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Microscopic Estimation of Freeway Vehicle Positions Using Mobile Sensors

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Computerized Measurement

- Speed
- Heading
- Acceleration (lateral, longitudinal, vertical)
- Position (from GPS)
- Other diagnostics
  - Wipers on/off
  - Braking status
  - Tire pressure
  - Steering wheel angle
  - Headlights on/off
  - Turn signals on/off
  - Rain sensors
  - Stability control

Vehicle-to-Vehicle Communication: Not Sophisticated

- Hi-tech vehicles
- Low-tech communication with other vehicles
  - Brake lights
  - Turn signals
  - Horn

Vehicle-to-Infrastructure Communication: Not Much Better

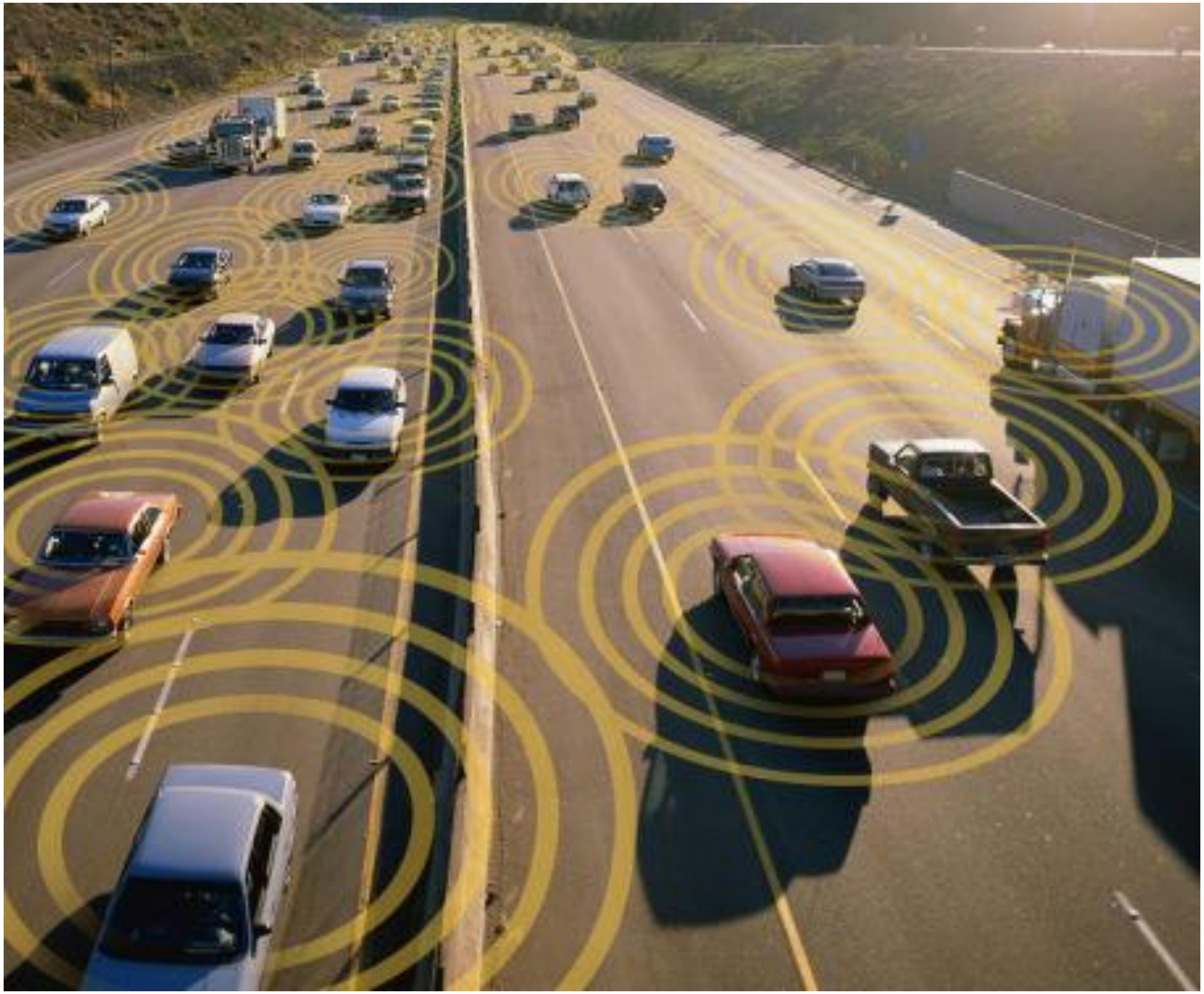
- Important to know where vehicles are and what they're doing
- Lot's of sensors already in the field to detect this

Field Detection

Field Sensor Shortcomings

- Poor data quality
- Point detection, not continuous coverage
- Difficult/expensive to repair = frequent downtime
- Limited types of data
  - – Aggregated speed, density, and volumes at a single point

Solution: Connected Vehicles



Wireless Vehicle Communication

- Significant movement towards wireless communication between vehicles and infrastructure

IntelliDrive[SM]
Safer.
Smarter.
Greener.

Connected Vehicle
Technology Challenge

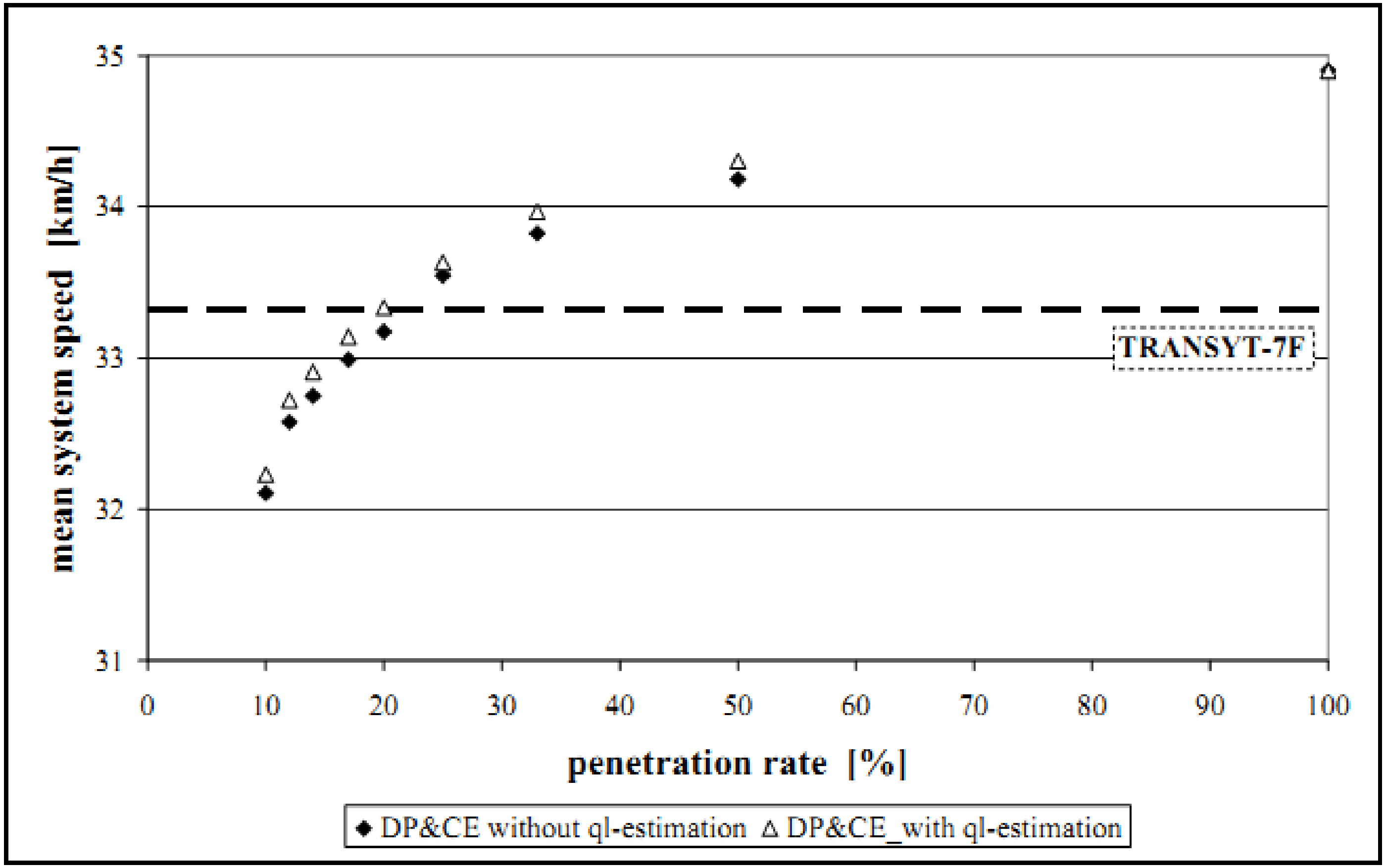
Connected Vehicle Applications

- Lots of connected vehicle mobility applications in development

Application	% Connected Vehicles Needed for Benefits
Traffic signal control	20-30%
Incident detection	20%
Freeway monitoring	2% (supplemented by loop detectors)

- Most of these applications need at least 25% of vehicles to be “connected” to see benefits
- These use data from individual vehicles, NOT aggregated data like speed/density/flow

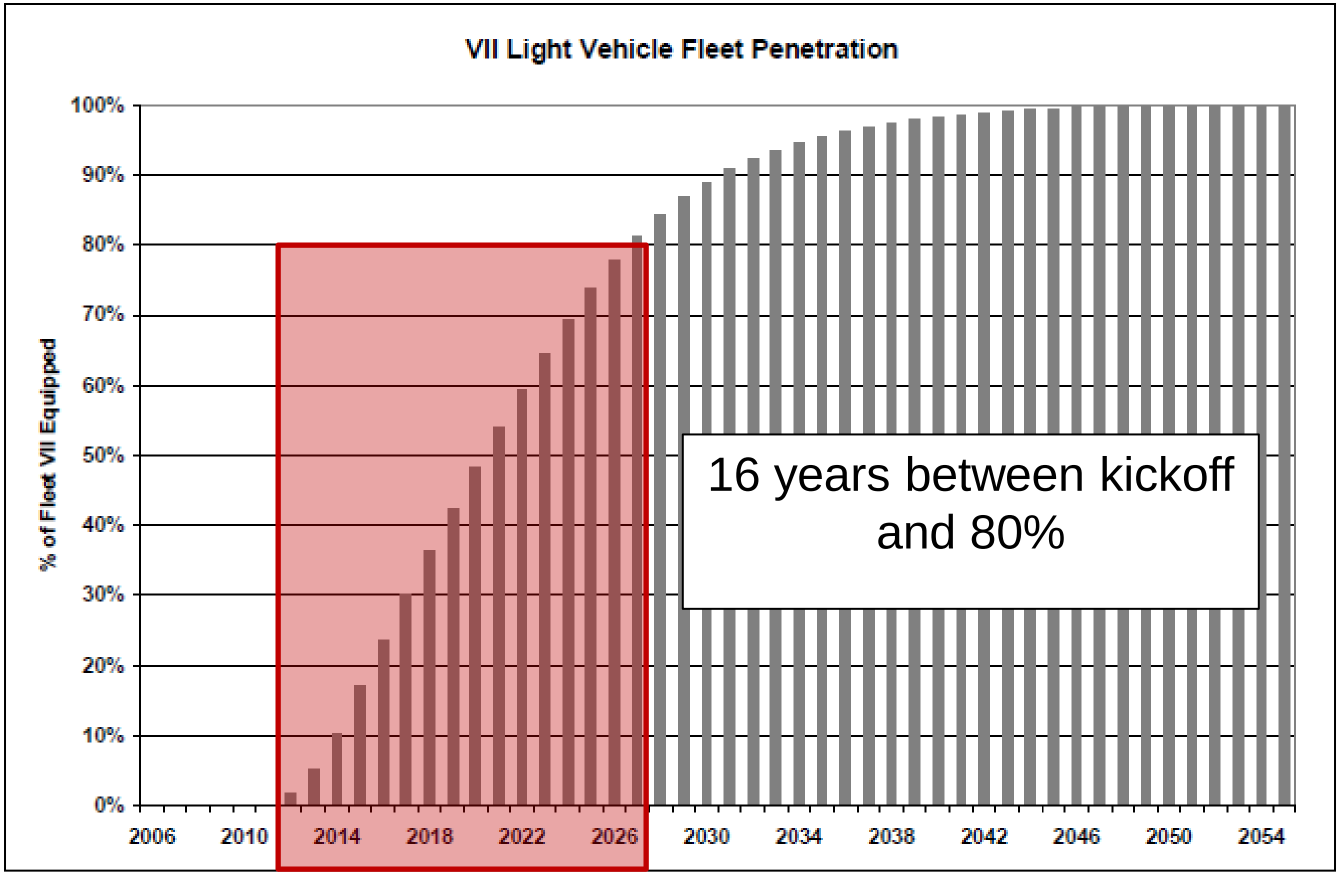
Better Performance with Higher Market Penetration



Premier and Friedrich, "A Decentralized Adaptive Traffic Signal Control Using V2I Communication Data," *Proceedings of the 12th International IEEE Conference on Intelligent Transportation Systems*, October 2009.

Background

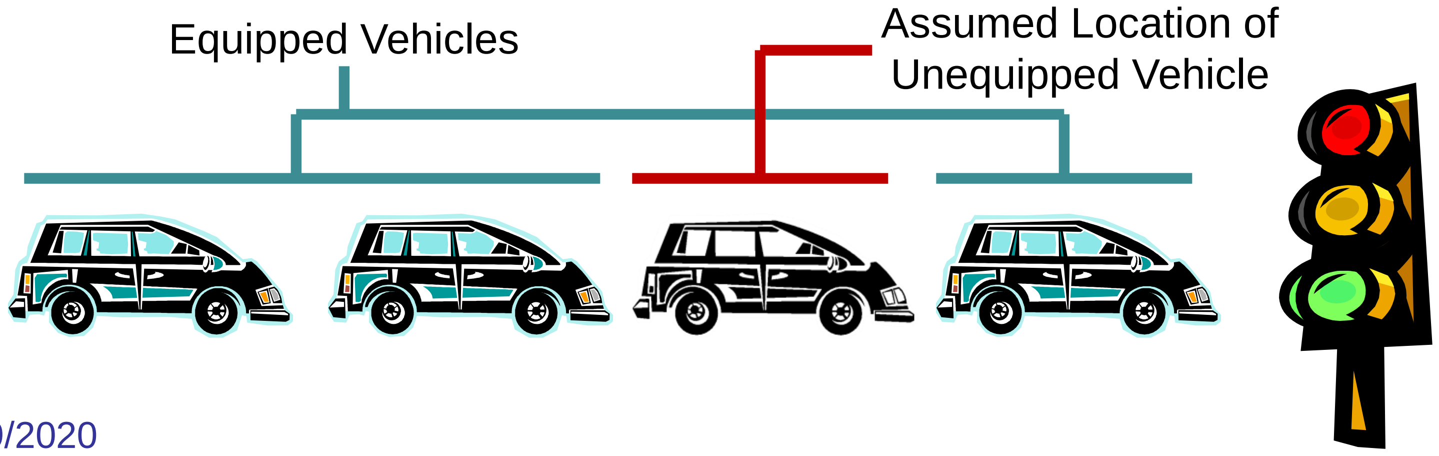
- Rollout of connected vehicles will not be instantaneous



Projected rollout of on-board equipment in US Fleet (Volpe, 2008)

What it Means

- **Problem –** Mobile sensors and connected vehicle data are not constant or ubiquitous. Leads to poor performance of connected vehicle applications.
- **Solution – "Location Estimation"**
  - Behavior of equipped vehicles may suggest location of unequipped vehicles.
  - Can artificially augment real penetration rates.

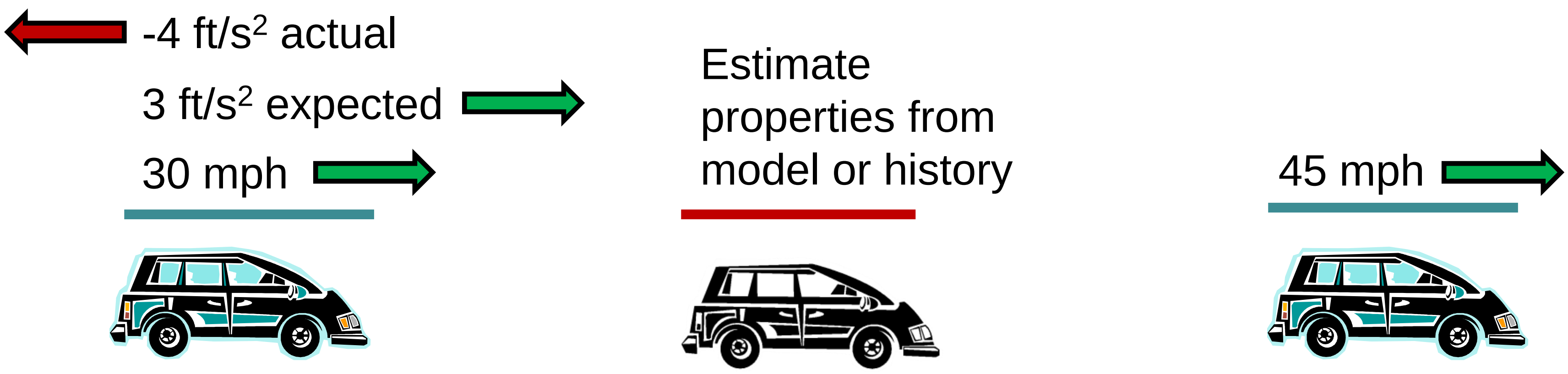


Methodology

- How to estimate vehicle locations
  - Depends on unexpected behavior of equipped vehicles – indicates an unequipped vehicle ahead
  - What is “unexpected”?
  - Car-following model

Algorithm

- Vehicles assumed to follow Wiedemann car-following model
  - Widely accepted, basis for VISSIM
- A deviation from expected acceleration indicates an unequipped vehicle ahead



Vehicle continues to drive according to model, until overtaken

Algorithm Details

- Acceleration threshold: 0.2g less than expected
- Estimate of lead vehicle's speed obtained from empirical observation

$$v_{n-1} = v_n + .162 a_n$$

  - v_{n-1} = speed of estimated leading vehicle (m/s)
  - v_n = speed of equipped trailing vehicle (m/s)
  - a_n = acceleration of equipped trailing vehicle (m/s^2)

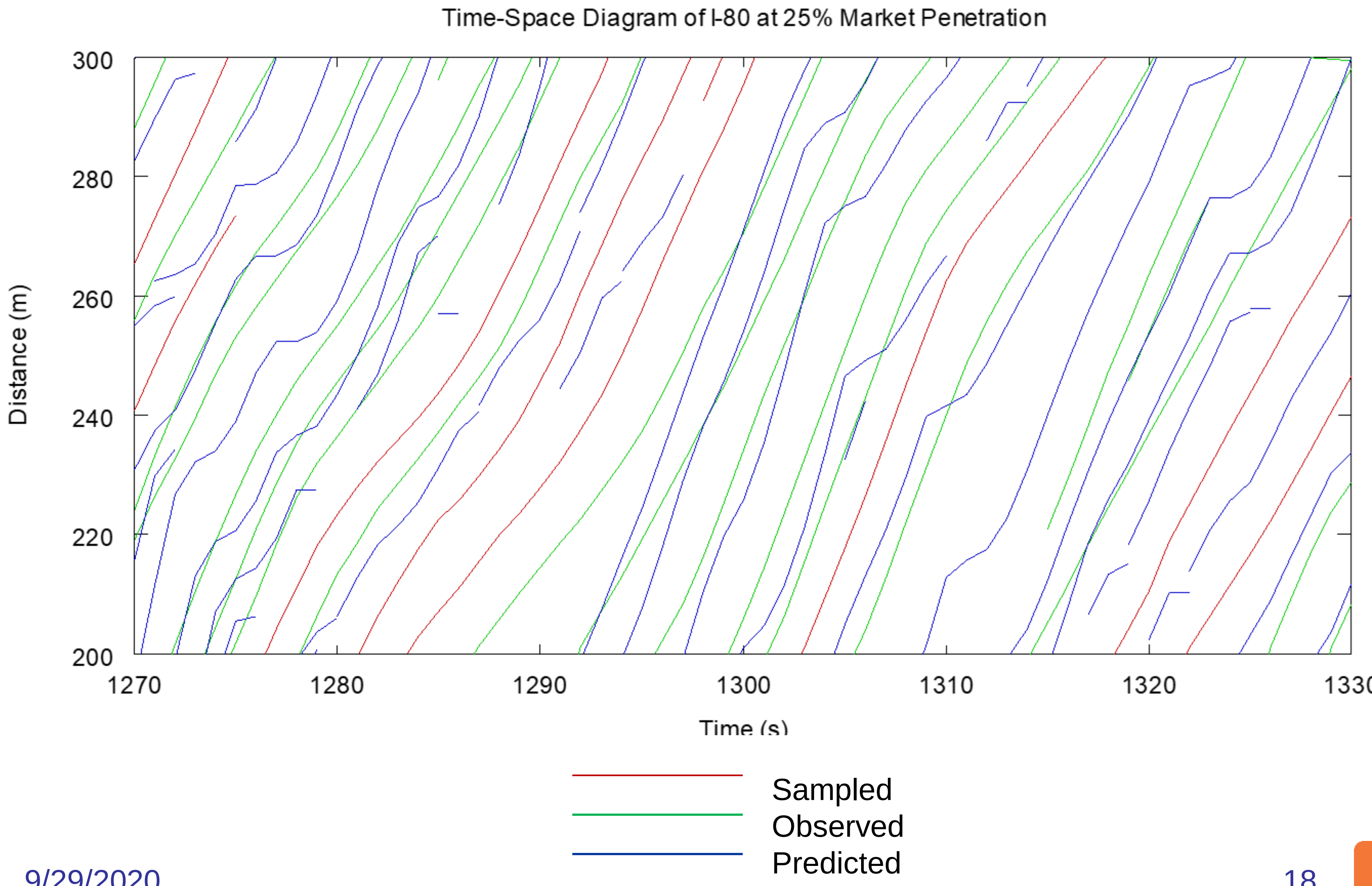
Algorithm Details

- If equipped, trailing vehicle is accelerating
  – Assume trailing vehicle is in “following” regime
- If equipped, trailing vehicle is decelerating
  – Assume trailing vehicle is in “closing” regime

Testing

- Using NGSIM datasets as ground truth
  - Two freeway segments
  - One arterial
- Calibrated VISSIM model to supplement
  - Rt 50 in Chantilly

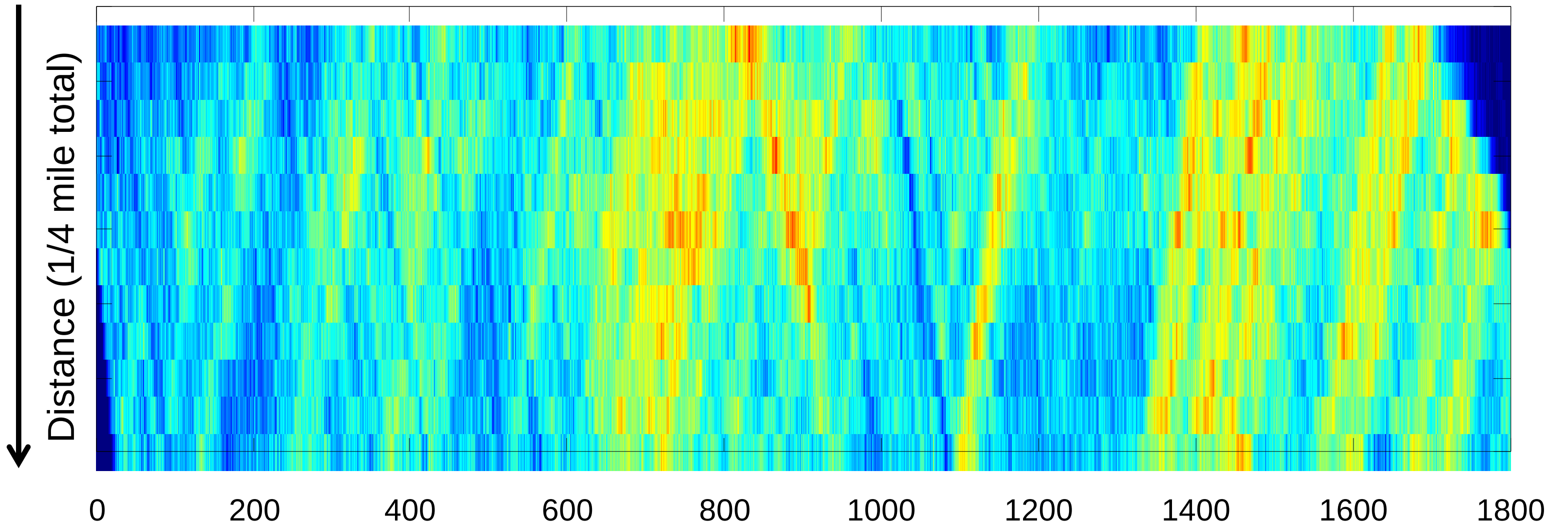
Results



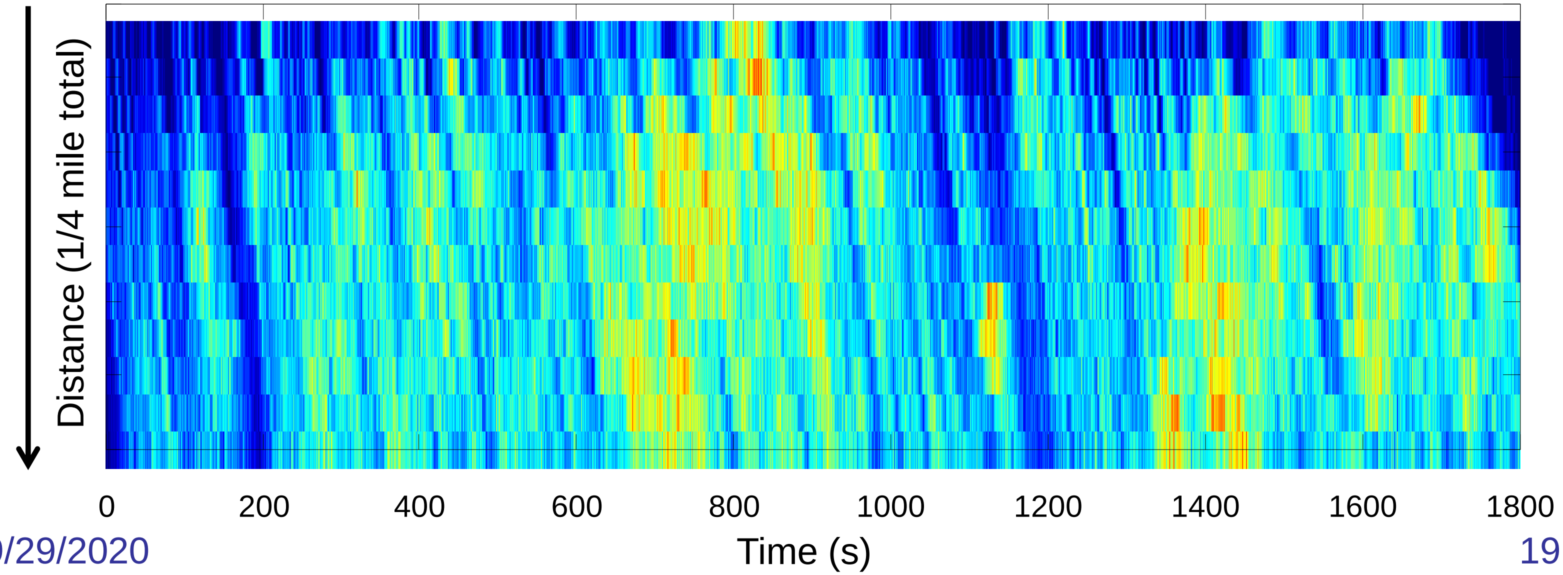
Time-Space Diagram of I-80 at 25% Market Penetration
300
280
260
240
220
200
Distance (m)
1270
1280
1290
1300
1310
1320
1330
Time (s)
Sampled
Observed
Predicted

Densities Along I-80 at 25% Market Penetration

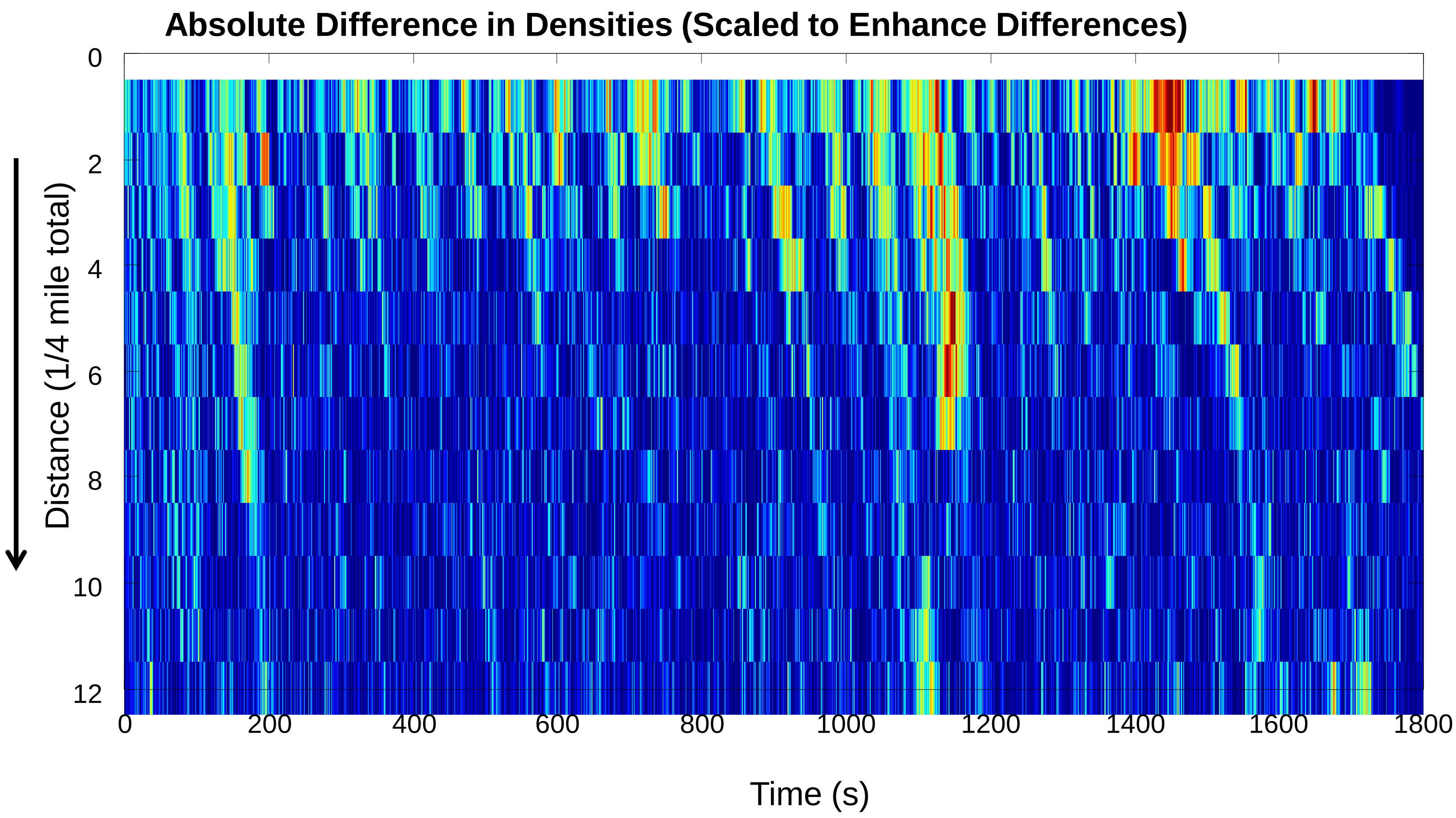
Actual Densities (Sampled and Observed Vehicles)



Estimated Densities (Sampled and Predicted Vehicles)



Absolute Difference between Observed and Predicted Densities Along I-80 at 25% Market Penetration



Estimates improve downstream, as the model populates itself

Metrics

- Not a one-to-one correlation between estimates and observed
- Need to determine which estimate belongs to which observation

My Approach

For all vehicles on a single lane at a single second, calculate distances

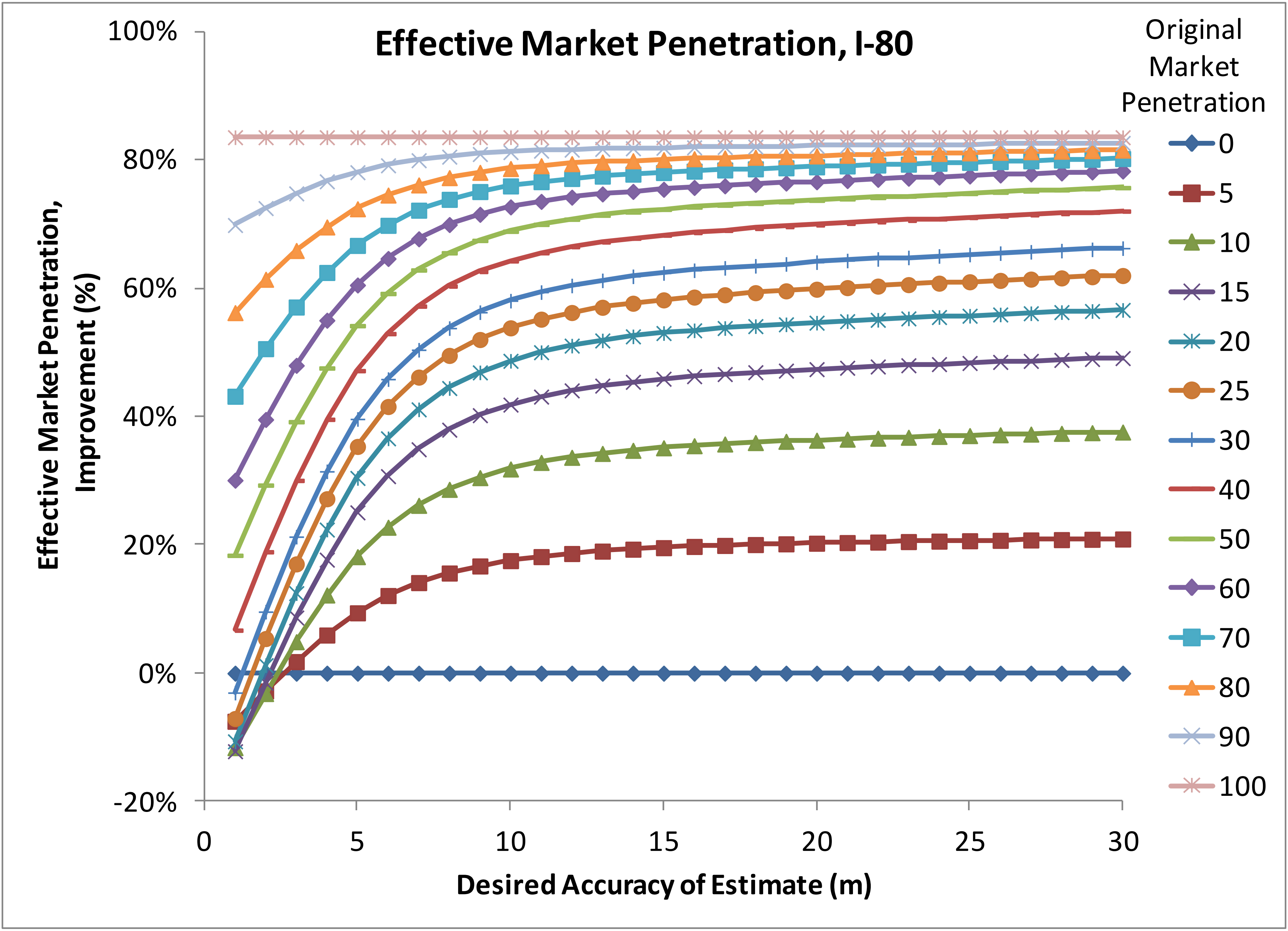
Distances		Estimated Vehicles					
		E1	[redacted]	[redacted]	E4	[redacted]	[redacted]
Observed Vehicles	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

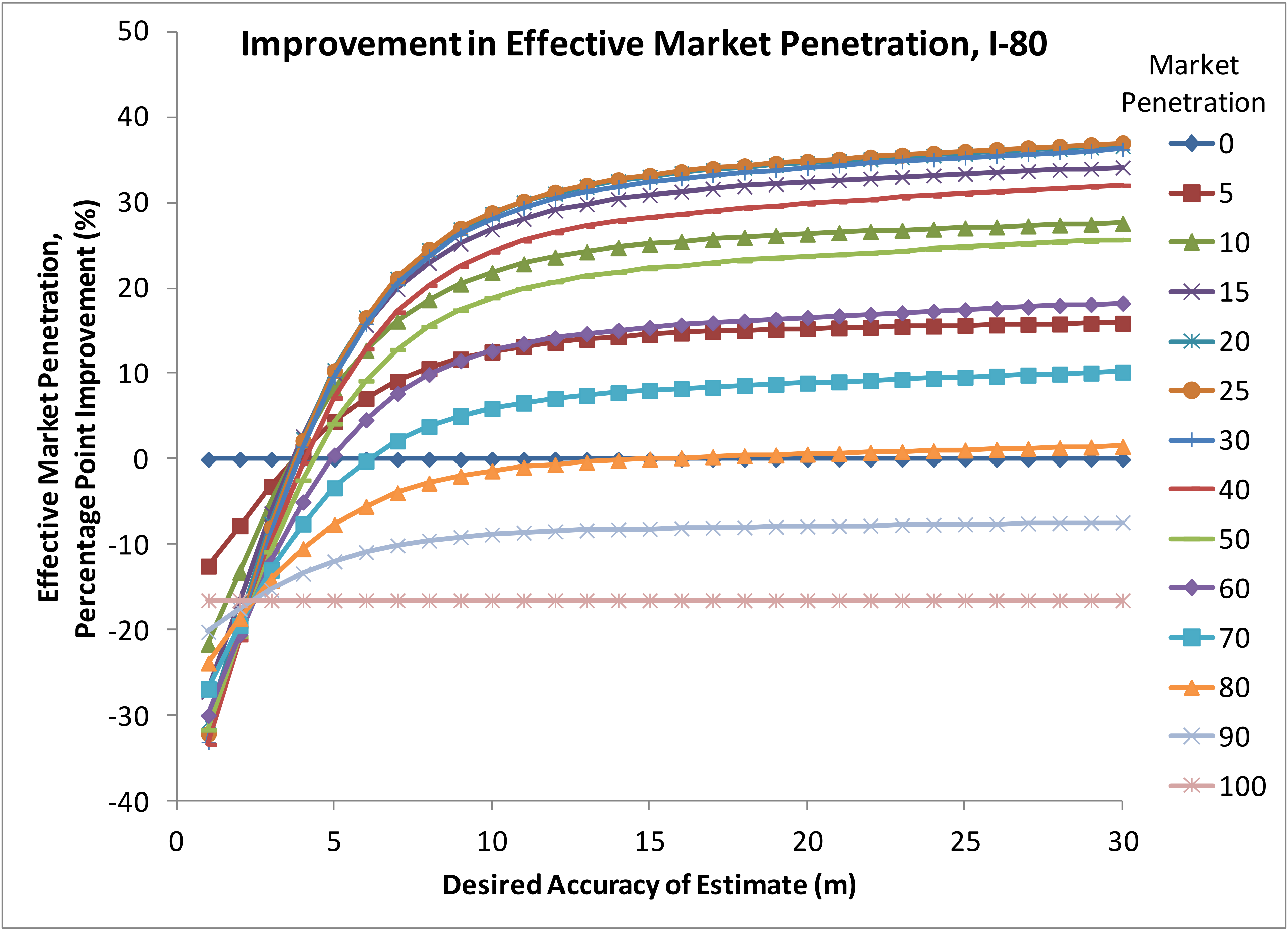
<u>Errors</u>

A3/E5: 1 meter
A1/E6: 2 meters
A2/E3: 6 meters
A4/E2: 16 meters
E1: infinite
E4: infinite

Effective Market Penetration =

$$\frac{\text{Accurate Estimates} - \text{False Estimates} + \text{Sampled (Known) Vehicles}}{\text{Total Actual Vehicle-Seconds}}$$


Effective Market Penetration, I-80
Effective Market Penetration, Improvement (%)
Desired Accuracy of Estimate (m)
Original Market Penetration
0
5
10
15
20
25
30
40
50
60
70
80
90
100
100%
80%
60%
40%
20%
0%
-20%
0
5
10
15
20
25
30


Improvement in Effective Market Penetration, I-80
Effective Market Penetration, Percentage Point Improvement (%)
50
40
30
20
10
0
-10
-20
-30
-40
0
5
10
15
20
25
30
Desired Accuracy of Estimate (m)
Market Penetration
0
5
10
15
20
25
30
40
50
60
70
80
90
100

Challenges

- Not all estimations are of the same quality
  - More confidence in a gap in a queue than unexpected behavior in free flow traffic
- Arterials provide another challenge - vehicle not always reacting to another vehicle
  - Driveways
  - Turning movements
  - Pedestrians

Conclusions

- The algorithm can predict the locations of some unequipped vehicles at various levels of accuracy, especially during and after congestion
- Reliance on a car-following model limits the algorithm to freeways
- More sophisticated techniques needed for surface streets

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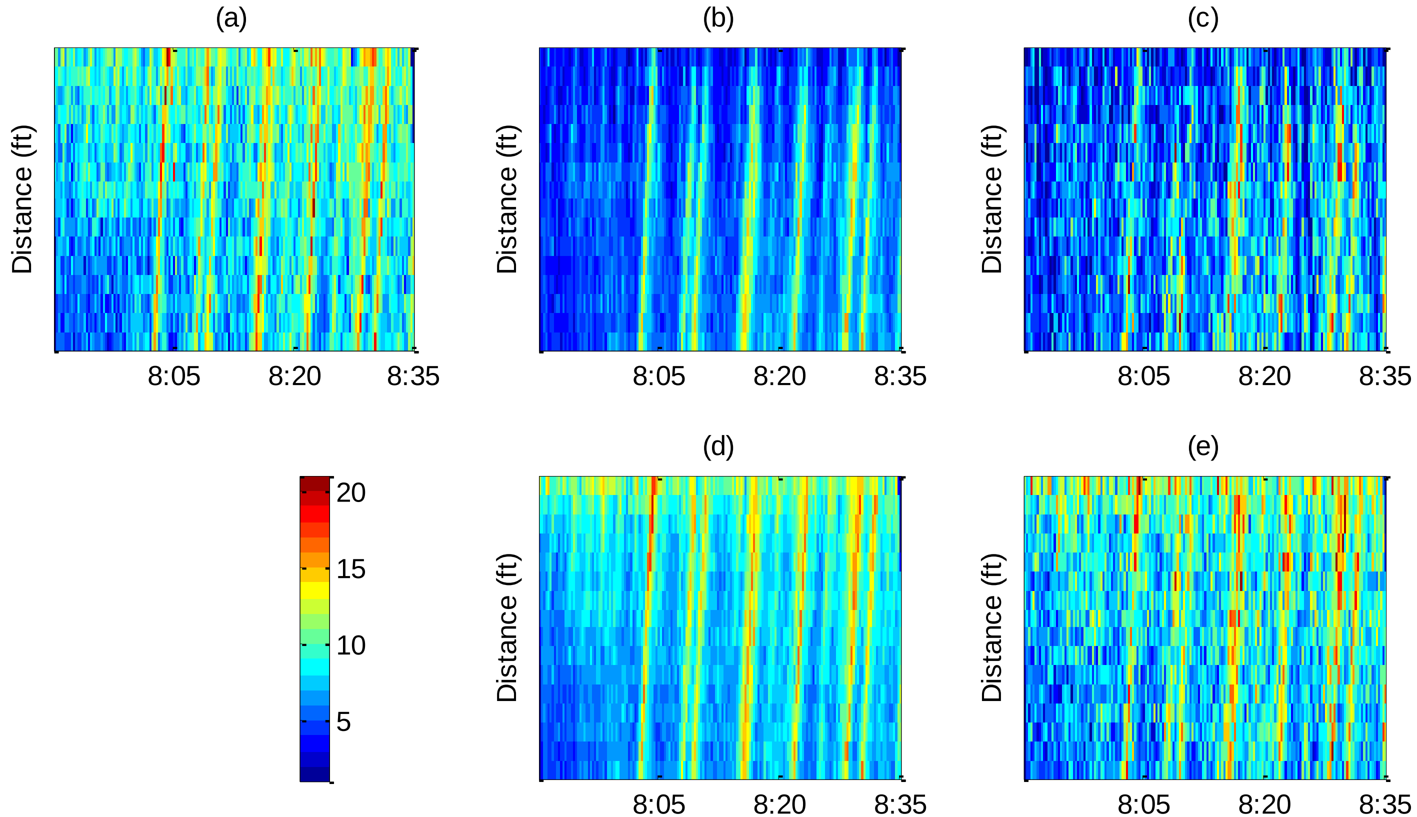
Preliminary Results: Predicting Locations with 25% Market Penetration



Number of vehicles in each of 120-foot long cells during each second of the NGSIM data set for (a) ground truth, (b) mobile sensors only averaged over twenty repetitions, (c) mobile sensors only for a single repetition, (d), detector-supplemented averaged over twenty repetitions, and (e) detector-supplemented for a single repetition. In each scenario, 25% of vehicles were able to transmit their locations and speeds once per second.