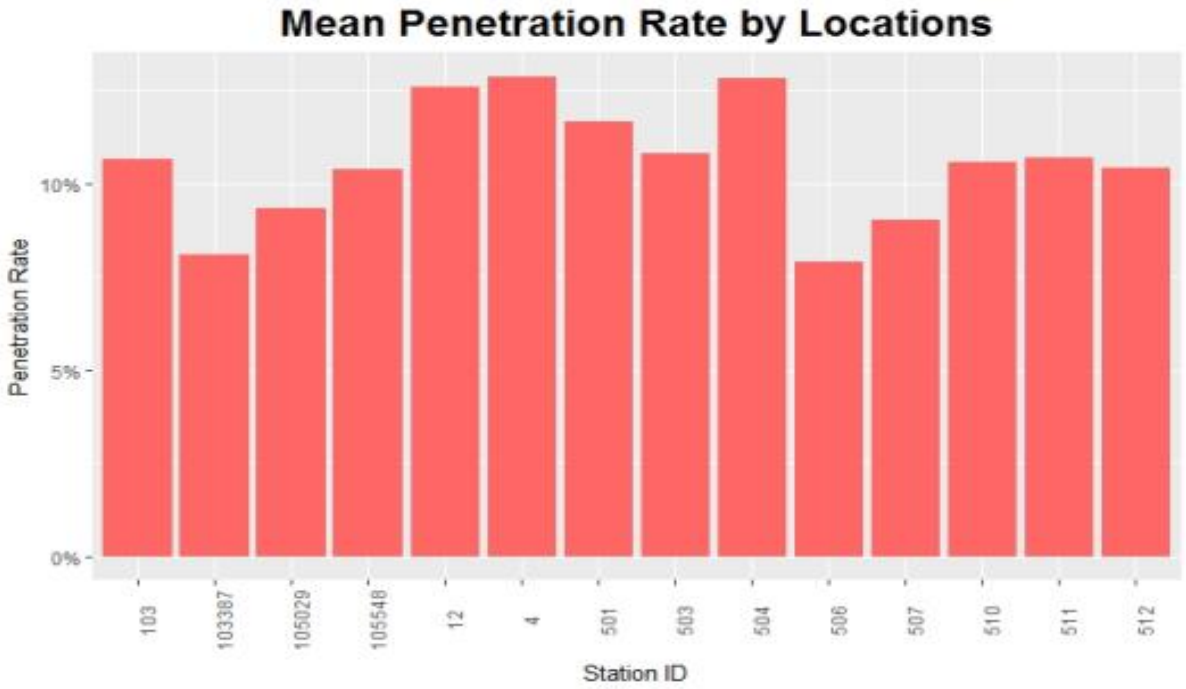
All locations, all time, historic and real-time

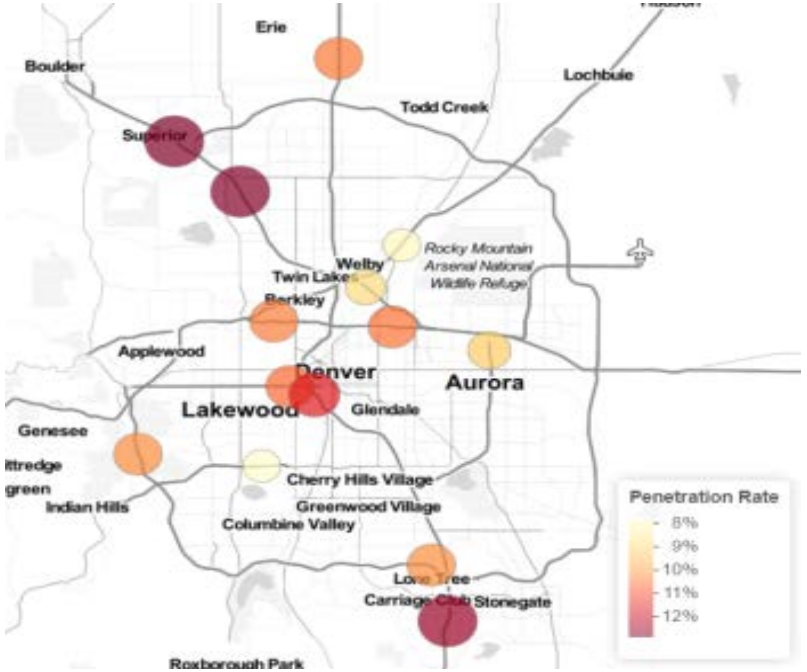
Take Aways – NREL/Colorado Work

- Variation in penetration rates (8% to 12%)
- Large variations in volume, can create problematic outliers
- Volume fluctuation along a roadway a concern
  - Possibly introduce a constrained model

Penetration Rates

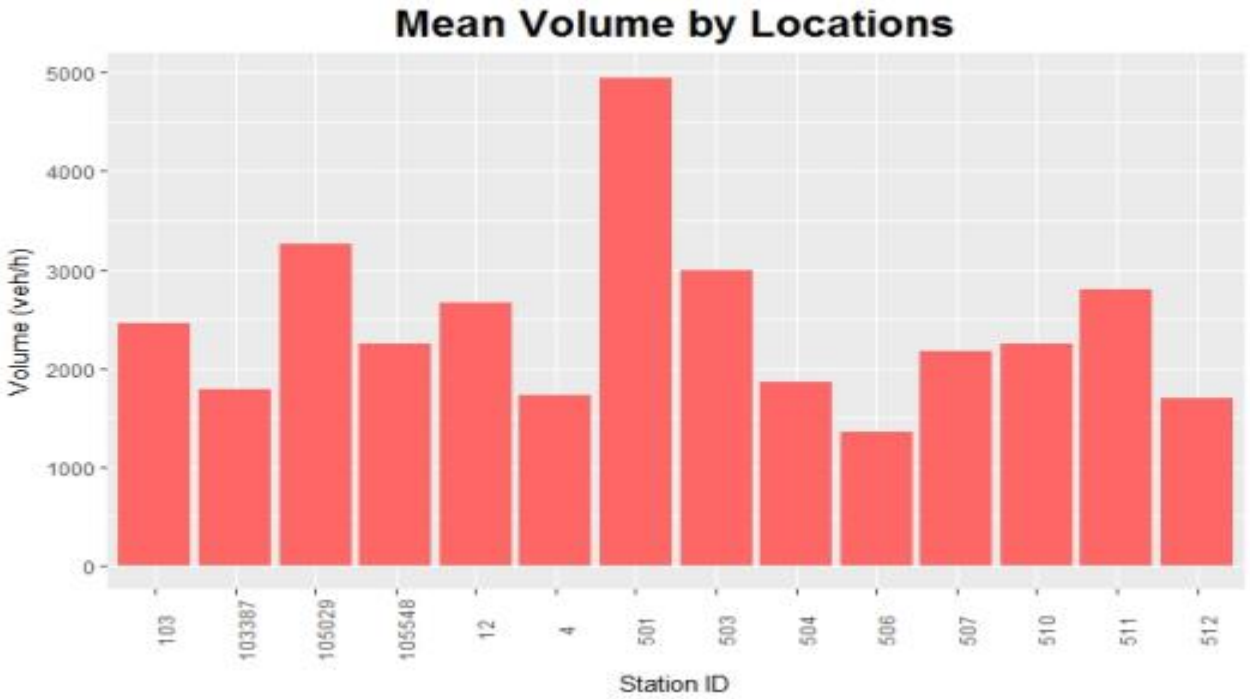
- **Ranges from 8%-12%**

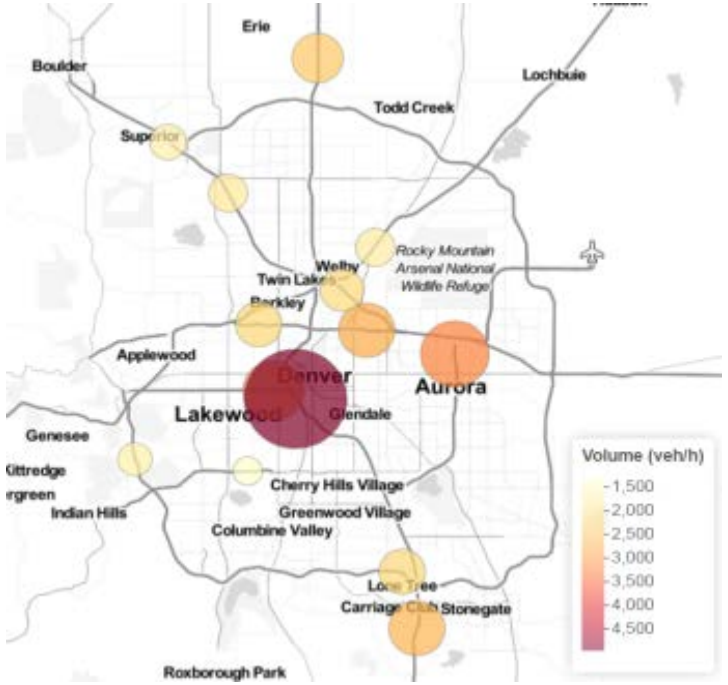




Average Volume

- **All Ranges from 1500-3500 veh/hr except 501**
- **501 is an unique case**

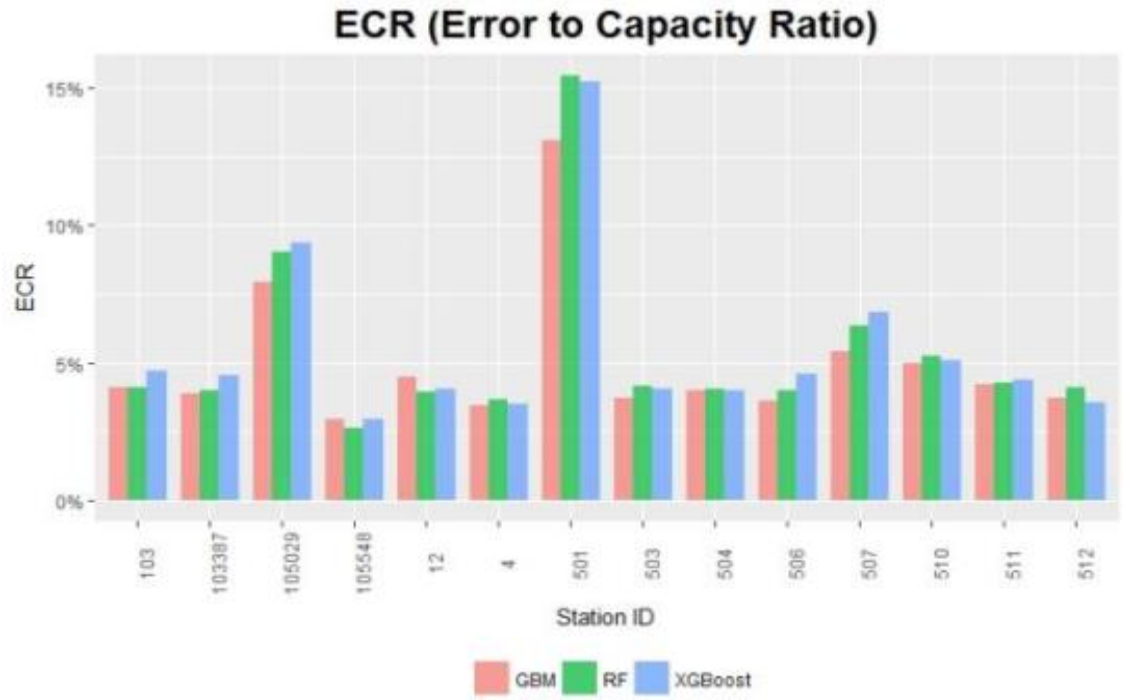




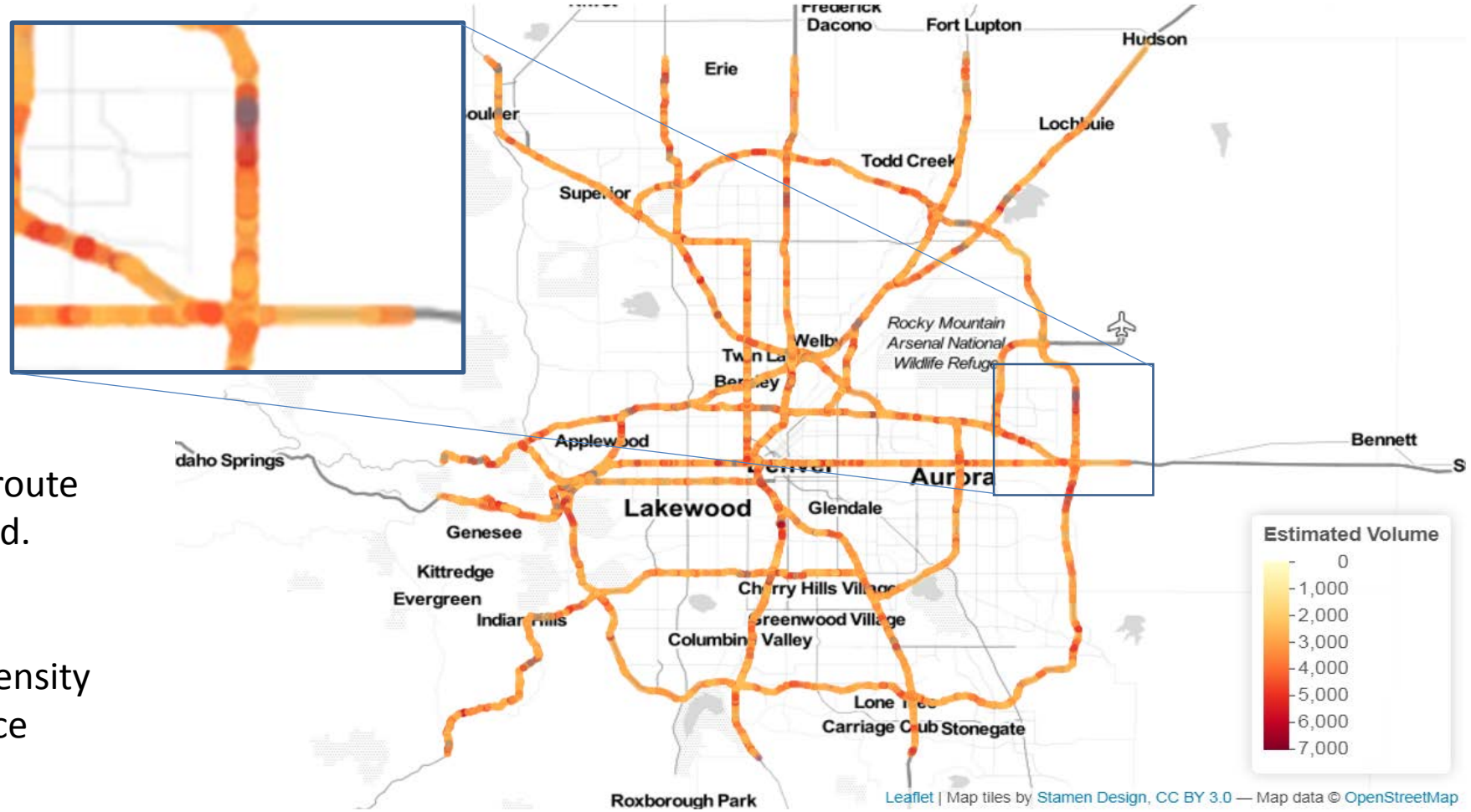
Error to Capacity Ratio (ECR)

- **Volume Outlier had the highest error**

  - RF
    - Range: 2.6%-15.4%
    - Median: **4.1%**
  - GBM
    - Range: 2.9%-13.0%
    - Median: **4.0%**
  - XGBoost
    - Range: 3.0%-15.2%
    - Median: **4.5%**



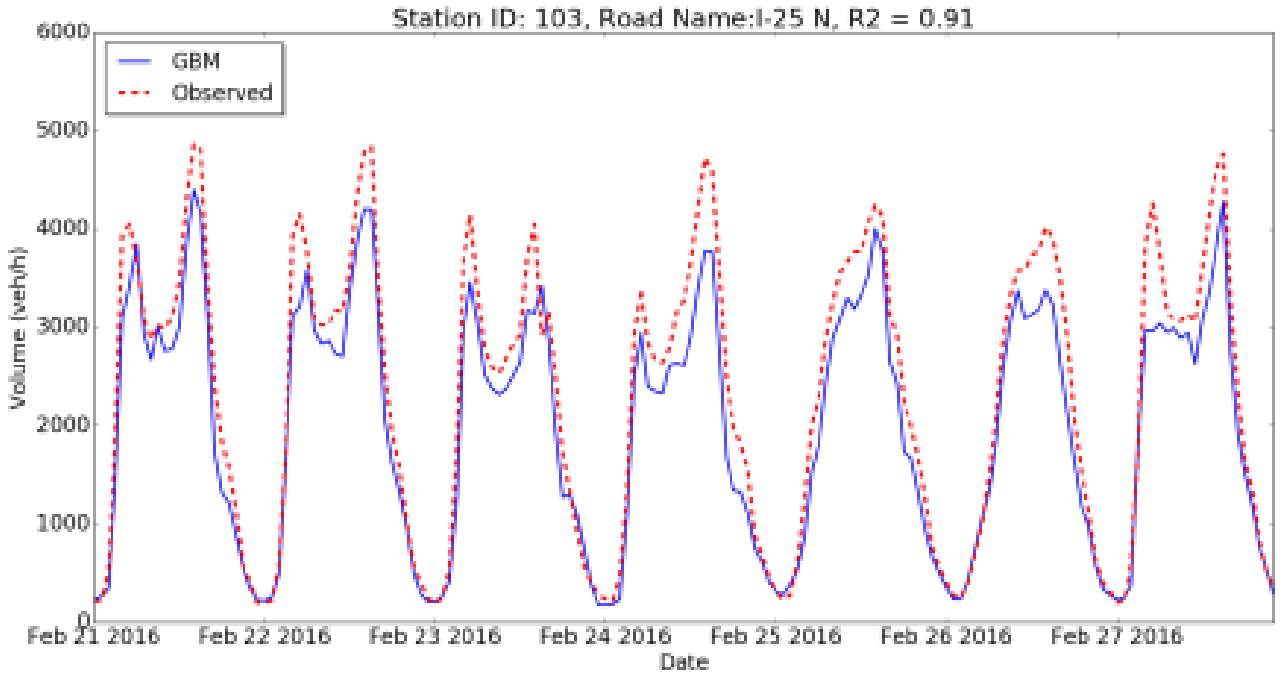
Problem Statement



- Variations along the route need to be considered.
- TMAS provides no calibration data for sequential volume/density
- May need to introduce constrained model

Final Thoughts

- Larger penetration rates helped
- Volume estimates approached ~5% Error to Capacity ratio (ETCR)
- Moving toward a formalized validation approach



Wrap Up

- Next meeting/webinar
  - Thursday, November 9, 2017
  - 10:30a.m. - 12:00p.m. (EST)

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
- UMD PM/Contracts – Kathy Frankle (UMD-CATT) 301-405-8271 or kfrankle@umd.edu
- Logistics –Joanna Reagle (KMJ Consulting, Inc.) 610.228.0760 or jreagle@kmjinc.com