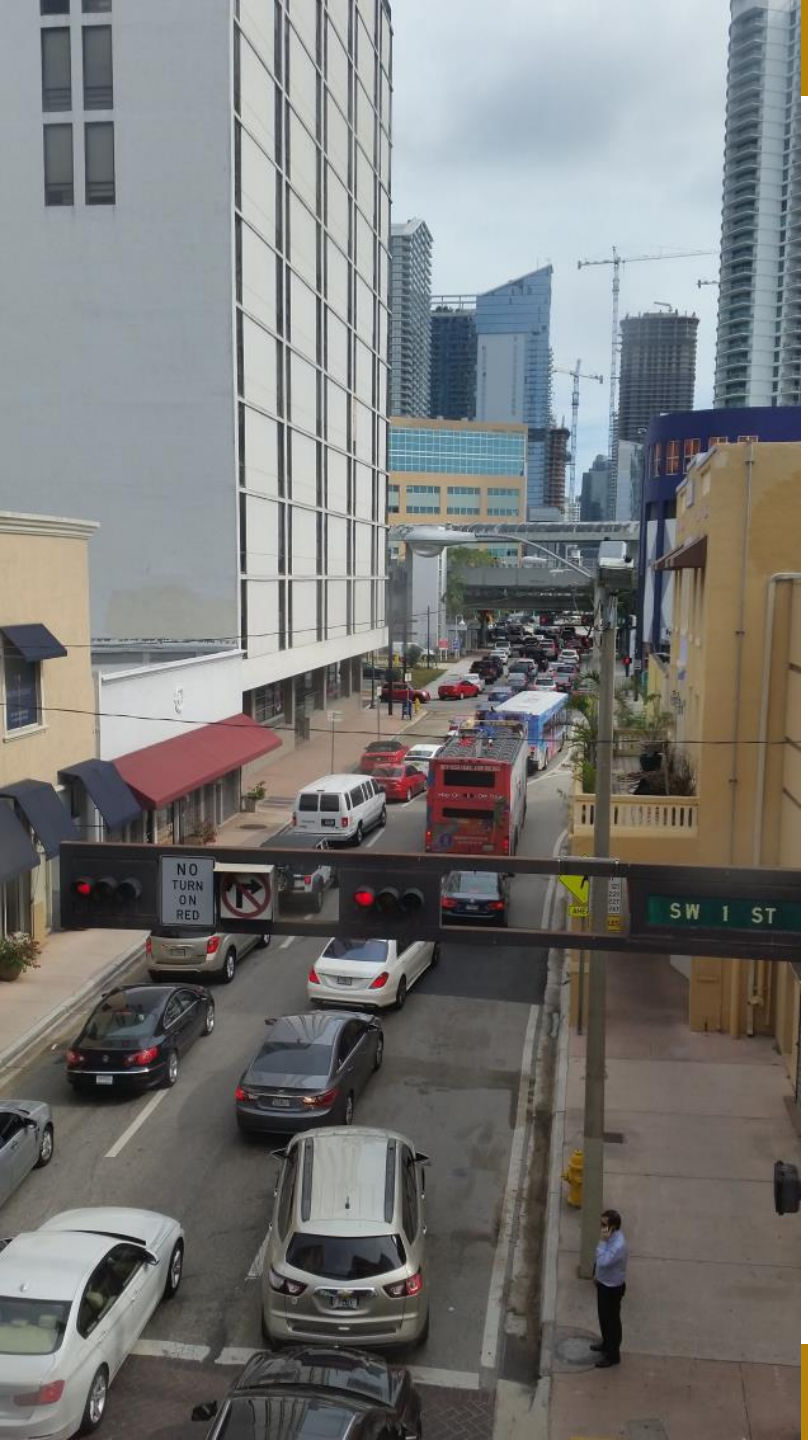


Putting High-Resolution Data to Work

Chris Day, P.E., Ph.D.

Sunday, May 1, 2016

Miami, Florida – NATMEC 2016

PURDUE
UNIVERSITY

Agenda

1st Session

- Motivation for Signal Performance Measures
- Background on Data
- System Needs
- Performance Measures for Communications and Detection
- Performance Measures for Capacity Allocation

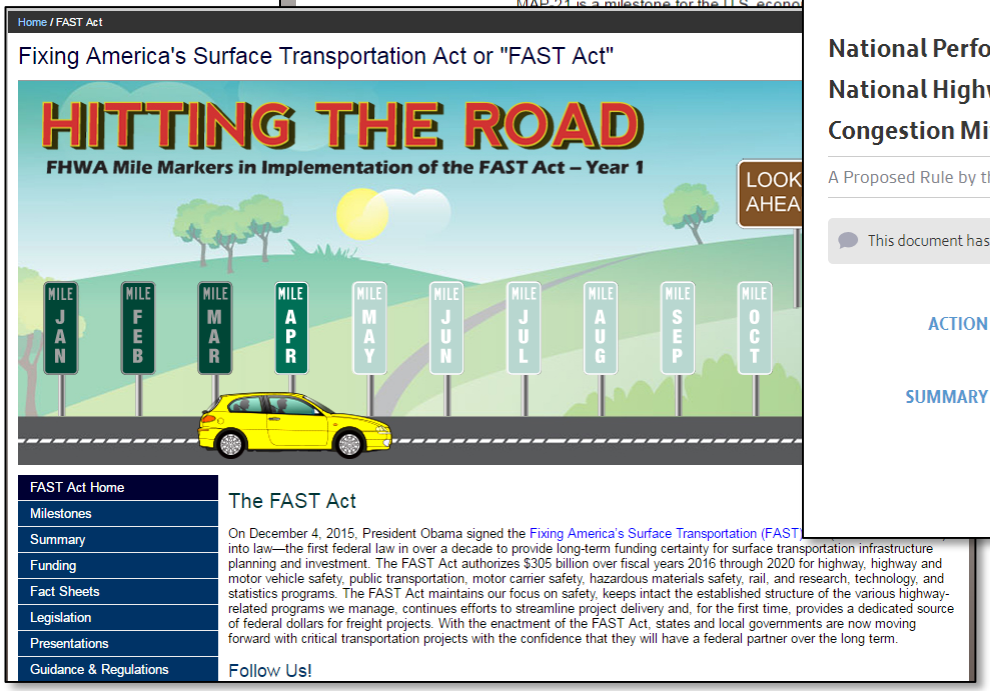
2nd Session

- Performance Measures for Signal Progression
- Case Study #1 – Freeway Detour onto Rural/Suburban Arterials
- Case Study #2 – Five-Year Longitudinal Analysis
- Nationwide Implementations

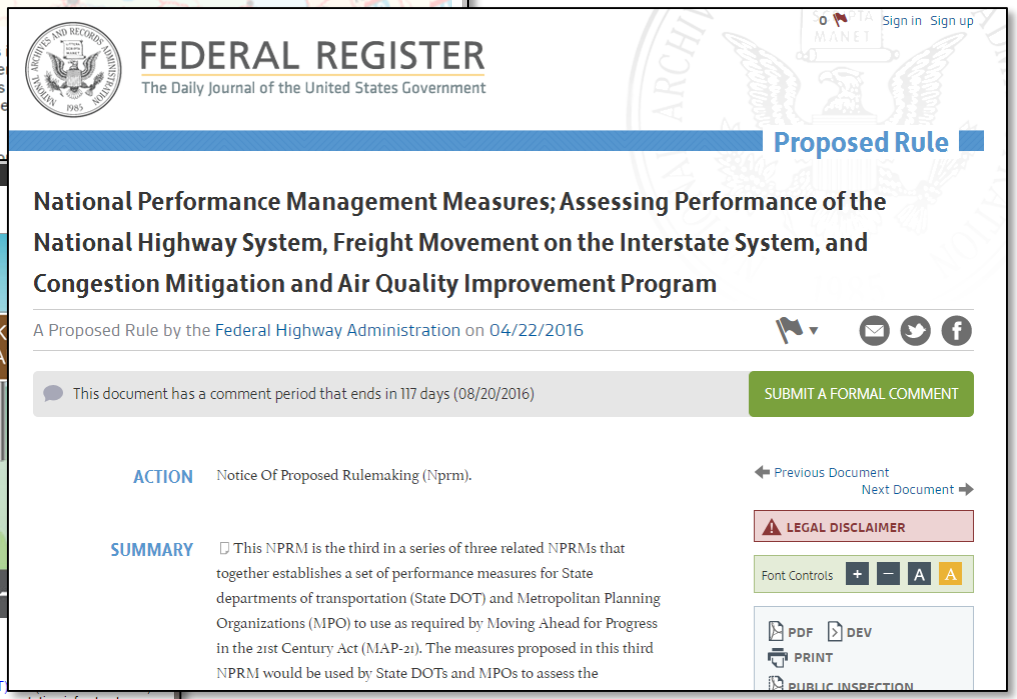
Why Arterial Performance Measures?
1. Policy

2012

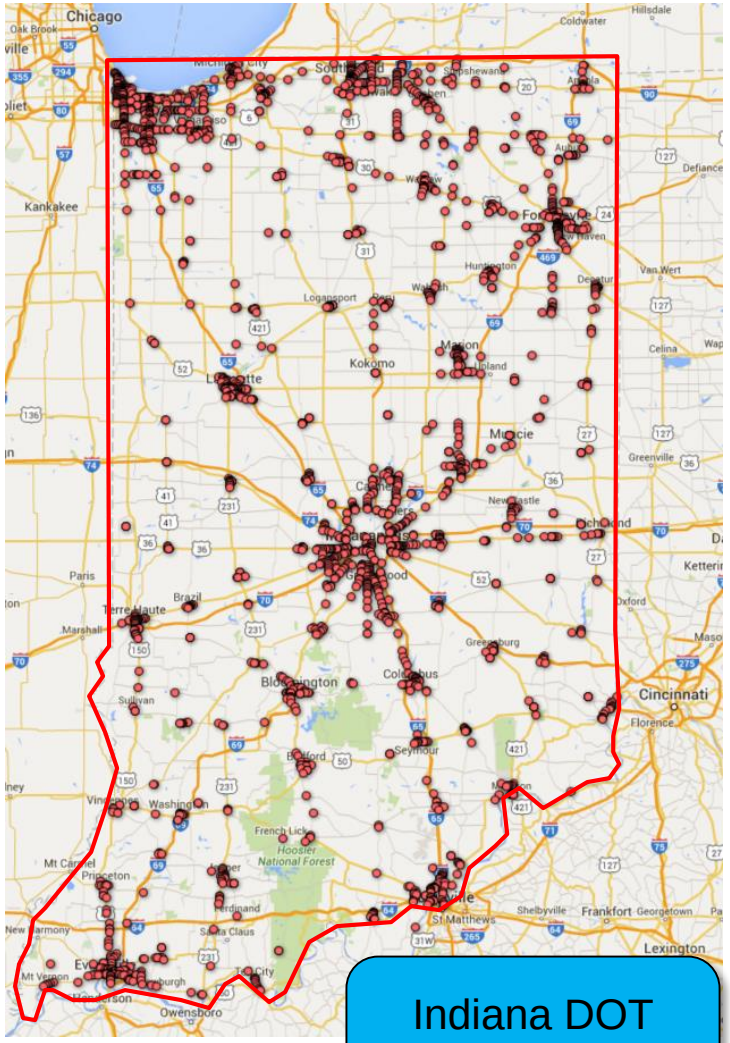
2015



April 2016

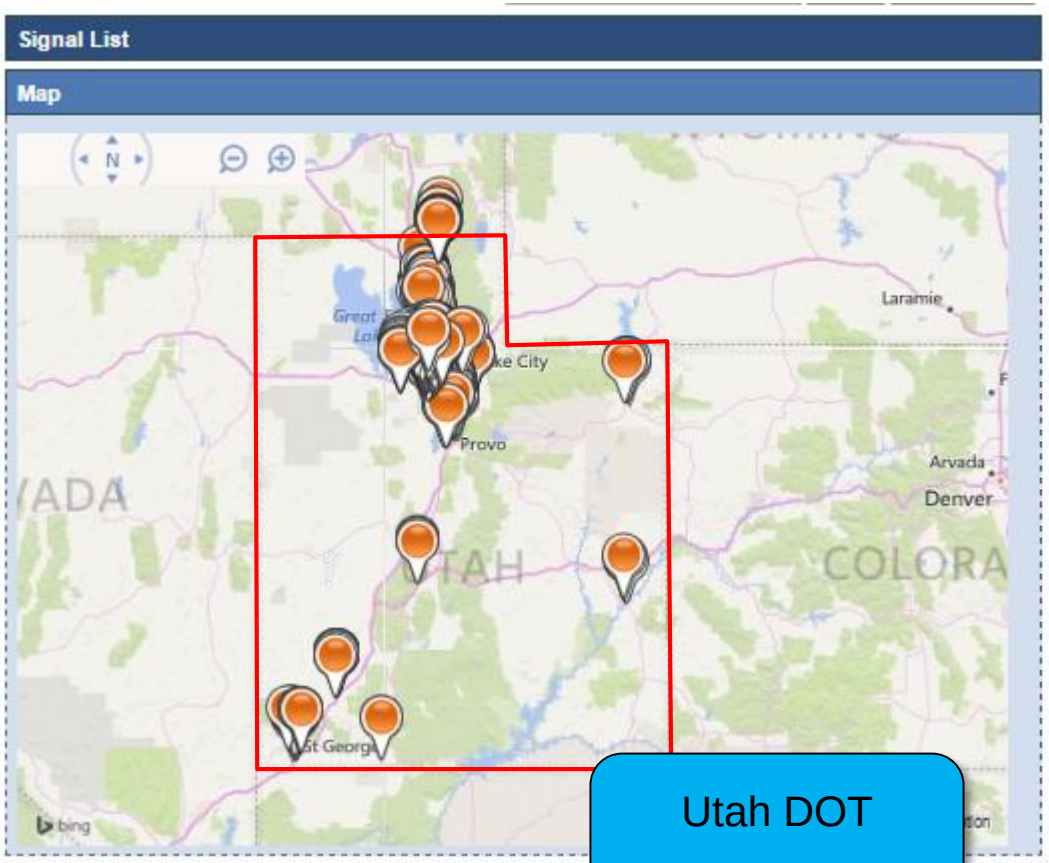


Why Arterial Performance Measures?
2. Practical Management Considerations



Indiana DOT

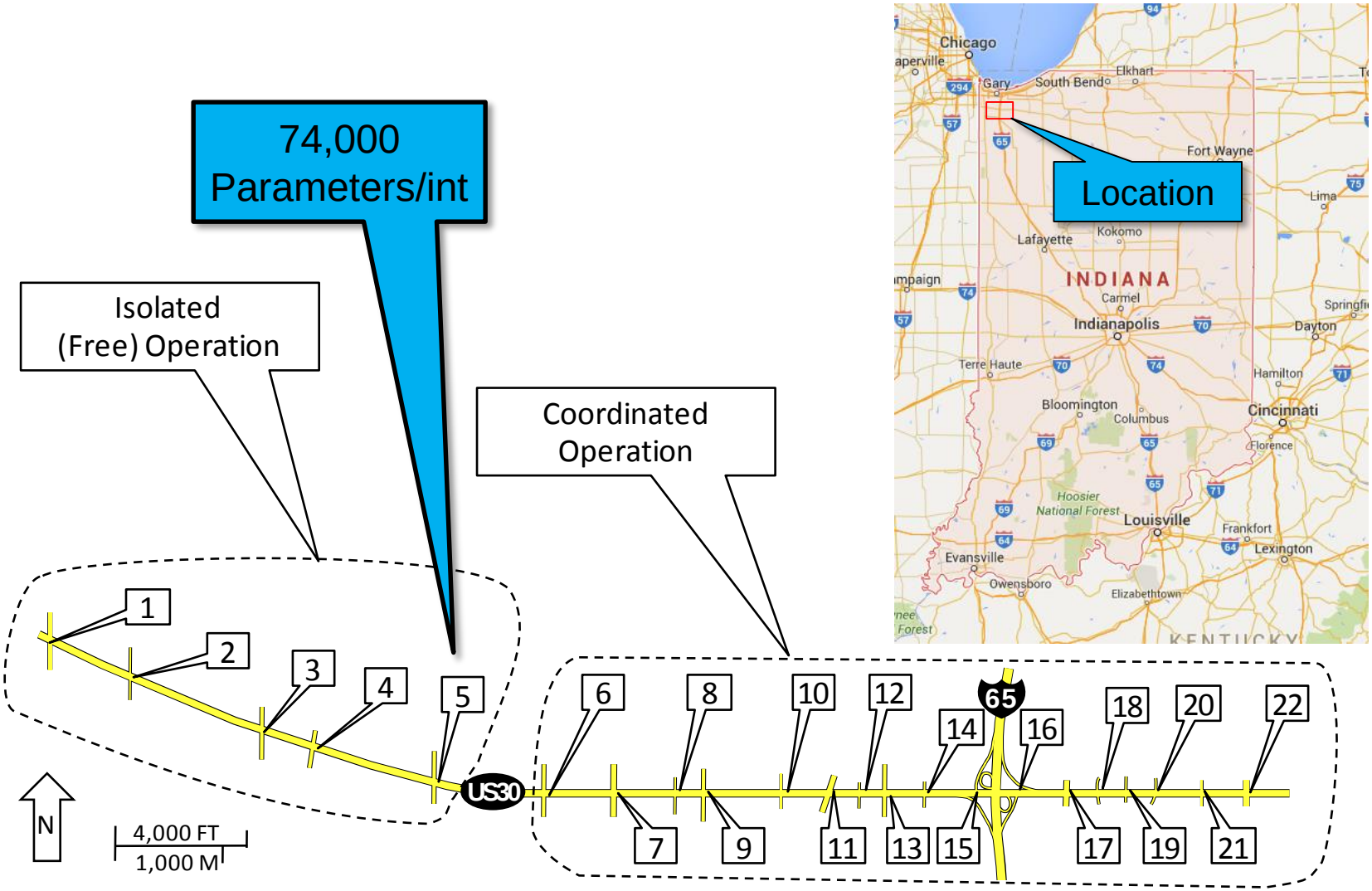
~2300 Signals



Utah DOT

~1600 Signals

Typical Corridor (22 Intersections)



Brennan, T.M., B.D. Griggs, G. Grimmer, A.M. Hainen, C.M. Day, J.R. Sturdevant, and D.M. Bullock. Defining design space for parameters of traffic signal timing: Empirical approach. *Transportation Research Record No. 2311,* 85-98, 2012.

Where to do we get started?

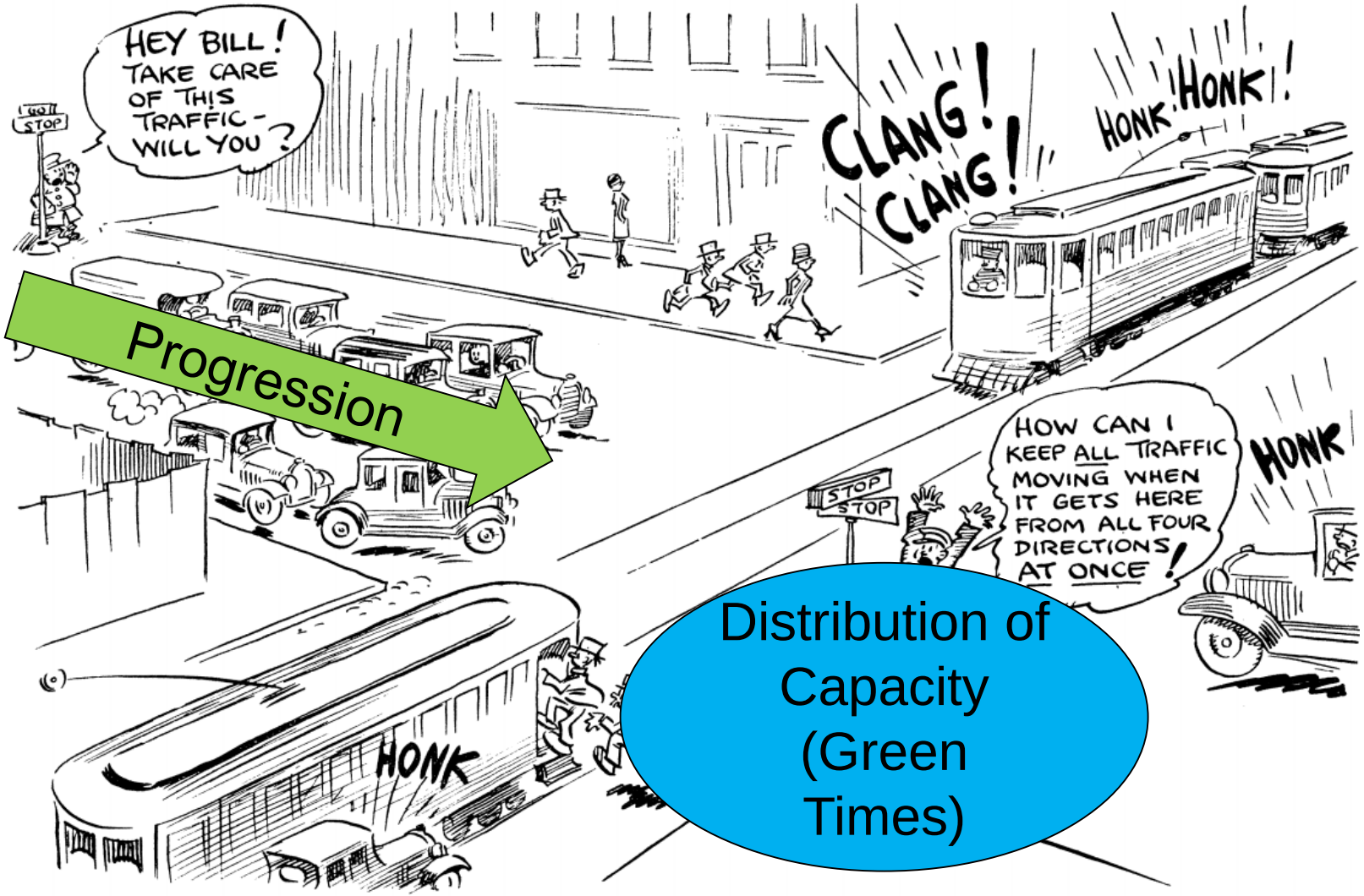


FIGURE 1

Marsh, B.W. “Traffic Control.” Annals of the American Academy of Political and Social Science, Vol. 133, pp.90-113, 1927.

Getting Started: What are the system requirements?

Preempt, Transit Priority, Dynamic Maximum, Responsive, Adaptive, Etc.

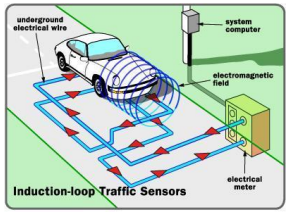
Efficient Coordination

System Timing

OPERATIONS

Local Timing

Efficient Local Control



Detection

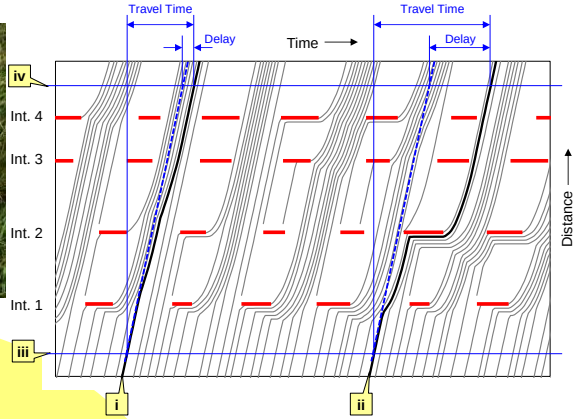
Detector Health

MAINTENANCE

Communications

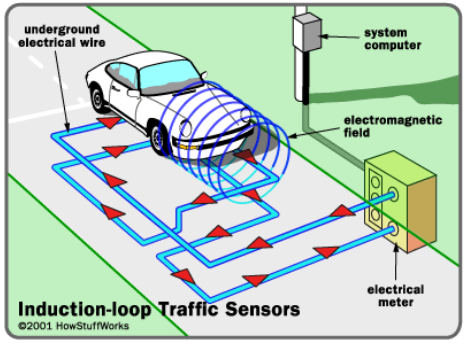
Working Communications

Our Approach…



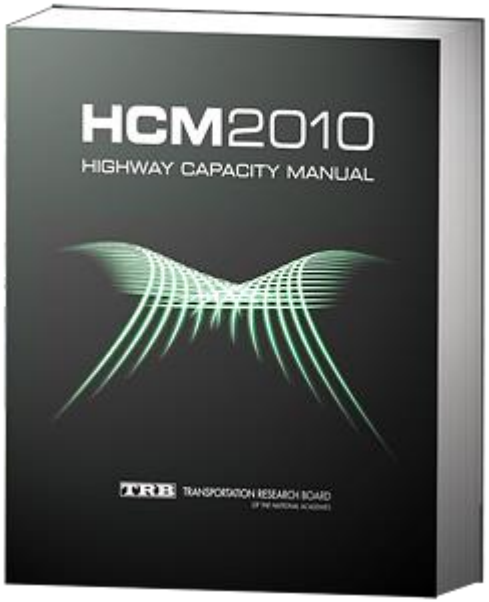
High Resolution Controller Data

Probe Data

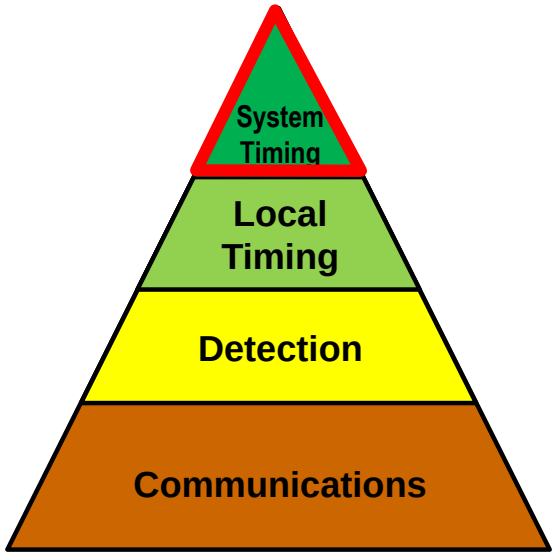


Opportunities to Better Leverage Existing Infrastructure

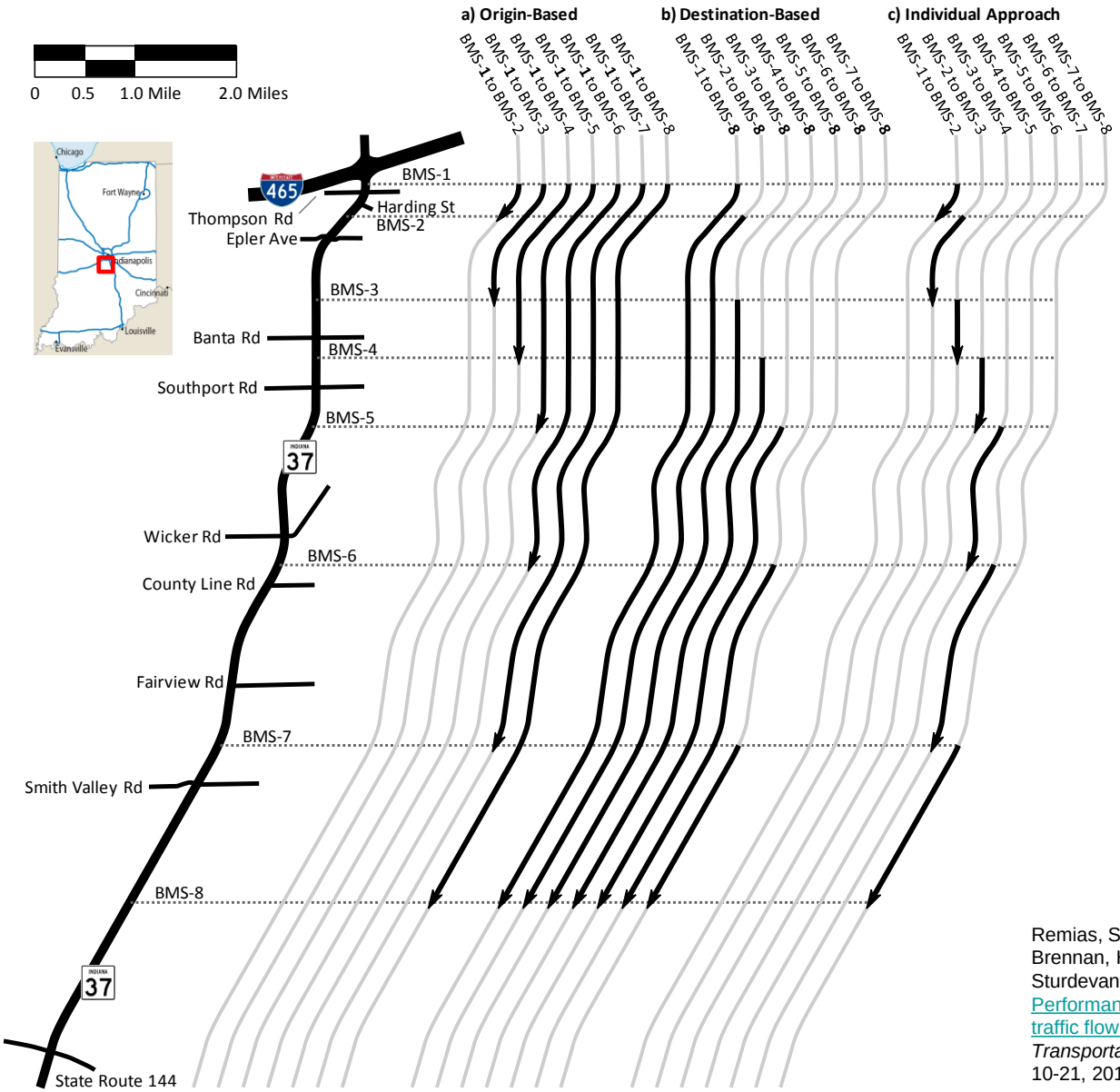
What Performance Measures Do We Use?

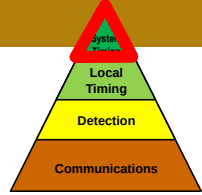


1. Delay at Intersections
2. Travel Times Along Streets

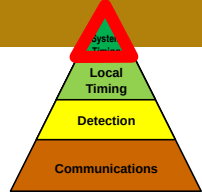


Measuring Travel Times on an Arterial with Vehicle Re-Identification

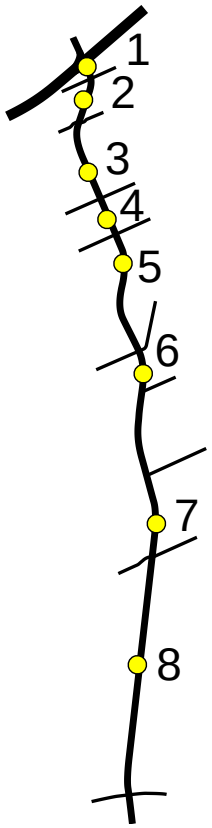


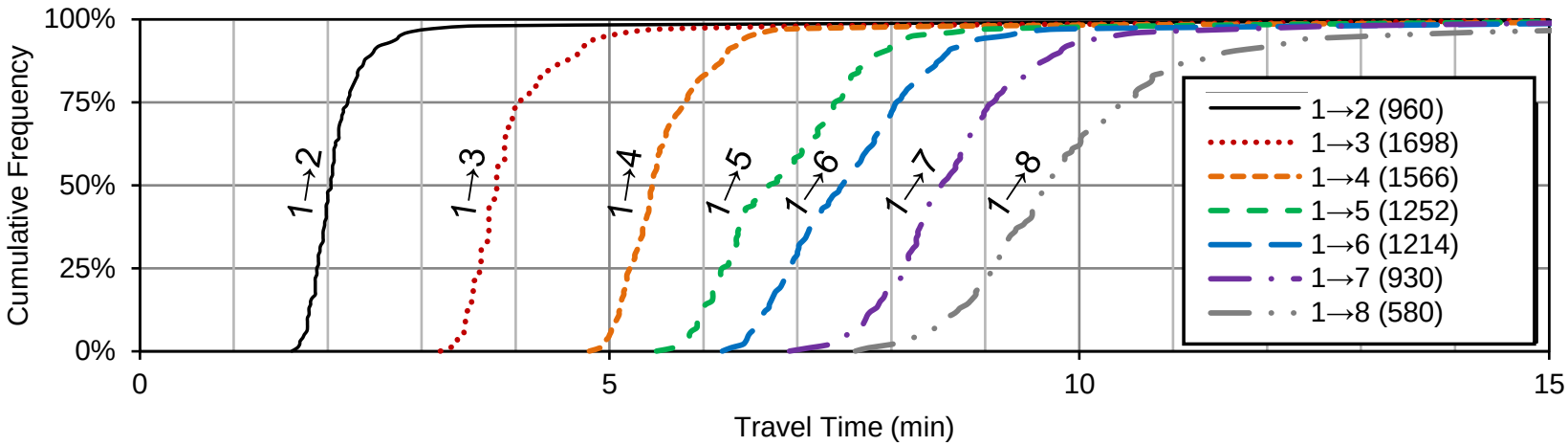


Remias, S.M., A.M. Hainen, C.M. Day, T.M. Brennan, H. Li, E.M. Rivera-Hernandez, J.R. Sturdevant, S.E. Young, and D.M. Bullock. Performance characterization of arterial traffic flow with probe vehicle data. *Transportation Research Record No. 2380*, 10-21, 2013.



Origin-Based Travel Times





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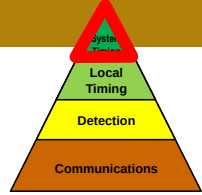
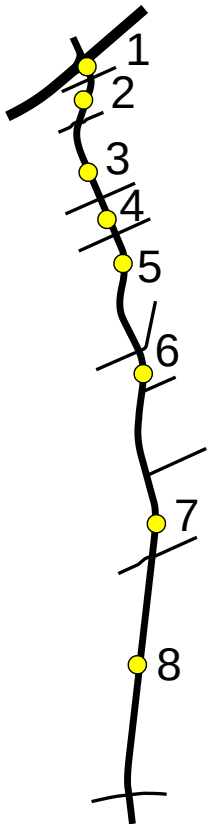
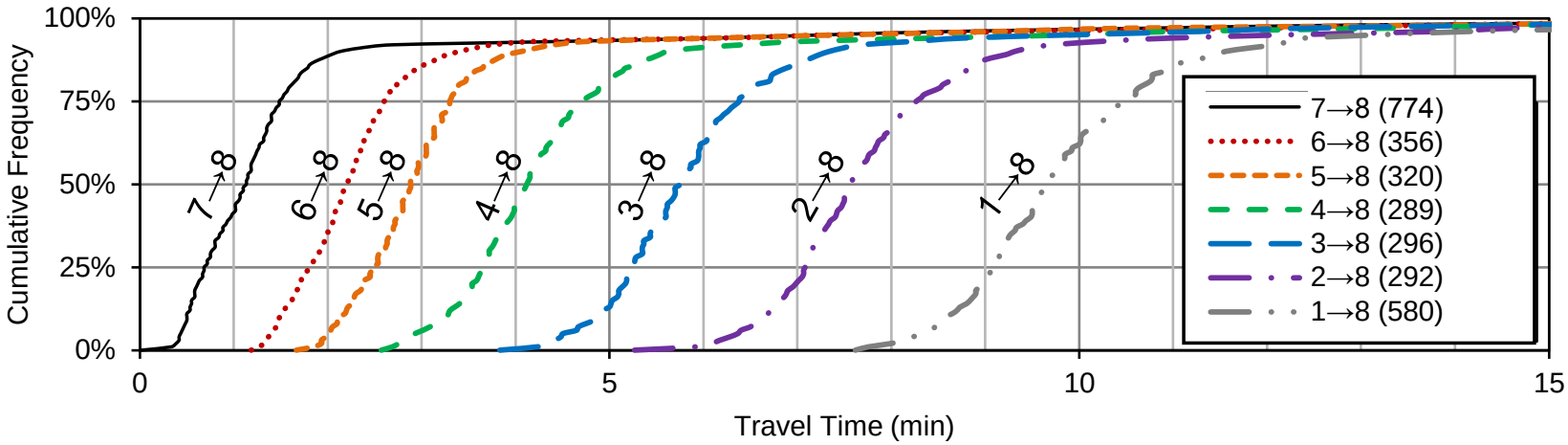


Destination-Based Travel Times





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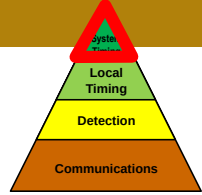
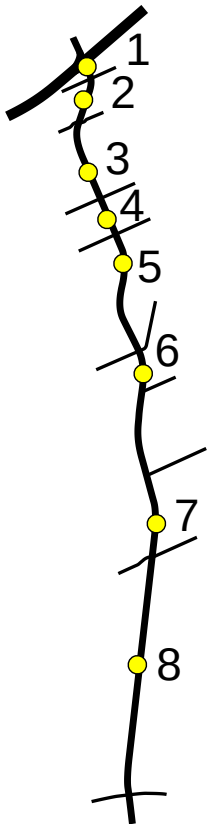
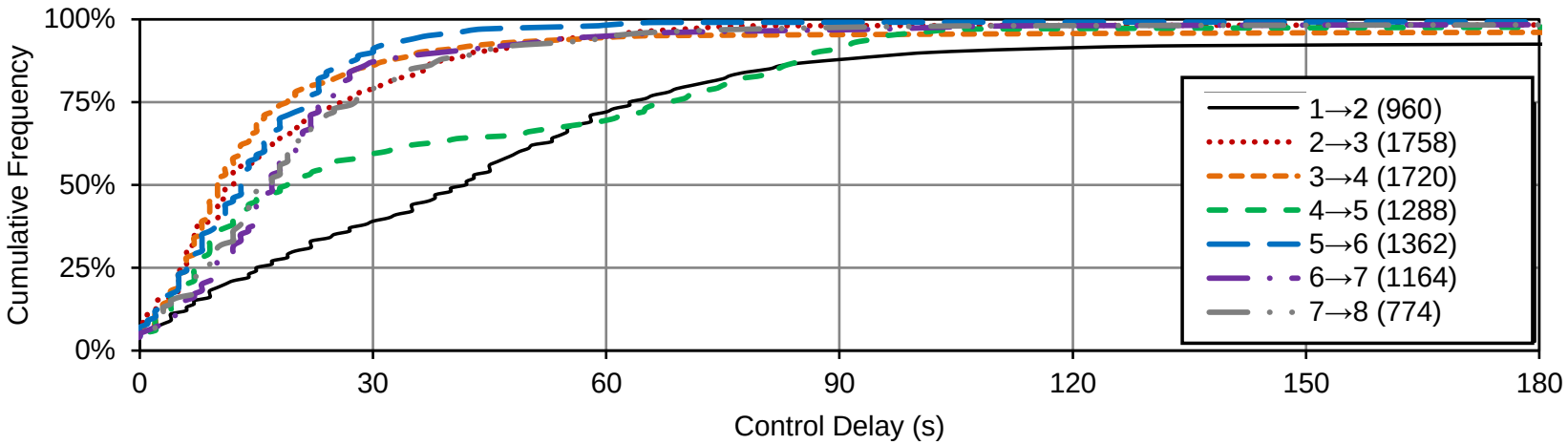


Link-Based Travel Times – Converted to Delay



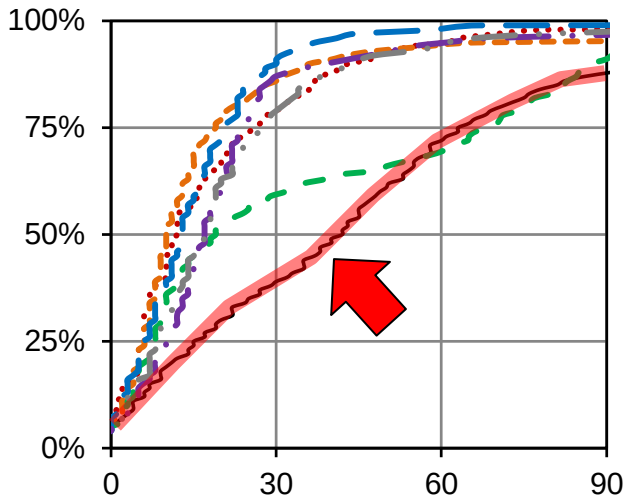


Remias, S.M., A.M. Hainen, C.M. Day, T.M. Brennan, H. Li, E.M. Rivera-Hernandez, J.R. Sturdevant, S.E. Young, and D.M. Bullock. Performance characterization of arterial traffic flow with probe vehicle data. *Transportation Research Record No. 2380*, 10-21, 2013.

Is Travel Time Data Alone Sufficient?

With vehicle re-identification travel times:

- We can quickly identify intersections where delay accumulates on paths along the arterial.

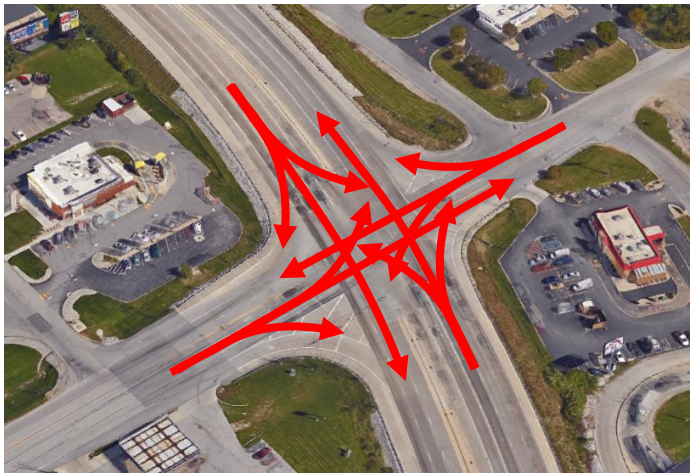


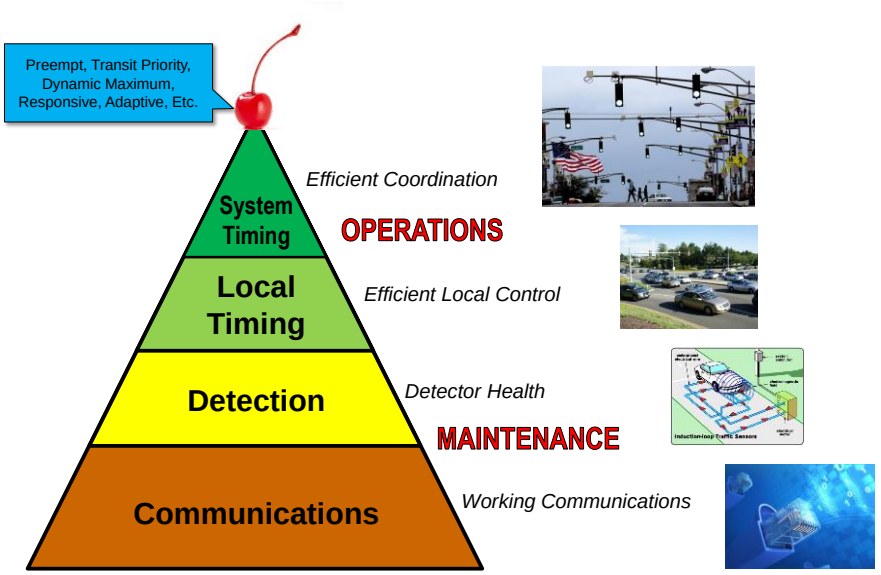
However:

- We don't know the *cause* of the delay
  - Demand greater than capacity?
  - Poor progression (Unsynchronized, Bad Offset, etc.)?
- Not much little information about "minor" movement performance unless we also add sensors on side streets.

2 out of 12 movements represented

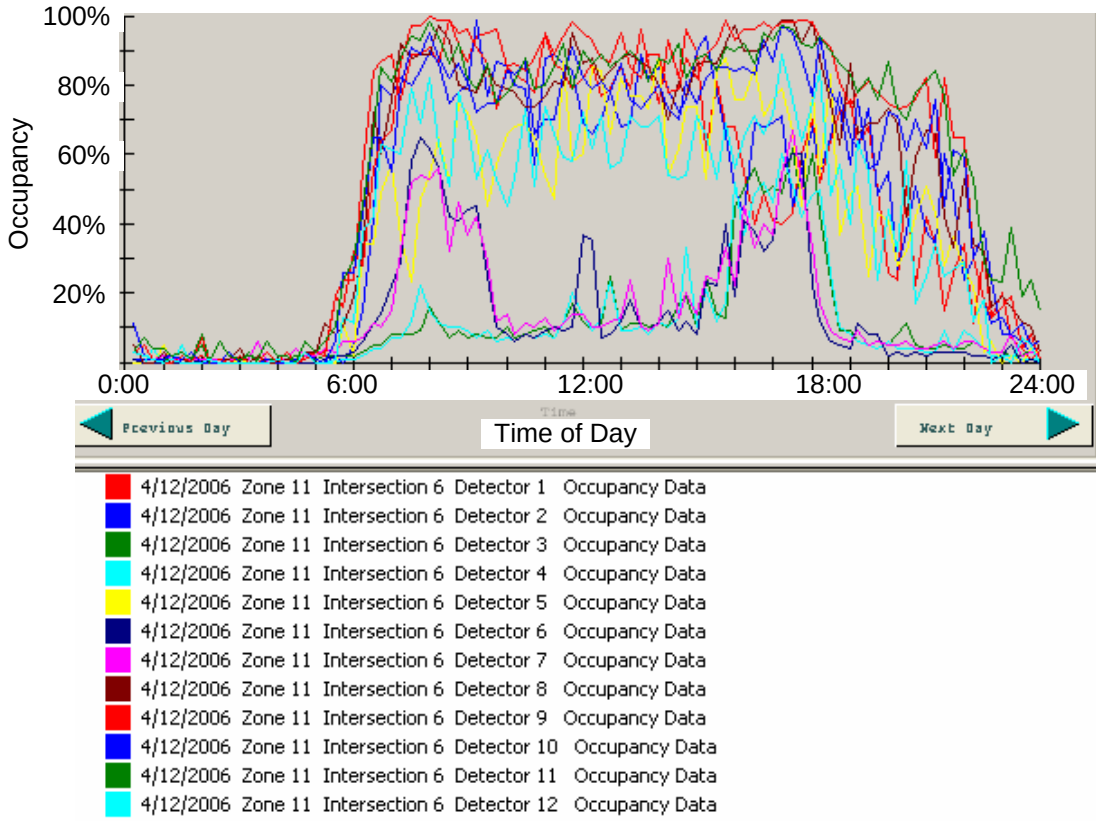
We need more detailed information about what is going on at the intersections.





- So… How can we find out what is happening on <u>all</u> the movements at an intersection?

Binned Occupancy Data… What does it tell us?



Detector Occupancy per arbitrary interval

- Where there's traffic, there's occupancy across a 1, 5, or 15 minute bin
- Provides little information unless cross-referenced with green time

Real-Time Status Displays… What do they tell us?

Real Time Phase/Detector Status

- Good to see what the signal is doing <u>right now</u>
- How long should we watch?
- Replaces standing on the street, but not a long-range analysis tool

1998–2006: Development of High Resolution Data

- Inspired by Hardware-in-the-Loop simulation
- 1998 – Logging with industrial I/O equipment (Opto 22)
- 2003 – 2nd Cabinet with patch panel
  - Two intersections = $1,500,000

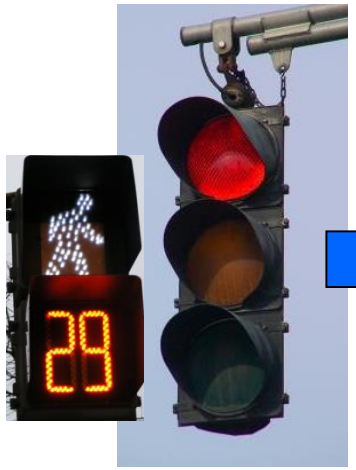
2006 –Data Logger in Controller

Econolite ASC 3 with Indiana Data Logger Enabled (FTP Transfer of hourly time stamped events)

Ethernet Switch

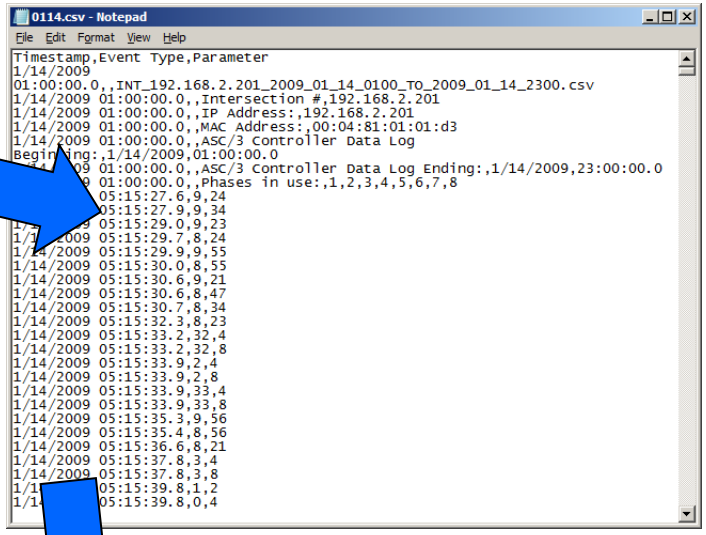
"High-Resolution" Event Data Concept

Internal data logger –
0.1 second resolution

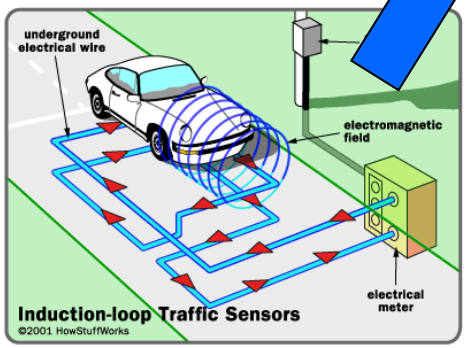


Output Events

Controller Unit

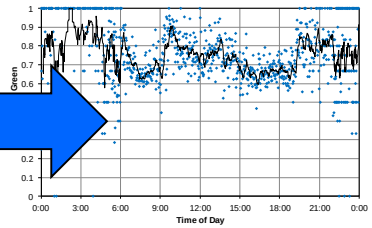


Compressed Binary File



Detector Events

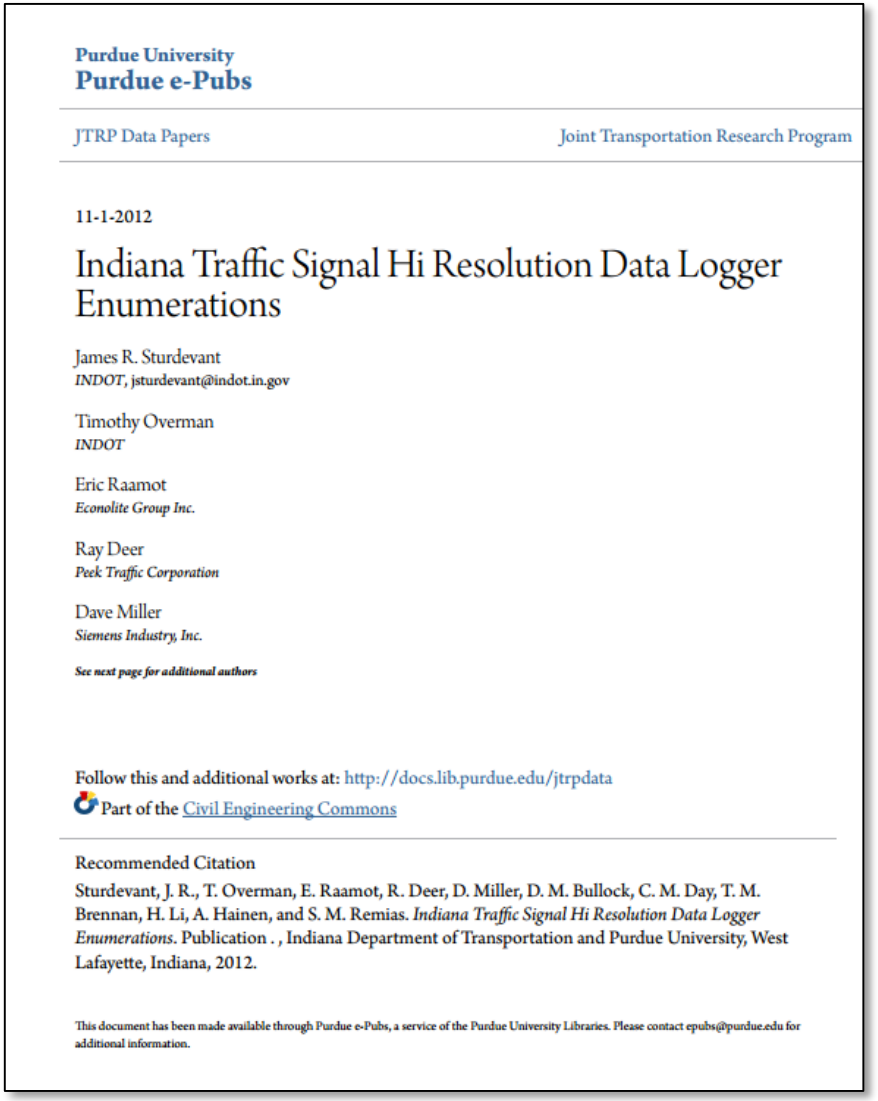
Relational Database



Performance Measures

2008-2012: Consensus on Event Definitions

- Standardized Enumerations for data types (Guidelines)
- http://docs.lib.purdue.edu/jtrpdata
- Currently available in newer models controllers from...
  - Econolite
  - Peek
  - Siemens
  - Intelight
  - Trafficware (Naztec)
  - McCain



Purdue University
Purdue e-Pubs

JTRP Data Papers — Joint Transportation Research Program

11-1-2012

Indiana Traffic Signal Hi Resolution Data Logger Enumerations

James R. Sturdevant
INDOT, jsturdevant@indot.in.gov

Timothy Overman
INDOT

Eric Raamot
Econolite Group Inc.

Ray Deer
Peek Traffic Corporation

Dave Miller
Siemens Industry, Inc.

See next page for additional authors

Recommended Citation
Sturdevant, J. R., T. Overman, E. Raamot, R. Deer, D. Miller, D. M. Bullock, C. M. Day, T. M. Brennan, H. Li, A. Hainen, and S. M. Remias. *Indiana Traffic Signal Hi Resolution Data Logger Enumerations*. Publication . , Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2012.

Emerging Vision on How to Put it All Together… Taking Communications Systems into Account

Architecture for Active Management of Geographically Distributed Signal Systems

THE NATIONAL TRANSPORTATION OPERATIONS COALITION (NTOC) IN ITS 2007 TRAFFIC SIGNAL REPORT CARD NOTED THAT, NATIONALLY, FIVE TO 10 PERCENT OF ALL TRAFFIC DELAY IS CAUSED BY IMPROPER TRAFFIC SIGNAL TIMINGS. THIS PAPER DESCRIBES OPPORTUNITIES TO MODERNIZE TRAFFIC SIGNAL MANAGEMENT ARCHITECTURES BY LEVERAGING COMMERCIAL

INTRODUCTION

Signalized arterials represent a substantial component of the highway transportation network in the United States. The National Transportation Operations Coalition (NTOC) in its 2007 Traffic Signal Report Card noted that, nationally, five to 10 percent of all traffic delay is caused by improper traffic signal timings along major roadways. In 2007, the National Report Card score for overall traffic signal systems operations was a D.

Upgraded intersection controllers, communication, detection equipment, closed loop systems, and/or central systems can provide modest improvements.[1,2] However, there are more significant improvement opportunities for traffic operations and agency manpower efficiency by defining active management practices and implementing alternative traffic signal architectures that go beyond traditional closed loop and central system models. The following sections document the state of Indiana's vision and

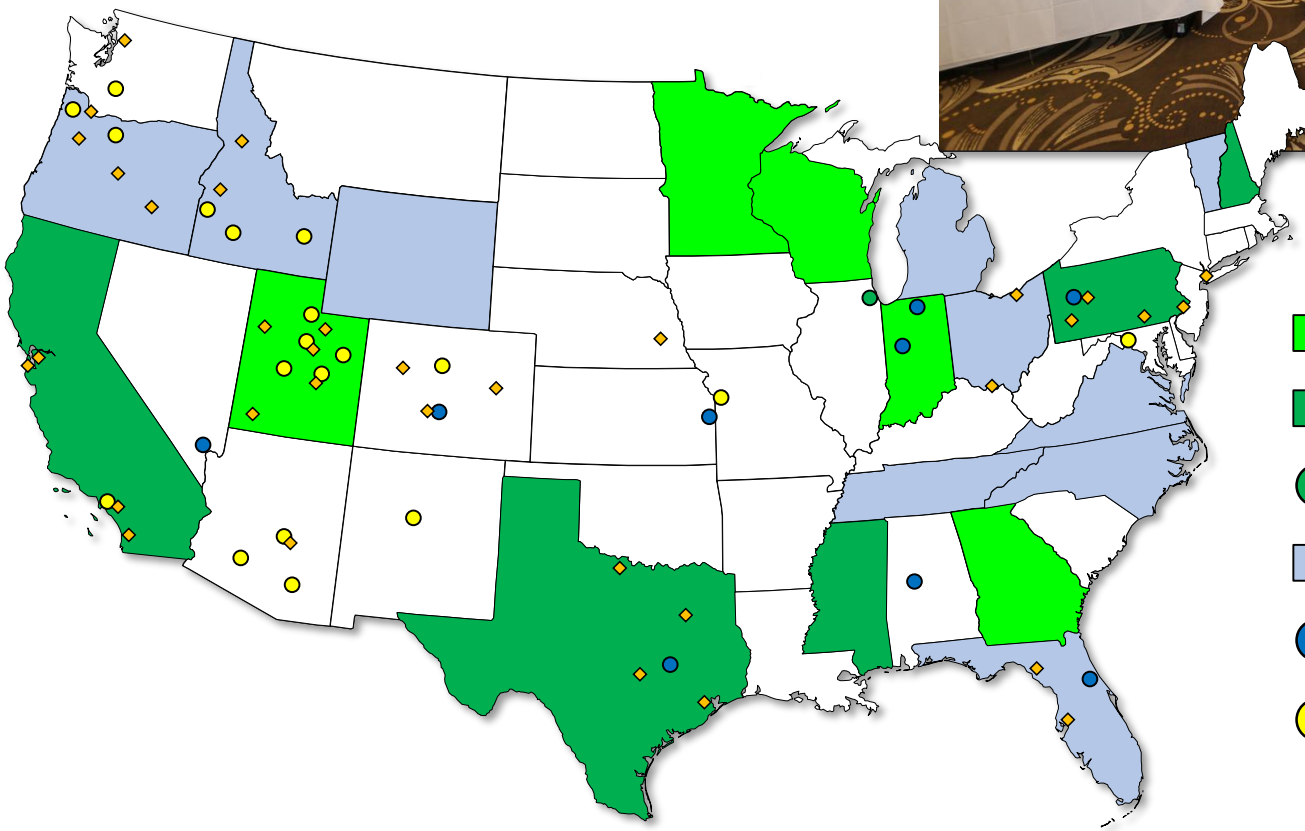
green time to ensure that all movements have sufficient capacity. However, there are clearly other objectives that may or may not enter into consideration, such as pedestrian service, transit priority, and emergency vehicle operations. Although this is an obvious step, agency staff responsible for managing the system will not have clear guidance on how to prioritize competing demands unless there is clear consensus on an agency's priorities.

2. **Collect fundamental signal operations data.** Historically, central and closed-loop monitoring systems have displayed near real-time status of phase indications and detectors, but only archived five- or 15-minute flow rates. For any substantive analysis of the signals operation, high-resolution phase indication and detector status must be collected.[4,5]
3. **Analyze data using theoretically**

Bullock, D.M., C.M. Day, T.M. Brennan, J.R. Sturdevant, and J.S. Wasson. Architecture for active management of geographically distributed signal systems. *ITE Journal*, 81(5), 20-24, 2011.

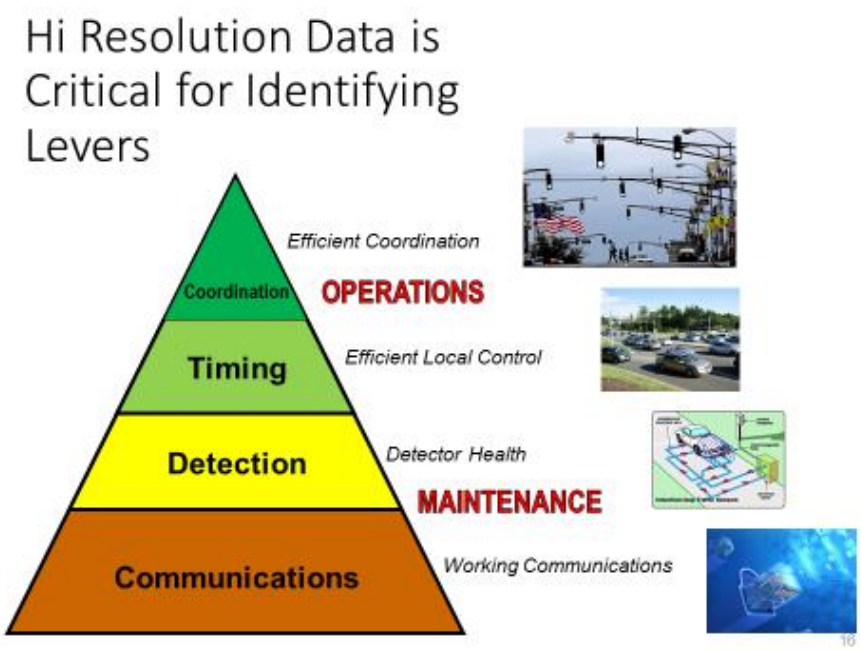
Signal Performance Measures (SPM) Pooled Fund Study (2012-2016)

SPM Workshop,
Salt Lake City, Jan. 2016

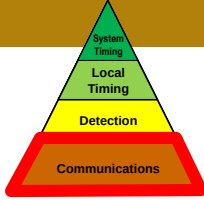


- State DOT w/ SPM
- Other PFS State DOT
- PFS Local Agency
- States at Workshop
- Local Agency w/ SPM
- Local at Workshop
- Private Sector Workshop Participant

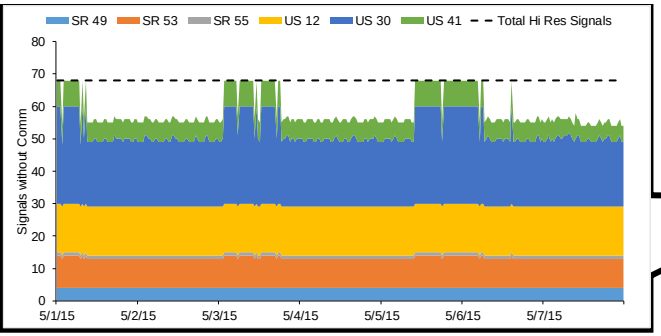
Critical Performance Measures for Managing Signals

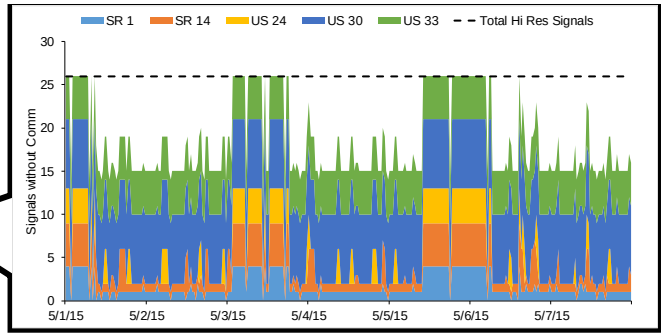


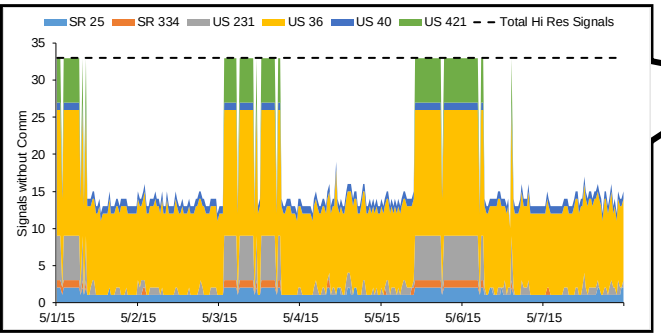
1. Is my communication working?
2. Are my detectors working?
3. Do I have adequate green time on each phase?
4. Do I have most of my vehicles arriving on green?

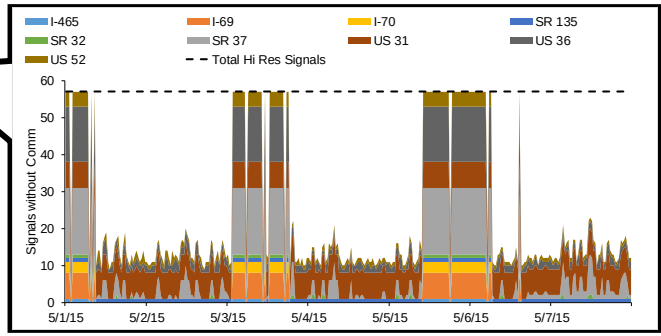


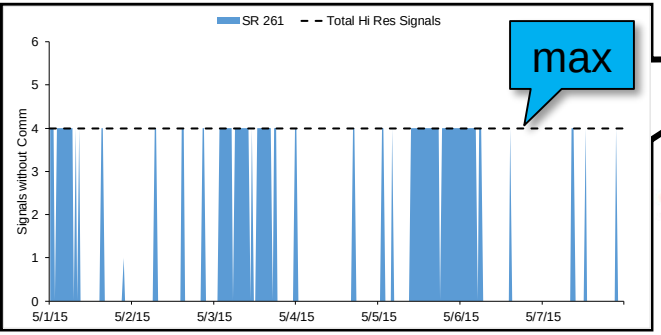
"Is my communication working?"
Number of signals online and reporting by district

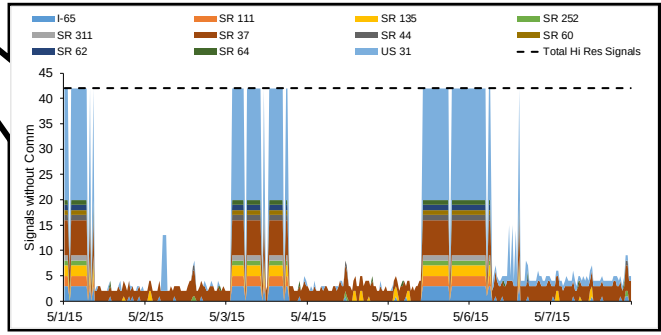


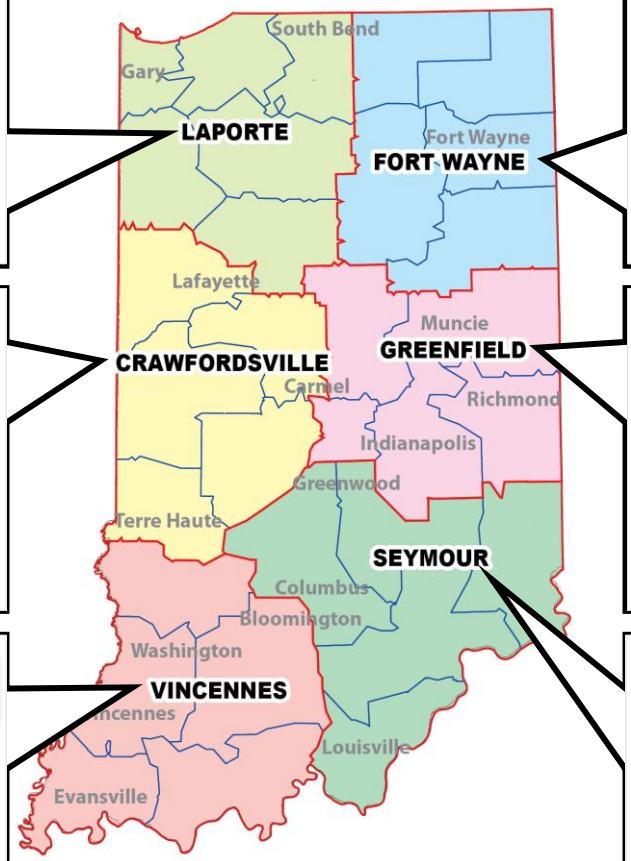




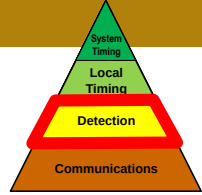




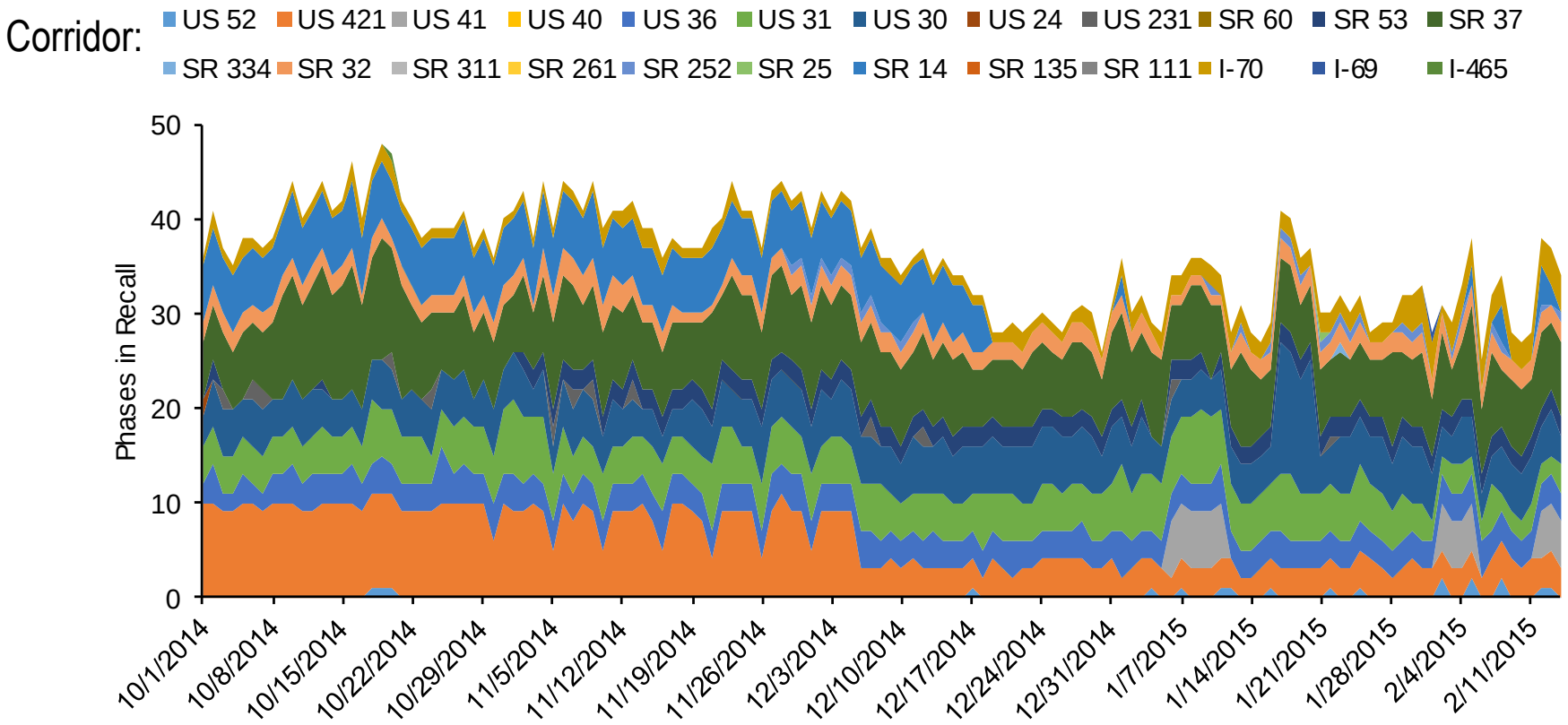




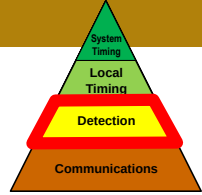
Lavrenz, S. *High-Resolution Data-Based Methods for Enhanced Asset Preservation, Mobility, and Safety at Signalized Intersections*. PhD thesis, Purdue University, 2015.



"Are my detectors working?"
Number of phases in recall because of failed detectors



Lavrenz, S. *High-Resolution Data-Based Methods for Enhanced Asset Preservation, Mobility, and Safety at Signalized Intersections*. PhD thesis, Purdue University, 2015.



"Are my detectors working?"
Automated alerts (UDOT / Salt Lake City)

DAILY EMAIL DETECTOR ALERTS

Alert Example

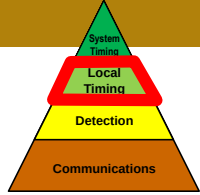
```
 --The following signals had too many force off occurrences:
1019 - 300 West & 800 South - Phase: 2 (Force Offs 100%)
1019 - 300 West & 800 South - Phase: 4 (Force Offs 100%)
1019 - 300 West & 800 South - Phase: 6 (Force Offs 100%)
1019 - 300 West & 800 South - Phase: 8 (Force Offs 100%)
7070 - 3300 South & I-15 SPUI - Phase: 1 (Force Offs 100%)
7070 - 3300 South & I-15 SPUI - Phase: 5 (Force Offs 100%)

 --The following signals had too many  max out occurrences:
1035 - West Temple & 1700 South - Phase: 4 (Max Outs 100%)
1035 - West Temple & 1700 South - Phase: 8 (Max Outs 100%)
1122 - University St & 400 South - Phase: 5 (Max Outs 91.7%)
7635 - 600 South & 300 West - Phase: 2 (Max Outs 100%)

 --The following signals had too few records in the database:
5297 - Main St. (SR-165) & 1700 S (Providence) - Phase: 0 (Missing Records)

 --The following signals had unusually low detector hits:
6045 - US-6 (Spanish Fork) & Canyon Road - Phase: 2 ( Has Unusually Low Counts. )
6045 - US-6 (Spanish Fork) & Canyon Road - Phase: 6 ( Has Unusually Low Counts. )

 --The following signals have stuck ped detectors:
5033 - 2100 South (Wilson) & 1100 West - Phase: 2
5507 - Lincoln & 25th - Phase: 2
```

- Force Offs
- Max Outs
- No Data
- Low Detector Hits
- Stuck Pedestrian Button

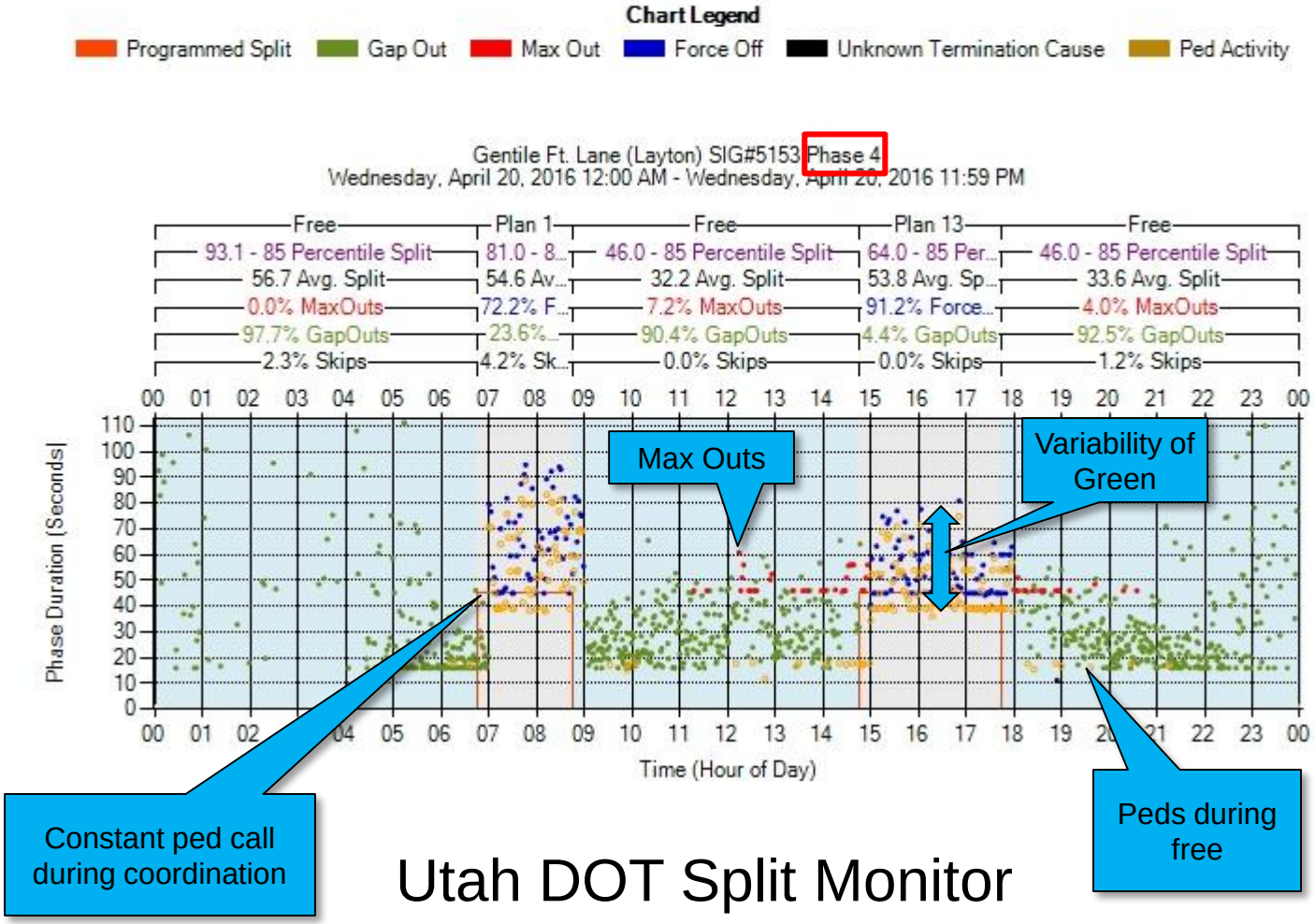
- Daily email sent at 7 a.m.
- Compare to previous day's data. Only phases with new flags are reported.

Metric: Purdue Phase Termination
Detection Requirements: None

http://udottraffic.utah.gov/signalperformancemetrics/

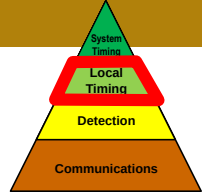


"Do I have Adequate Green Time on Each Phase?"



Utah DOT Split Monitor

http://udottraffic.utah.gov/signalperformancemetrics/

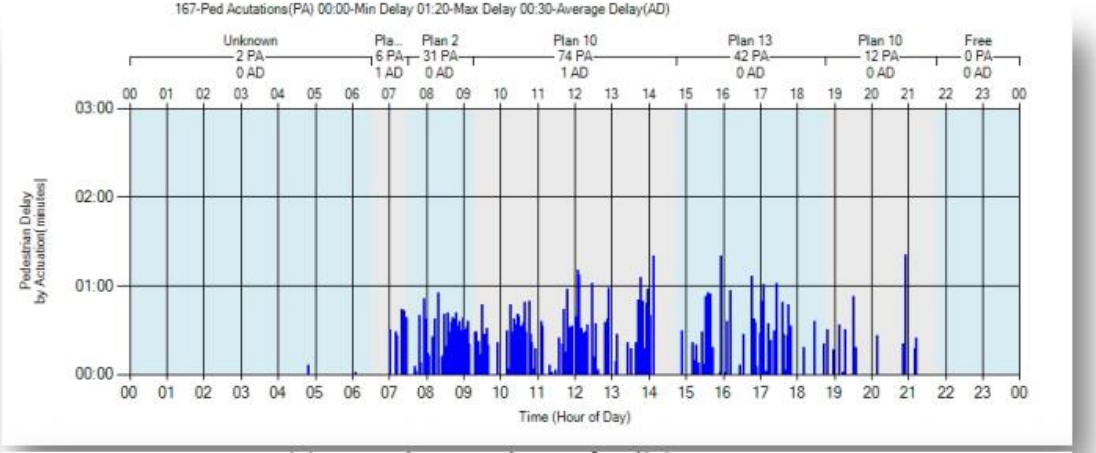


"Do I have Adequate Green Time on Each Phase?"

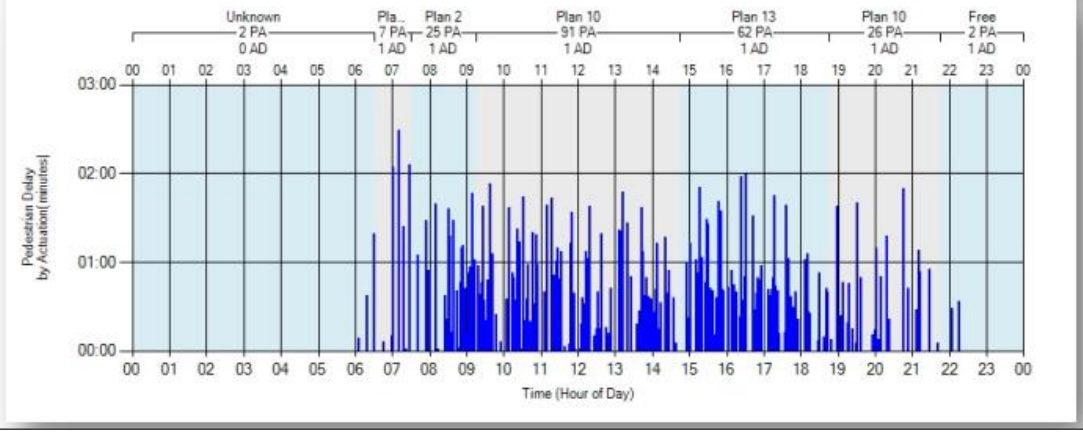
Pedestrian Delay

EVENT CODES
45 – Ped Call on
21 – Ped Walk on

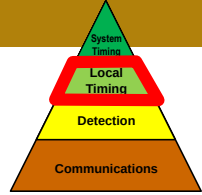
Phase 2
Coordinated phase



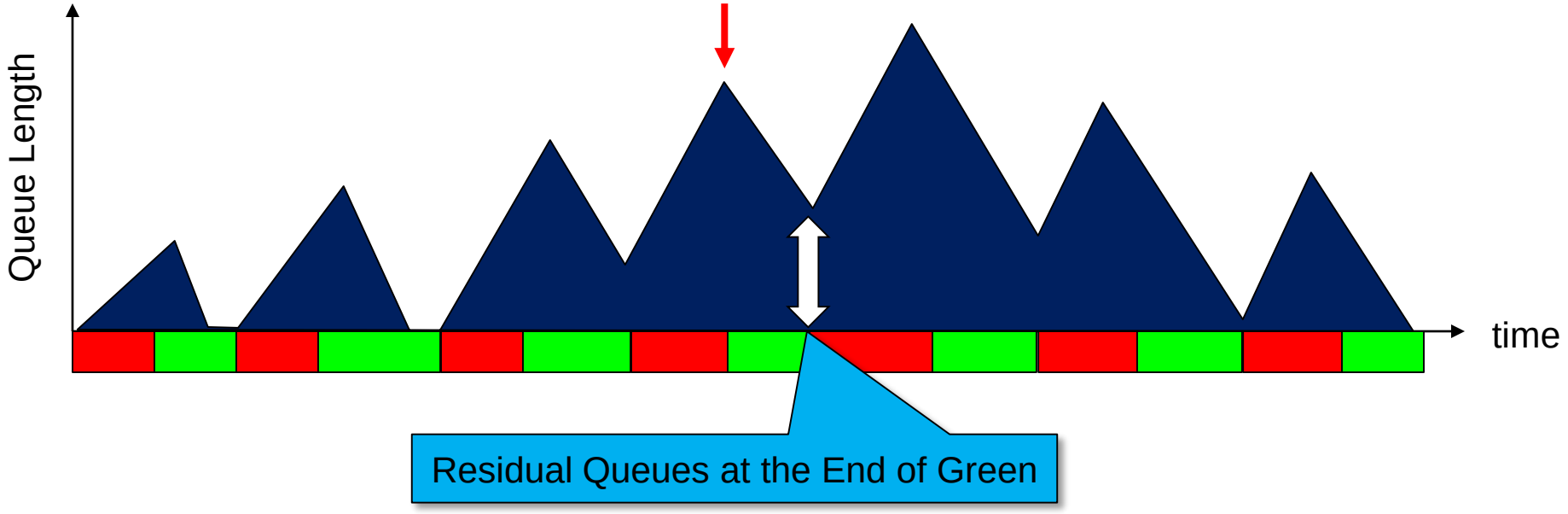
Phase 4
Side street

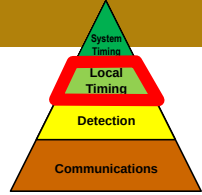


http://udottraffic.utah.gov/signalperformancemetrics/

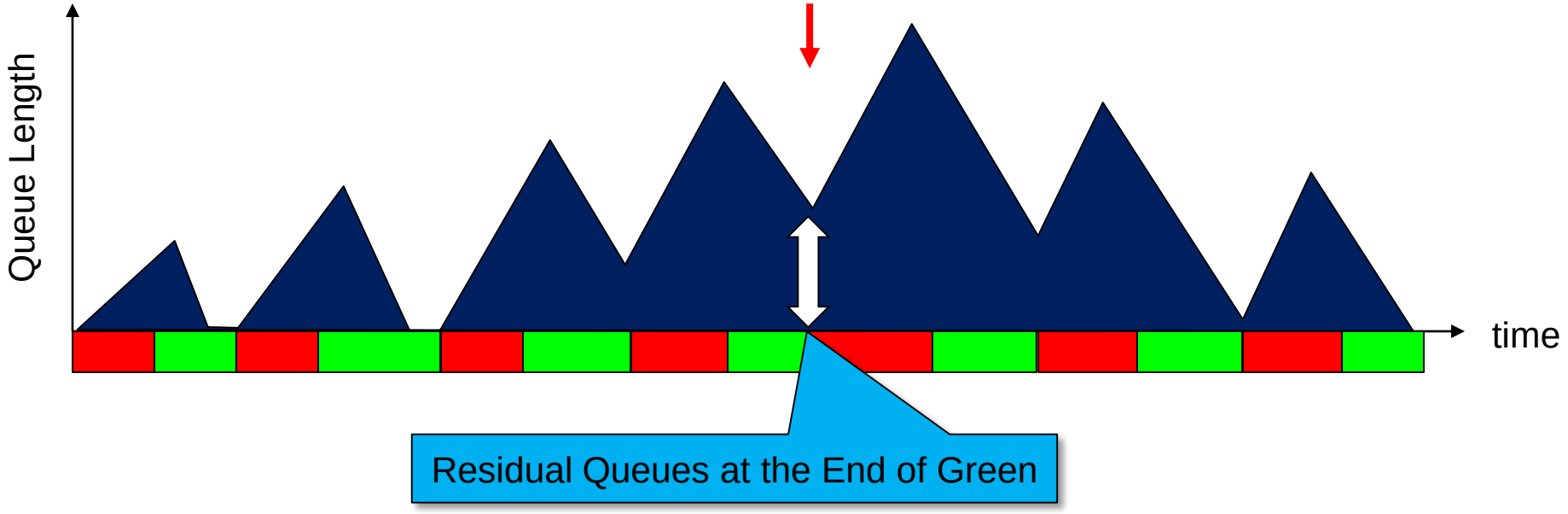


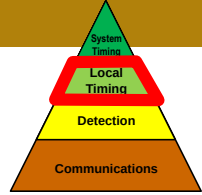
Detection of Split Failures



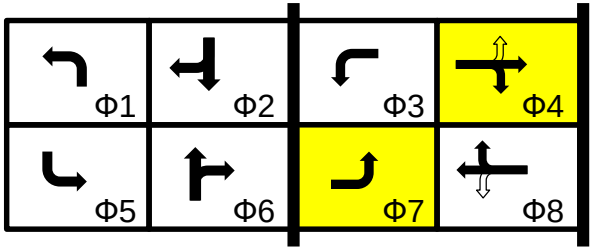


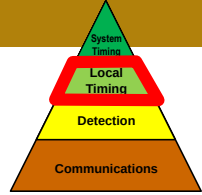
Detection of Split Failures





Study Intersection Overview

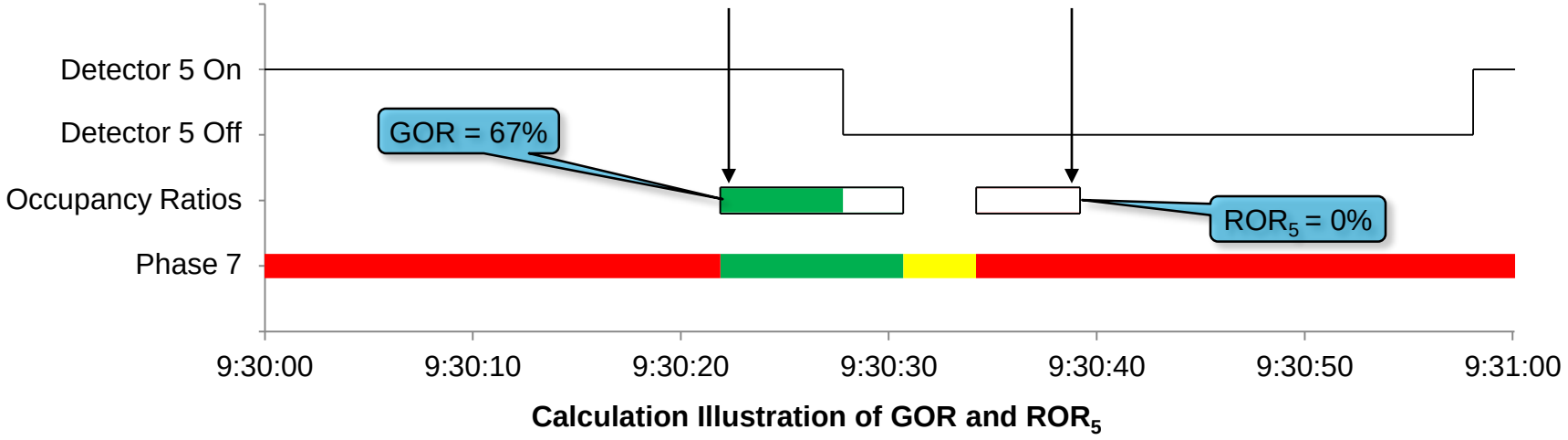




Red Occupancy and Green Occupancy – Undersaturated Phase

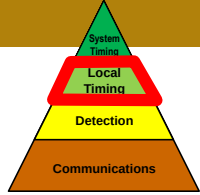
Just After the Start of Green

5 Seconds After Start of Red

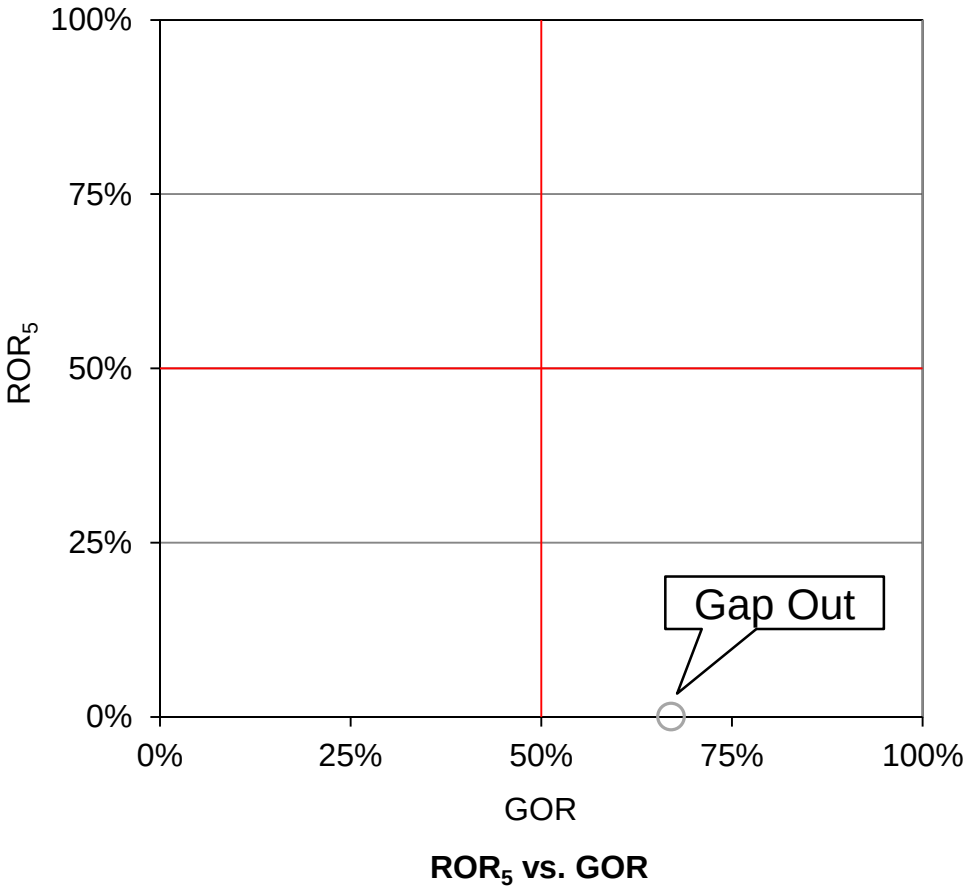


Calculation Illustration of GOR and ROR_5

Freije, R., A.M. Hainen, A. Stevens, H. Li, W.B. Smith, C.M. Day, J.R. Sturdevant, and D.M. Bullock. Graphical performance measures for practitioners to triage split failure trouble calls. *Transportation Research Record No. 2439,* 27-40, 2014.



Red Occupancy and Green Occupancy – Undersaturated Phase



ROR_5 vs. GOR

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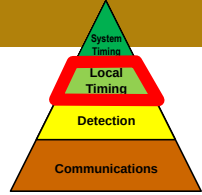
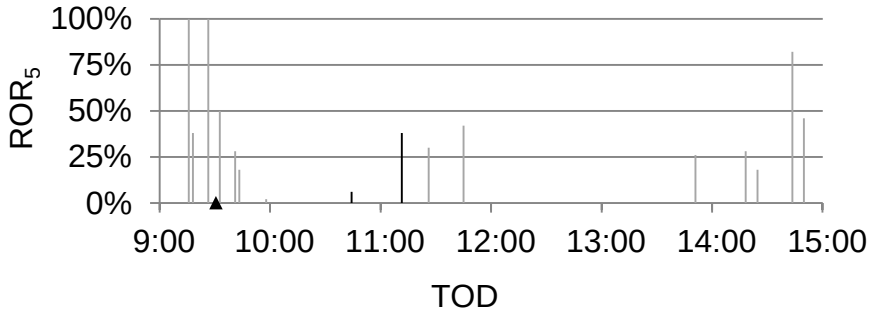
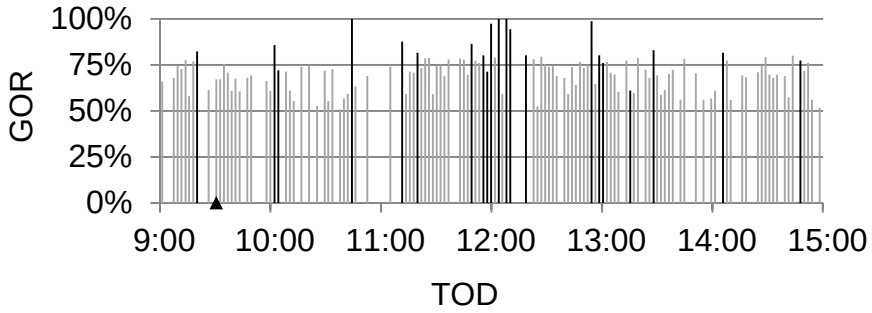


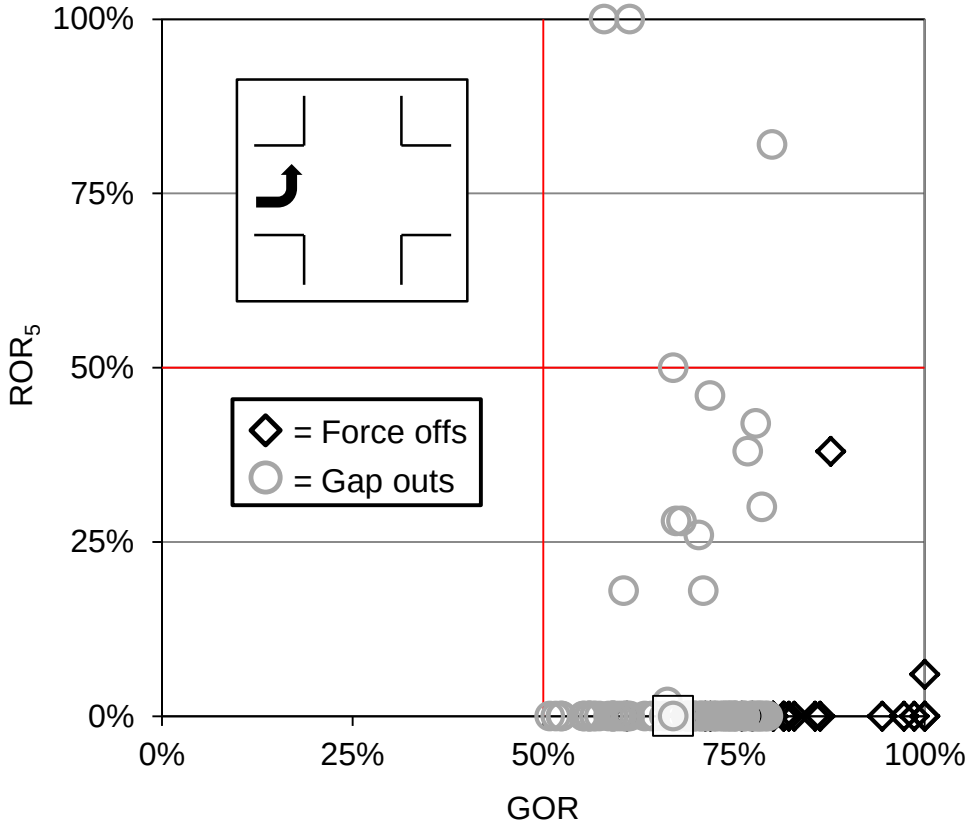
Red Occupancy and Green Occupancy – Undersaturated Phase Duration of Midday TOD Plan (0900-1500)



ROR_5 vs. TOD (0900-1500)

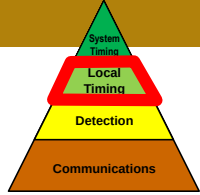


GOR vs. TOD (0900-1500)



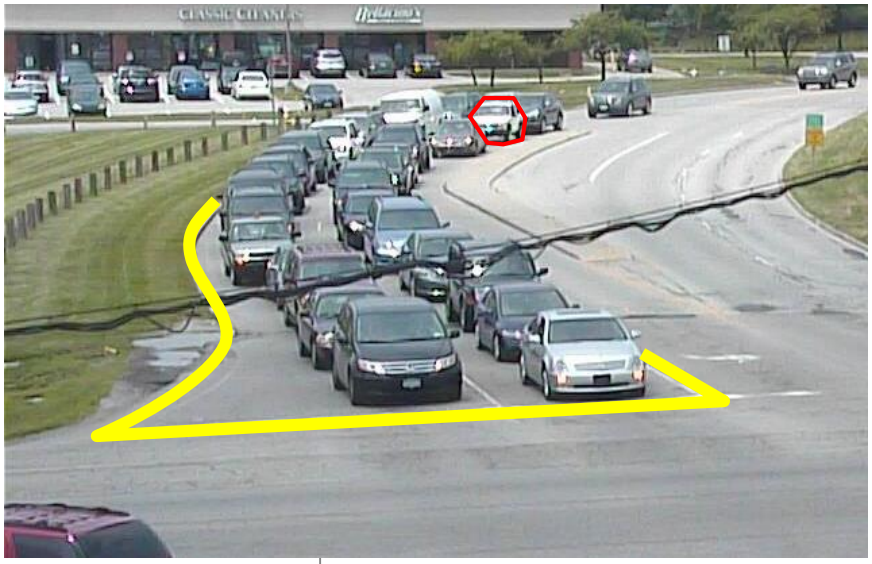
ROR_5 vs. GOR (0900-1500)

Freije, R., A.M. Hainen, A. Stevens, H. Li, W.B. Smith, C.M. Day, J.R. Sturdevant, and D.M. Bullock. Graphical performance measures for practitioners to triage split failure trouble calls. *Transportation Research Record No. 2439,* 27-40, 2014.

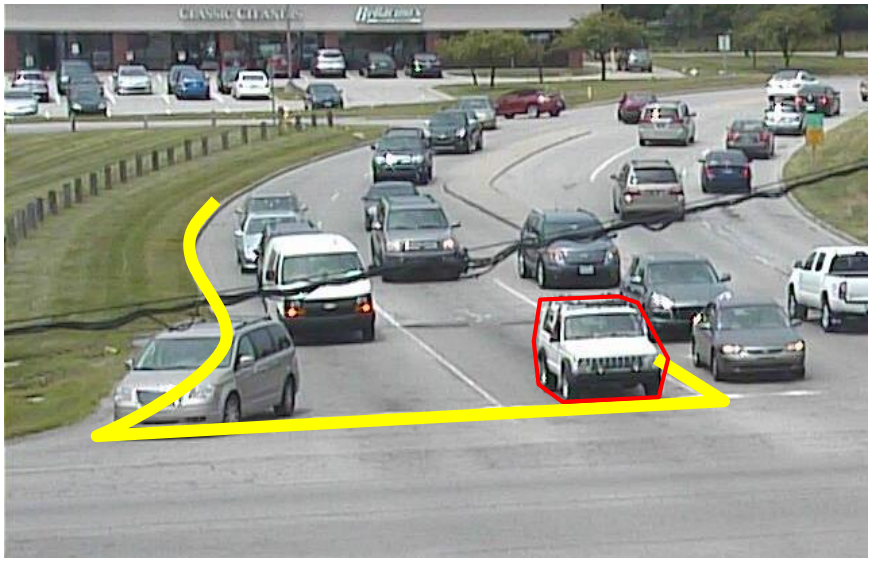


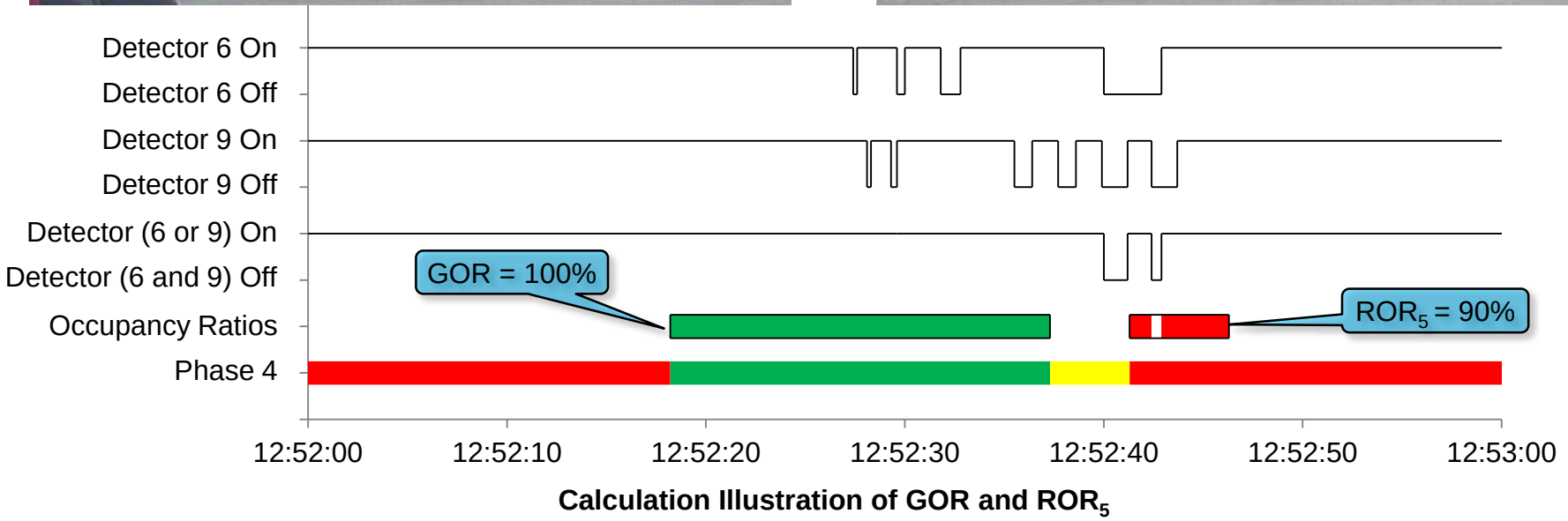
Red Occupancy and Green Occupancy – Oversaturated Phase

Just After the Start of Green



5 Seconds After Start of Red





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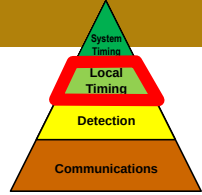
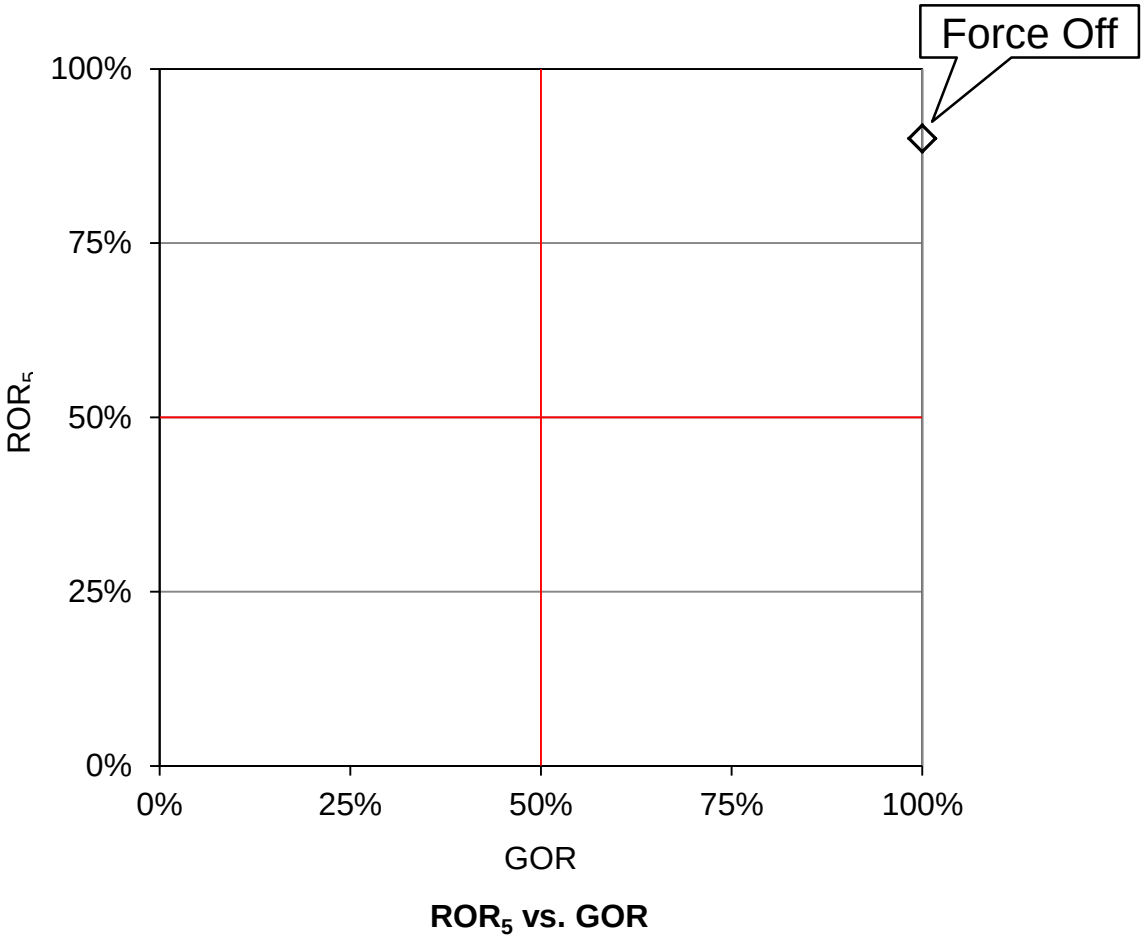


Red Occupancy and Green Occupancy – Oversaturated Phase



ROR_5 vs. GOR

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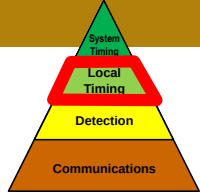
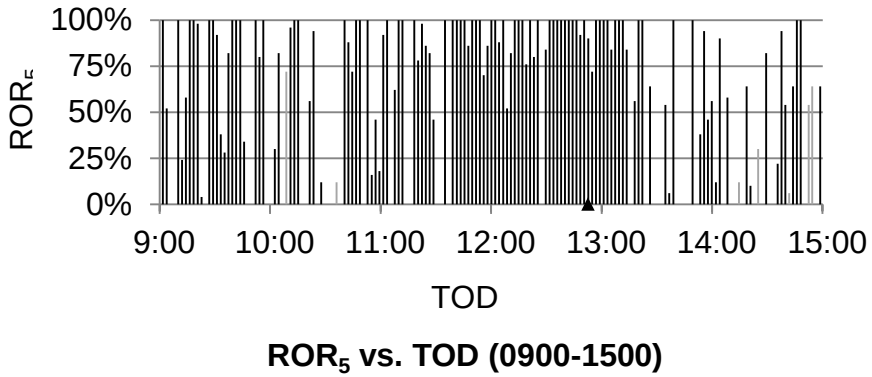
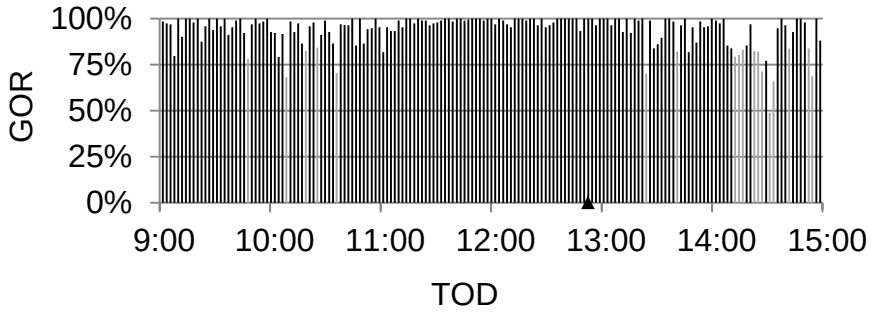


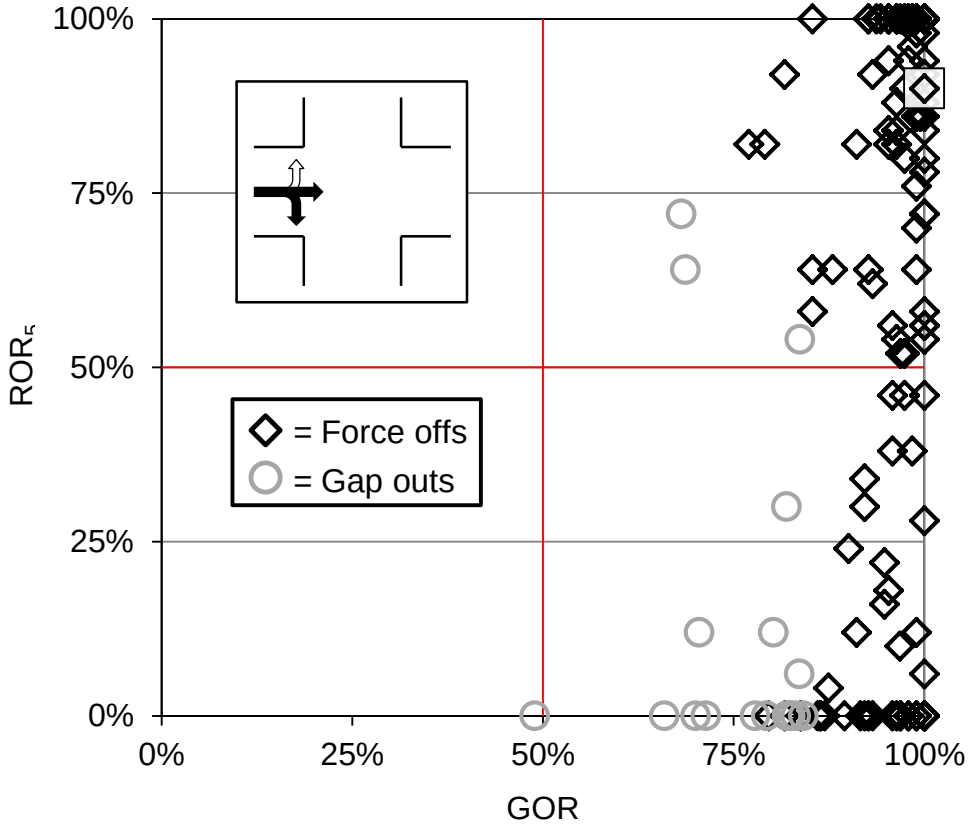
Red Occupancy and Green Occupancy – Oversaturated Phase Duration of Midday TOD Plan (0900-1500)



ROR_5 vs. TOD (0900-1500)



GOR vs. TOD (0900-1500)



ROR_5 vs. GOR (0900-1500)

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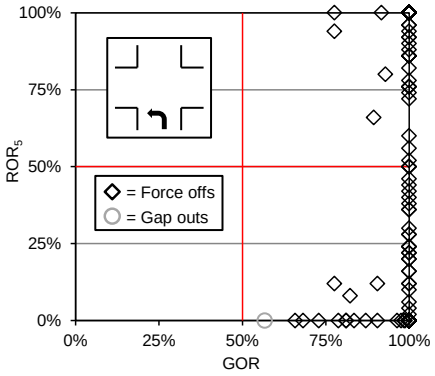
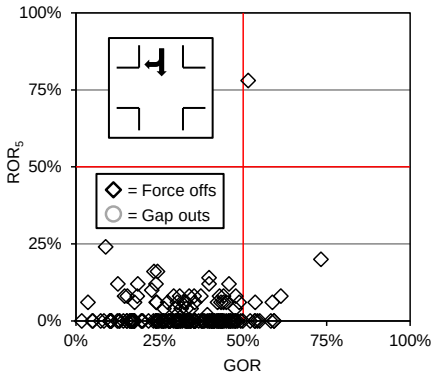
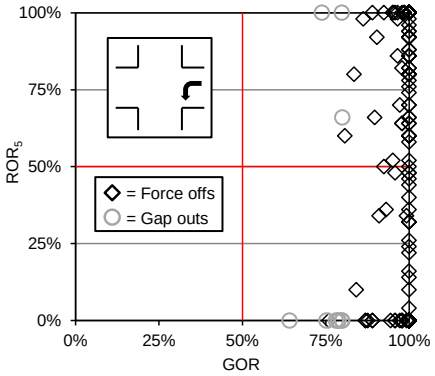
Analysis for 8 Phases…



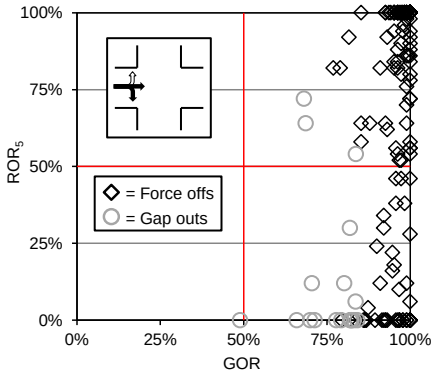
Phase 1 ROR_5 vs. GOR



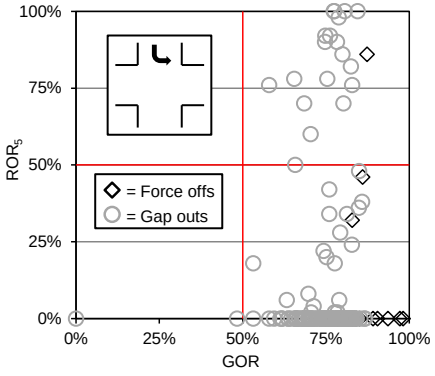
Phase 2 ROR_5 vs. GOR



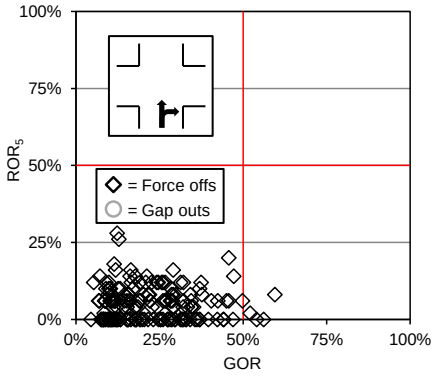
Phase 3 ROR_5 vs. GOR



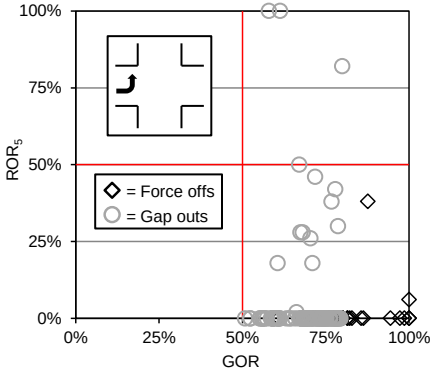
Phase 4 ROR_5 vs. GOR



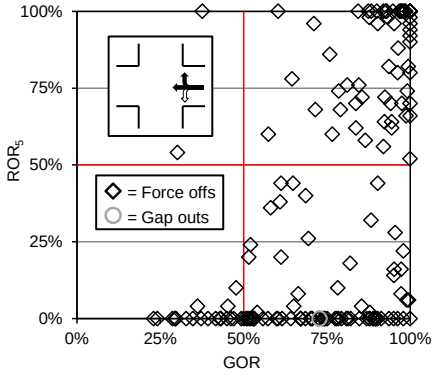
Phase 5 ROR_5 vs. GOR



Phase 6 ROR_5 vs. GOR

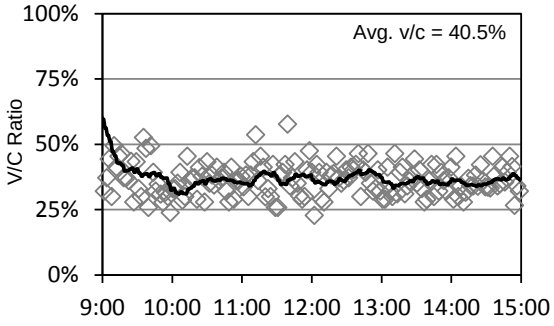


Phase 7 ROR_5 vs. GOR

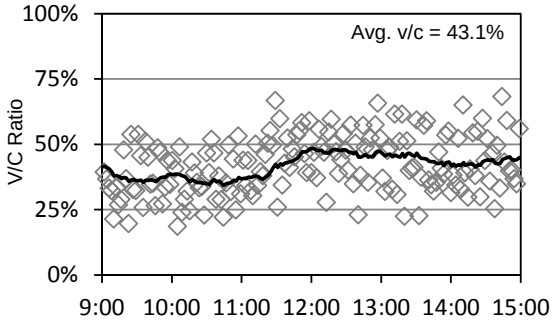


Phase 8 ROR_5 vs. GOR

Phase 2 V/C Ratio



Phase 6 V/C Ratio



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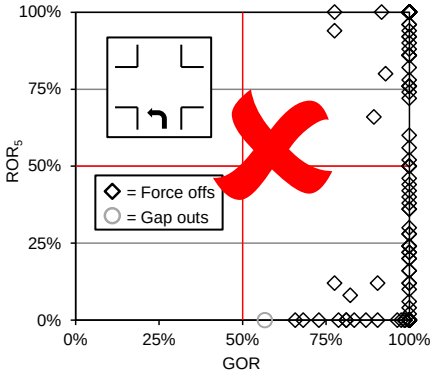
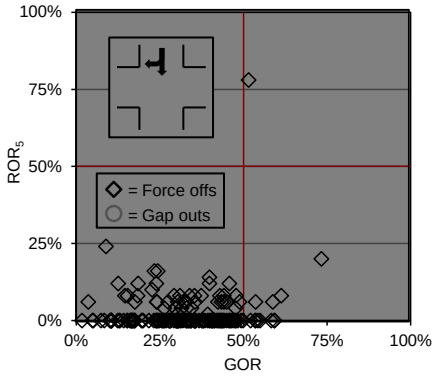
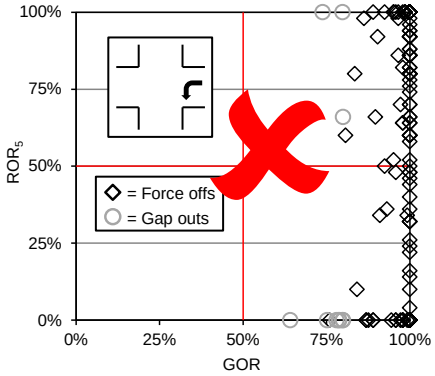
Analysis for 8 Phases…



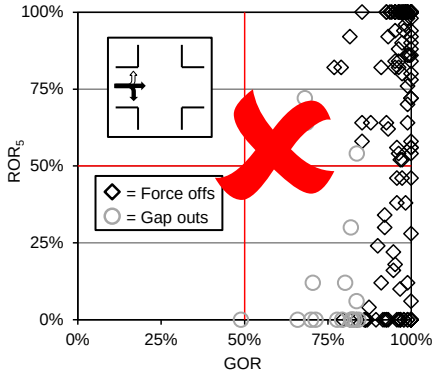
Phase 1 ROR_5 vs. GOR



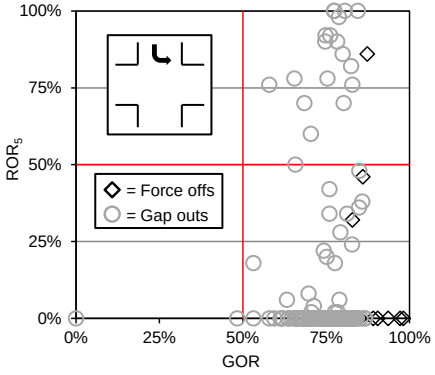
Phase 2 ROR_5 vs. GOR



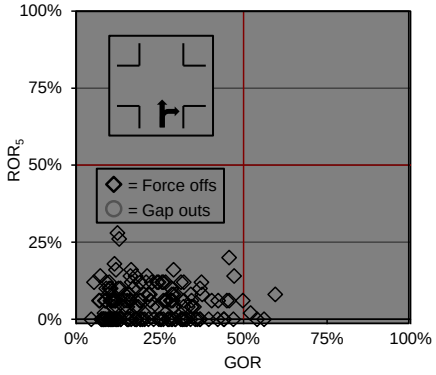
Phase 3 ROR_5 vs. GOR



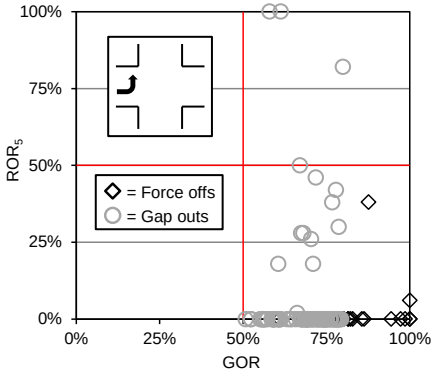
Phase 4 ROR_5 vs. GOR



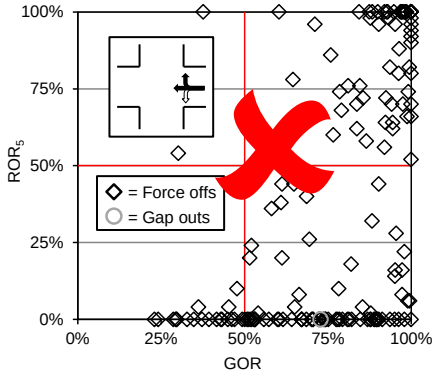
Phase 5 ROR_5 vs. GOR



Phase 6 ROR_5 vs. GOR

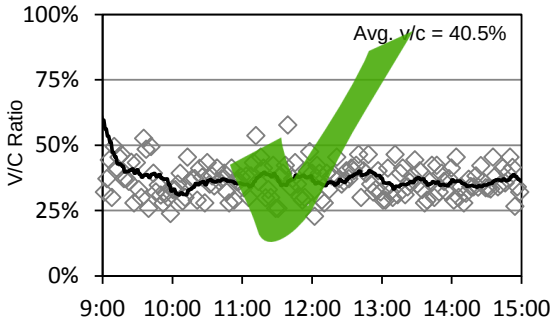


Phase 7 ROR_5 vs. GOR

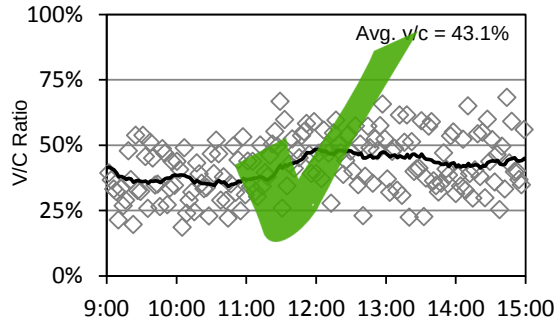


Phase 8 ROR_5 vs. GOR

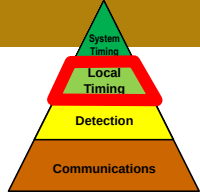
Phase 2 V/C Ratio



Phase 6 V/C Ratio

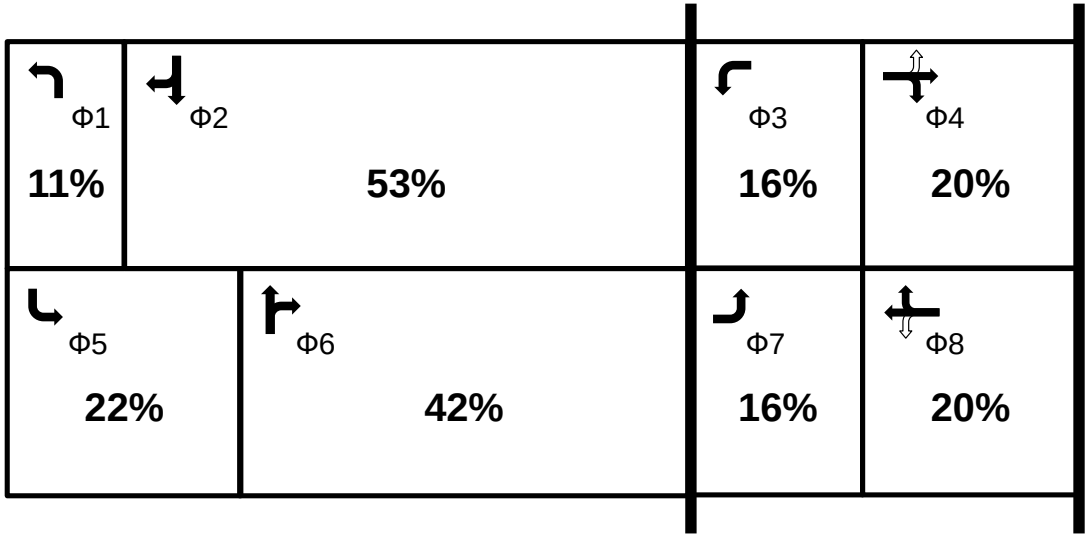


Freije, R., A.M. Hainen, A. Stevens, H. Li, W.B. Smith, C.M. Day, J.R. Sturdevant, and D.M. Bullock. Graphical performance measures for practitioners to triage split failure trouble calls. *Transportation Research Record No. 2439,* 27-40, 2014.

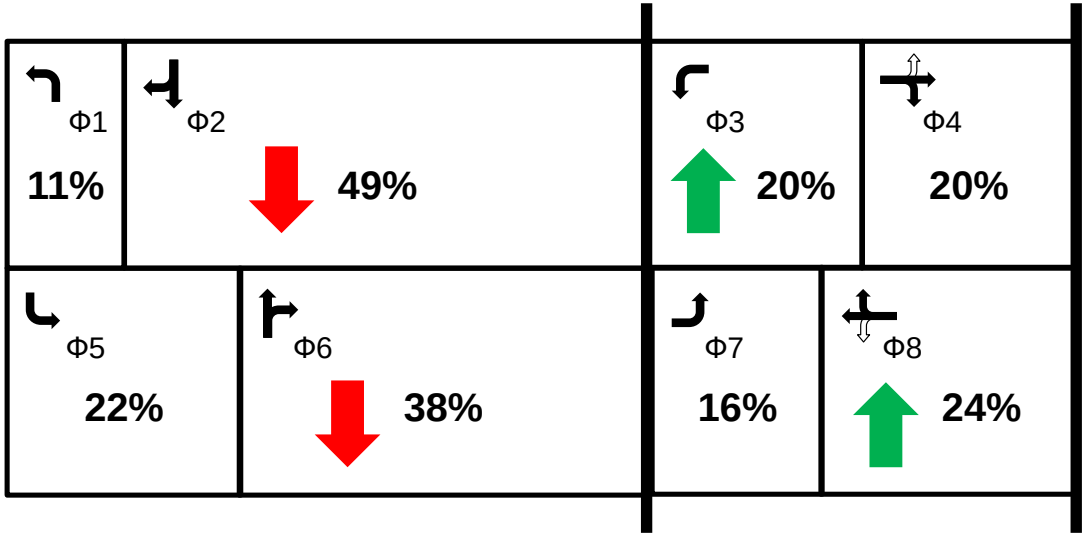


Split Time Adjustment

Before



After



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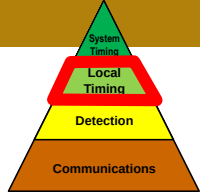
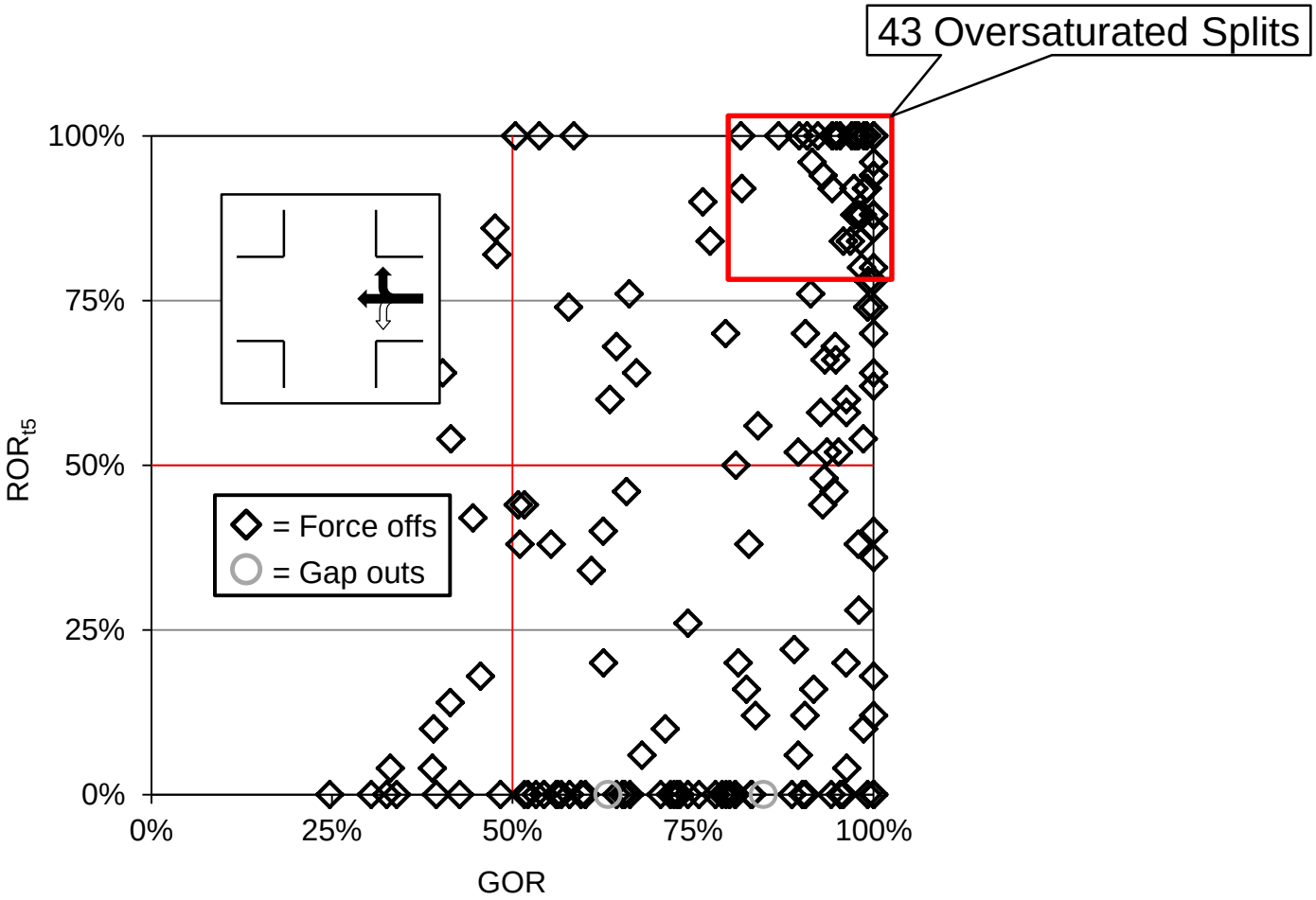


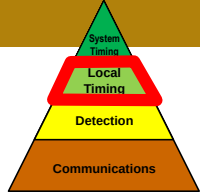
Phase 8 – Before and After Comparison

Before Split Adjustment



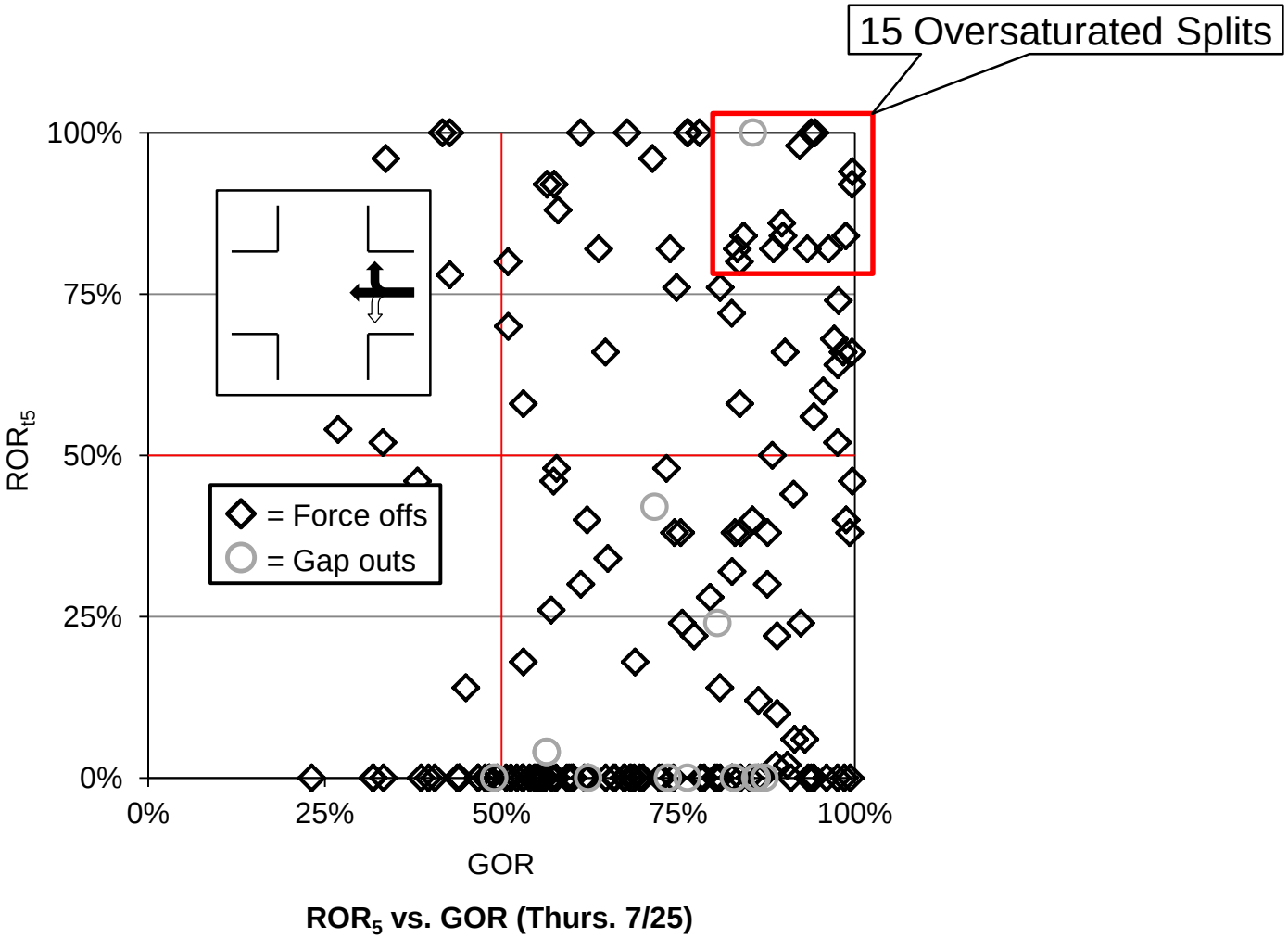
ROR$_5$ vs. GOR (Thurs. 7/18)

Freije, R., A.M. Hainen, A. Stevens, H. Li, W.B. Smith, C.M. Day, J.R. Sturdevant, and D.M. Bullock. Graphical performance measures for practitioners to triage split failure trouble calls. *Transportation Research Record No. 2439,* 27-40, 2014.



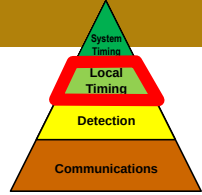
Phase 8 – Before and After Comparison

After Split Adjustment

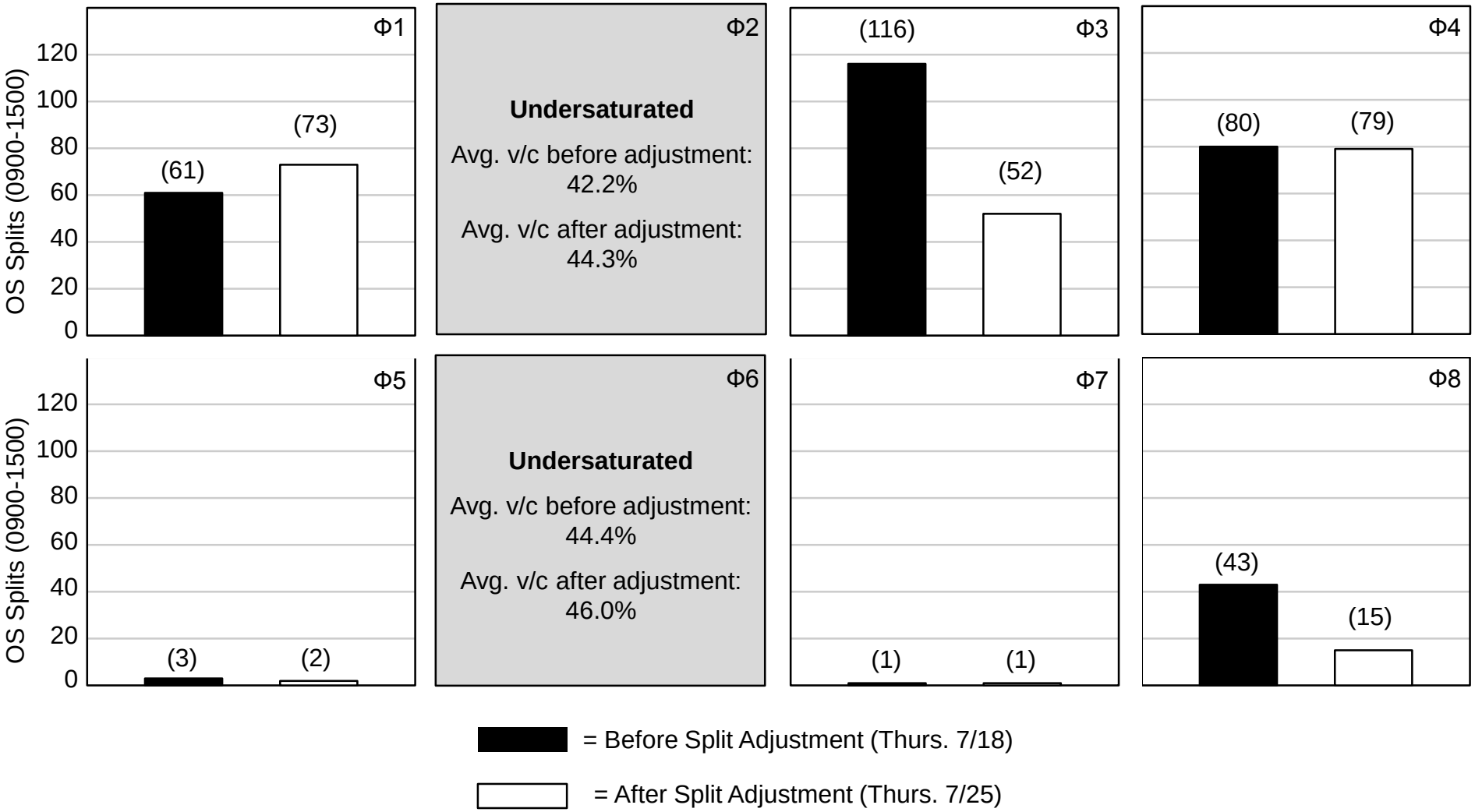


ROR$_5$ vs. GOR (Thurs. 7/25)

Freije, R., A.M. Hainen, A. Stevens, H. Li, W.B. Smith, C.M. Day, J.R. Sturdevant, and D.M. Bullock. Graphical performance measures for practitioners to triage split failure trouble calls. *Transportation Research Record No. 2439,* 27-40, 2014.



Before and After Comparison – All Phases



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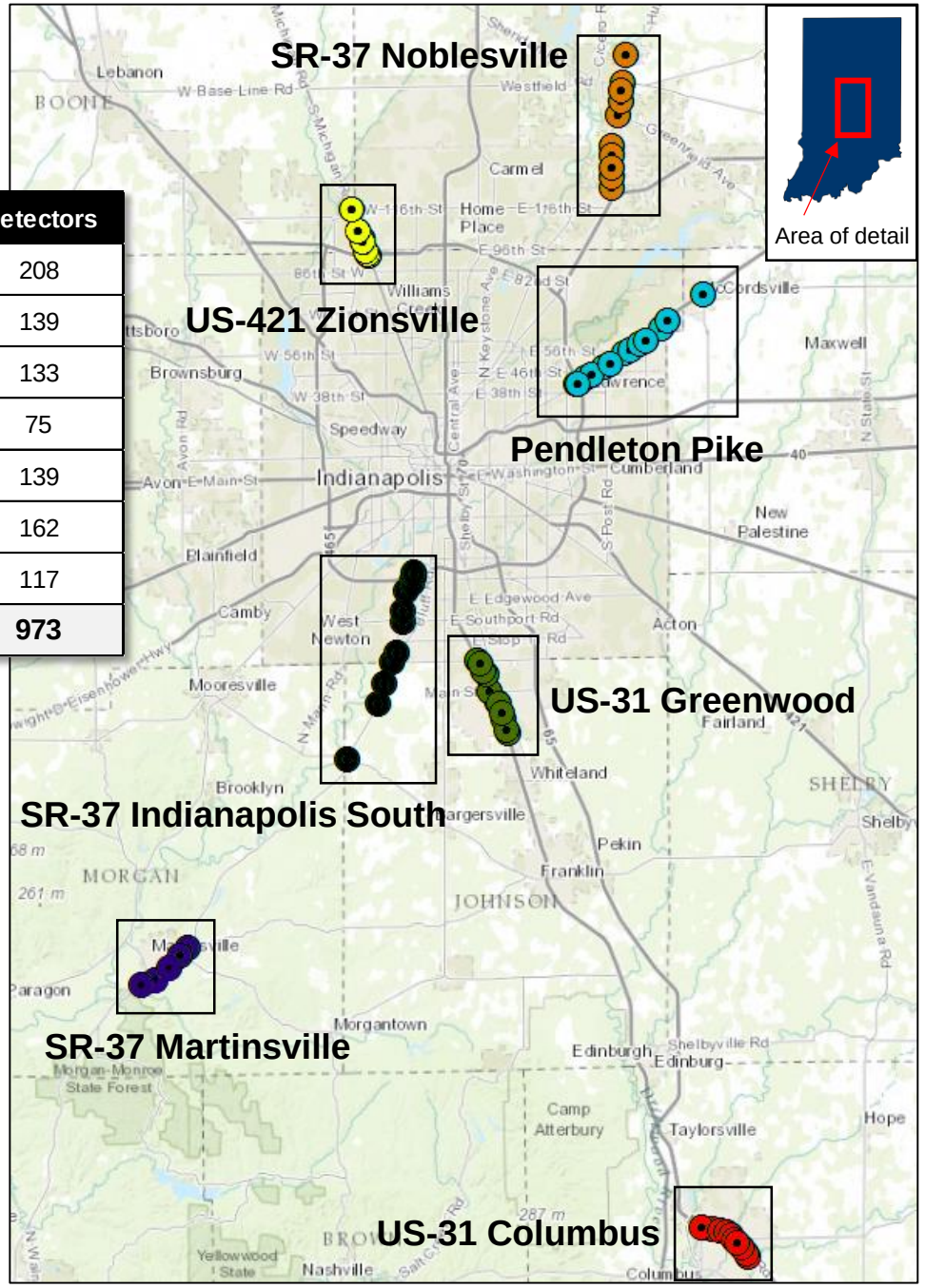
Scalability for Statewide & Longitudinal Analysis

Corridor	Intersections	Phases	Lanes	Detectors
Pendleton Pike	14	133	192	208
US-31 Greenwood	11	93	141	139
US-31 Columbus	10	95	132	133
SR-37 Martinsville	5	39	53	75
SR-37 Noblesville	10	99	137	139
SR-37 Indianapolis South	13	99	151	162
US-421 Zionsville	7	79	101	117
Total	**70**	**637**	**907**	**973**



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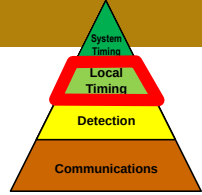
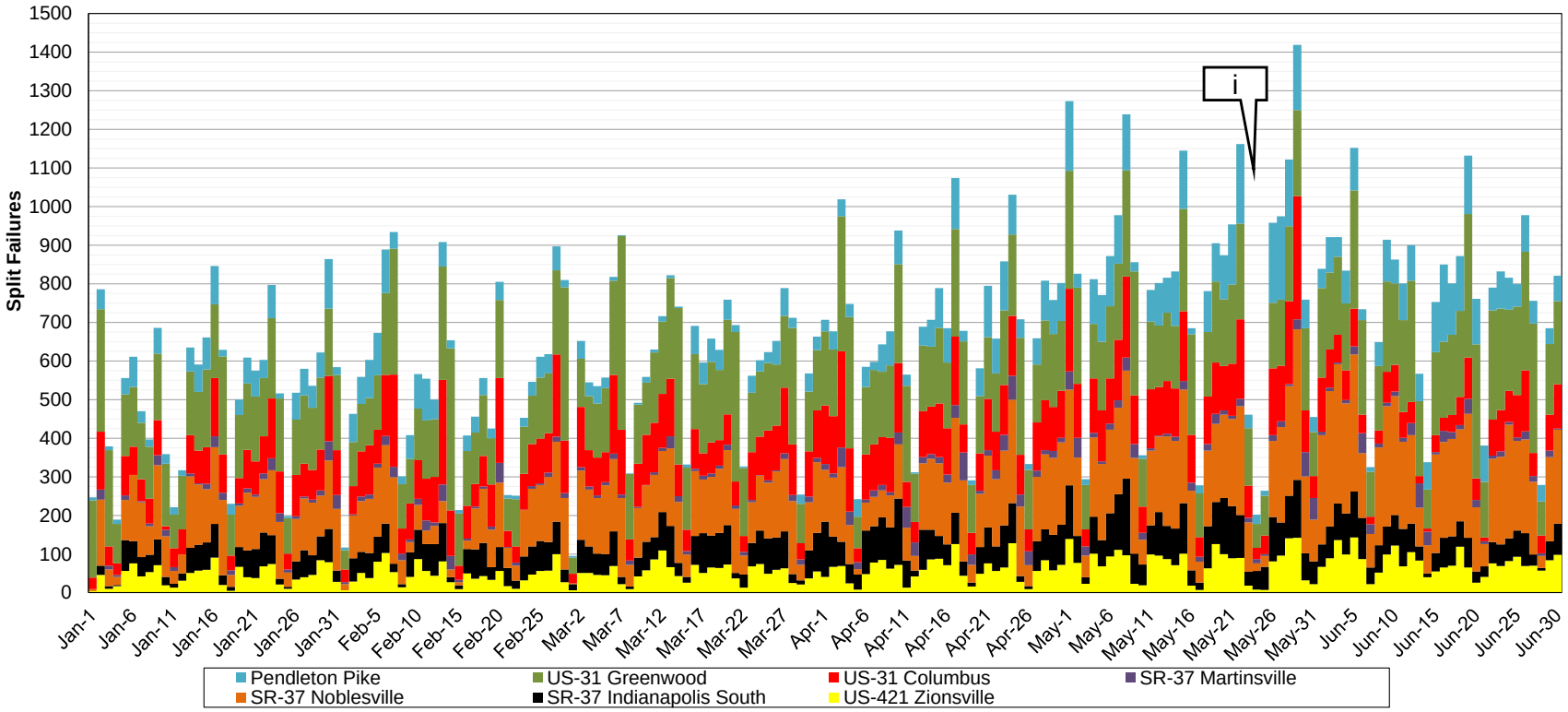


All Split Failures by Corridor in Indiana: 1/1/2015—6/30/2015



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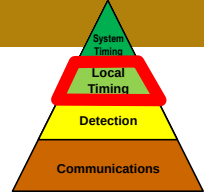
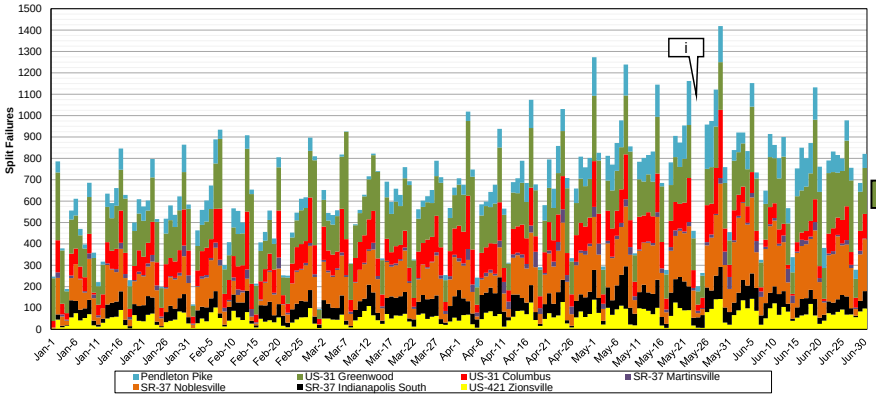
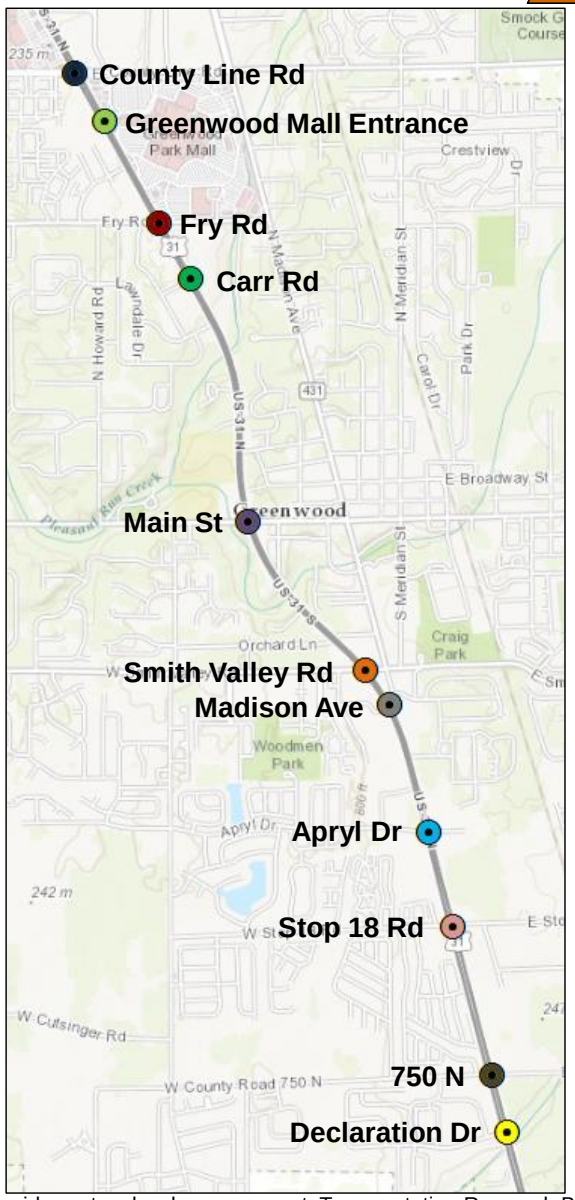


Drill down to corridor (US 31 Greenwood)





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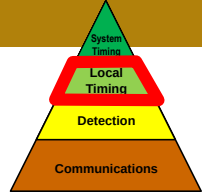
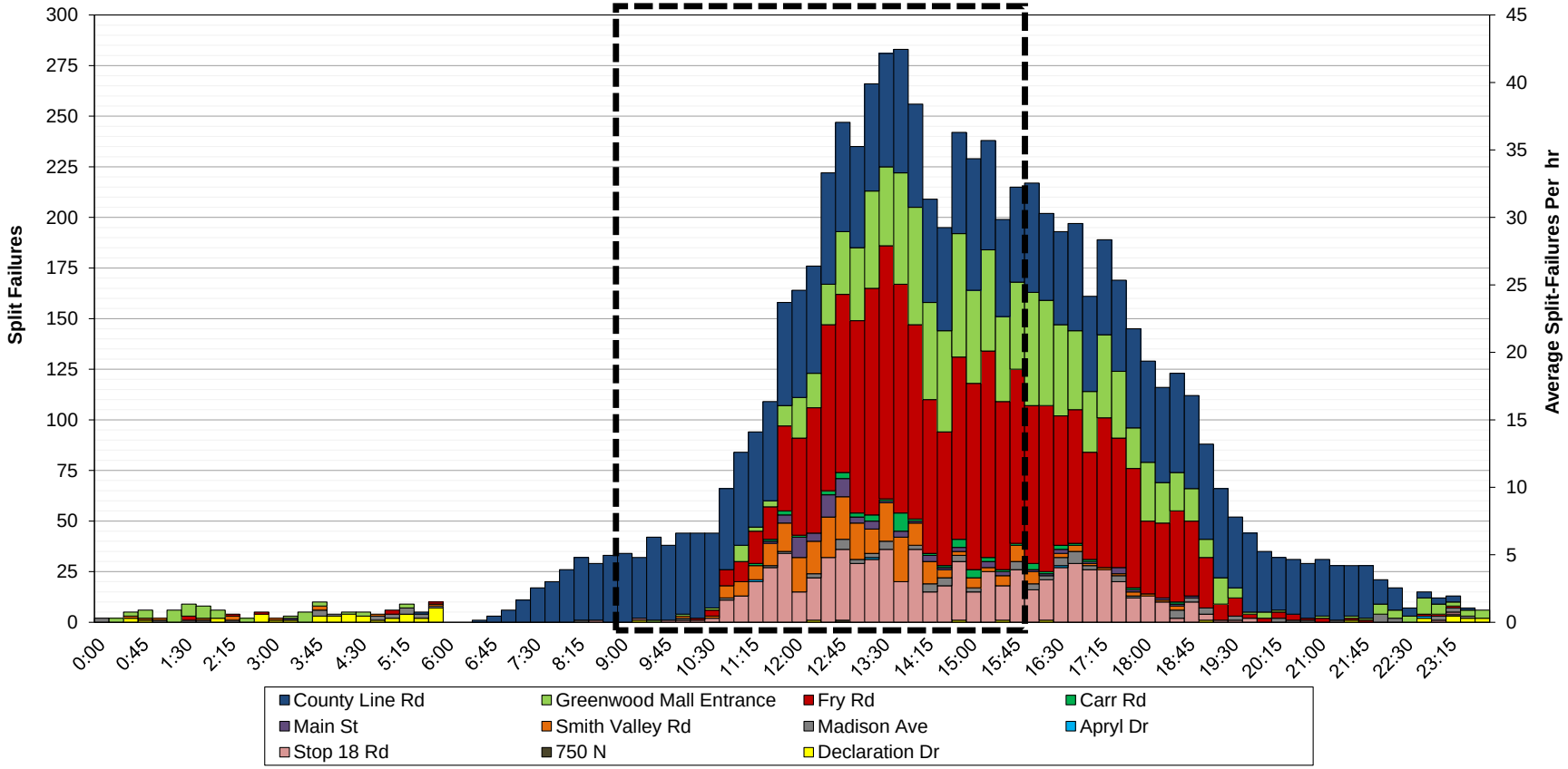


US 31 Greenwood: Split Failures by Intersection by Time of Day



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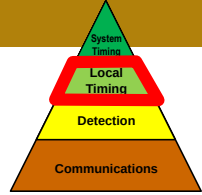
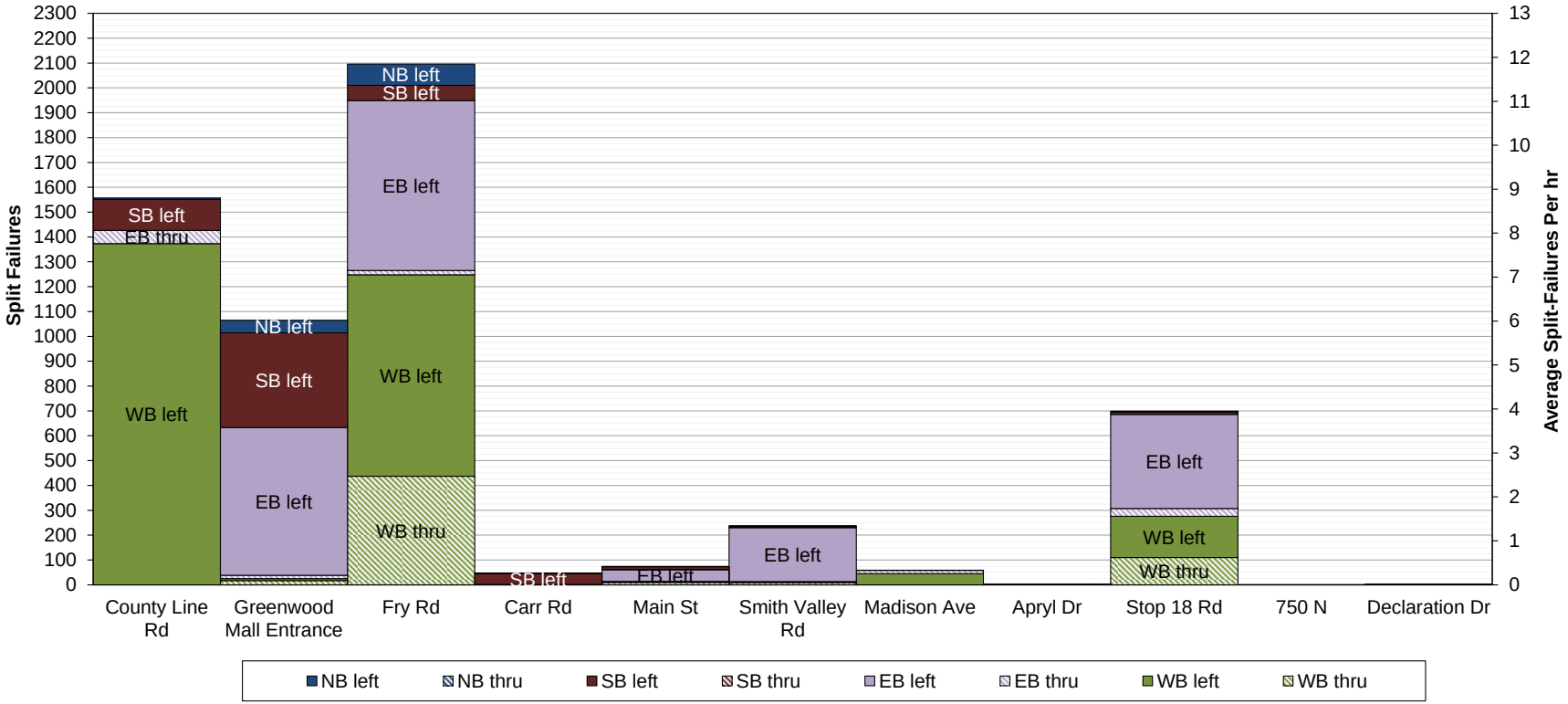


US 31 Greenwood: Split Failures by Intersection and Movement



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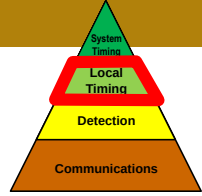


Integration with Maps and Video

Signal Metrics Canvas

https://its.ecn.purdue.edu/canvas_dev/

Performance Measure

Lane | Lanegroup

Volume | PCD
Green time | GOR/ROR5
Occupancy | Split Failure

Date Range

2015-04-07 to 2015-04-07

Time of Day

12AM 6AM 9AM 3PM 6PM

18:30 to 20:30

Map | Satellite

SR 228 & US 19, NBLT(Ø1), L

4/7/15 (18:30-20:30)

Red Occupancy Ratio (first 5 sec.)

Green Occupancy Ratio

Force-off
Time: 19:23:46
GOR: 0.97647
ROR5:0.96

4/7/2015 7:23:46 PM

Perry Hwy

ATM USA

Sheetz

AT&T

Vocelli Pizza

Gigliotti Plaza

Farmers Insurance

Dublin Rd

St Francis Way

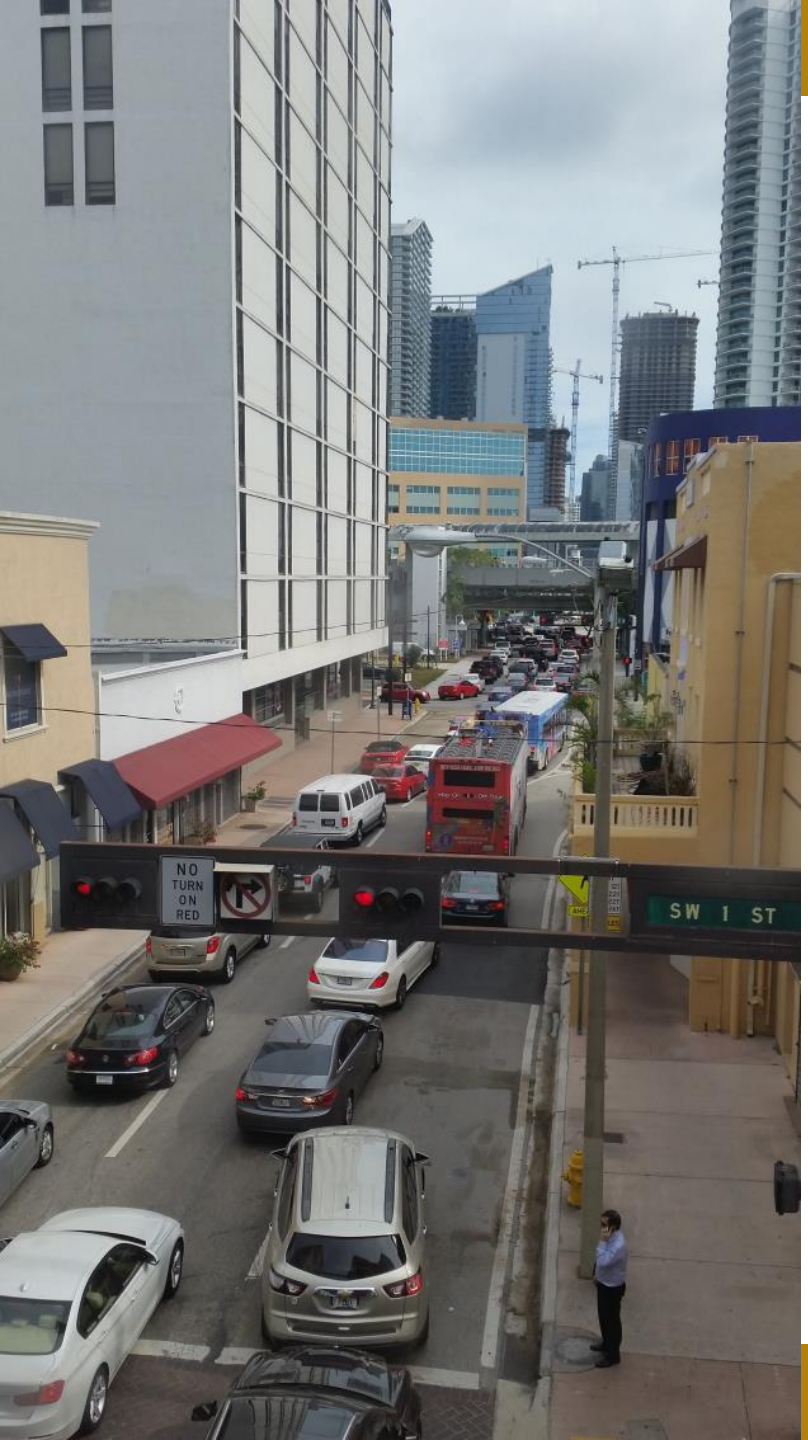
Rent-A

Google

PURDUE

Overview

- Motivation for performance measures
- Travel time example
- Introduction of high resolution data
- Hierarchy of needs: Communication, Detection, Capacity, Progression
- Example performance measures that begin at the movement level, which are scalable to a system level view
- Next session will focus on Progression



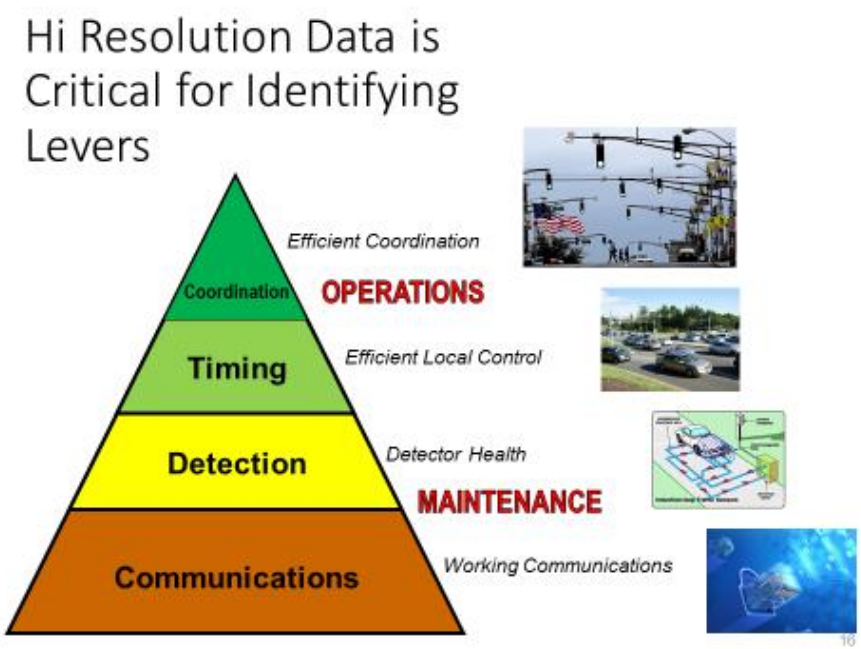
Longitudinal Arterial Corridor Optimization and Assessment

Chris Day, P.E., Ph.D.

Sunday, May 1, 2016

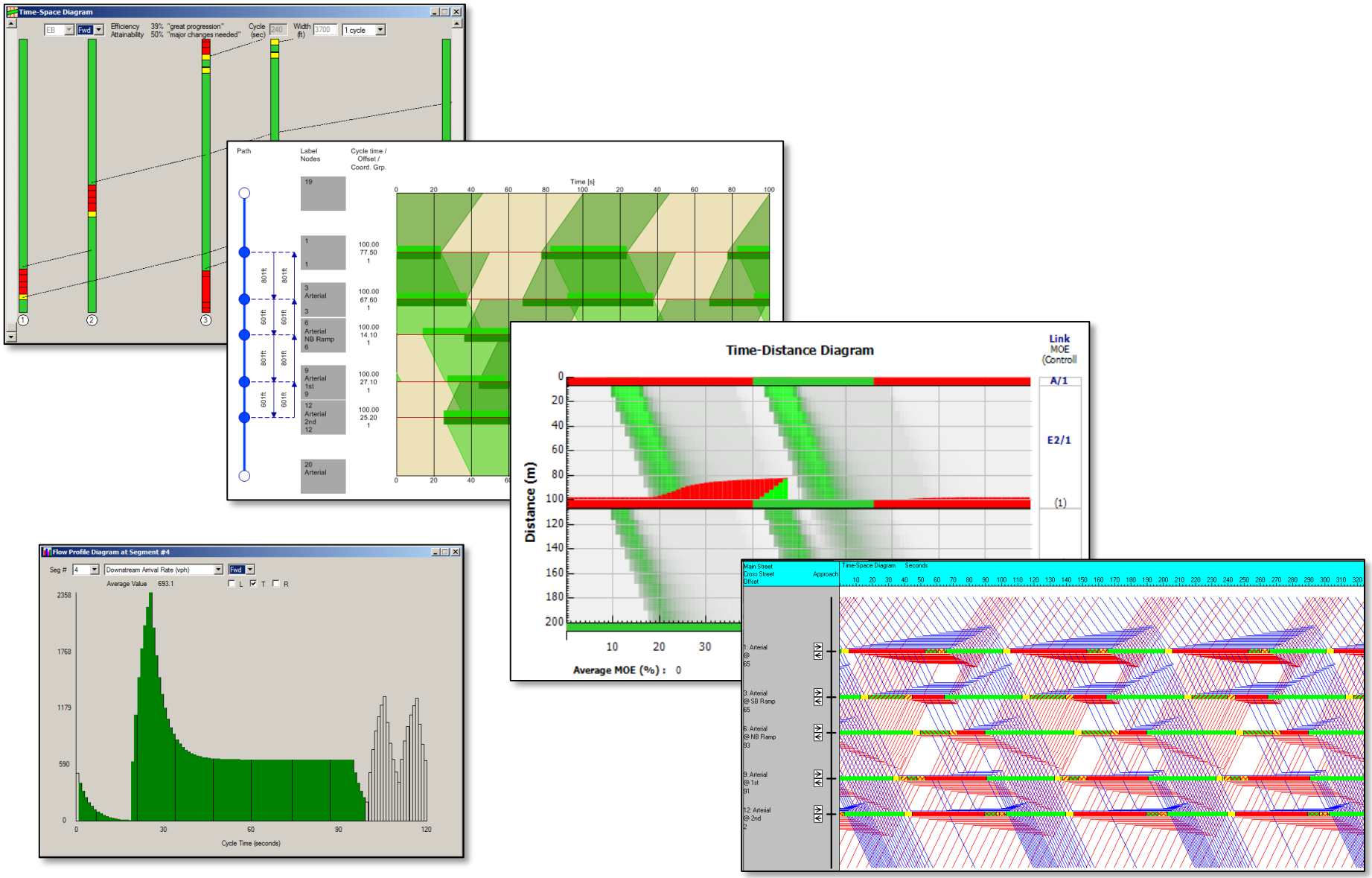
PURDUE
UNIVERSITY

Critical Performance Measures for Managing Signals

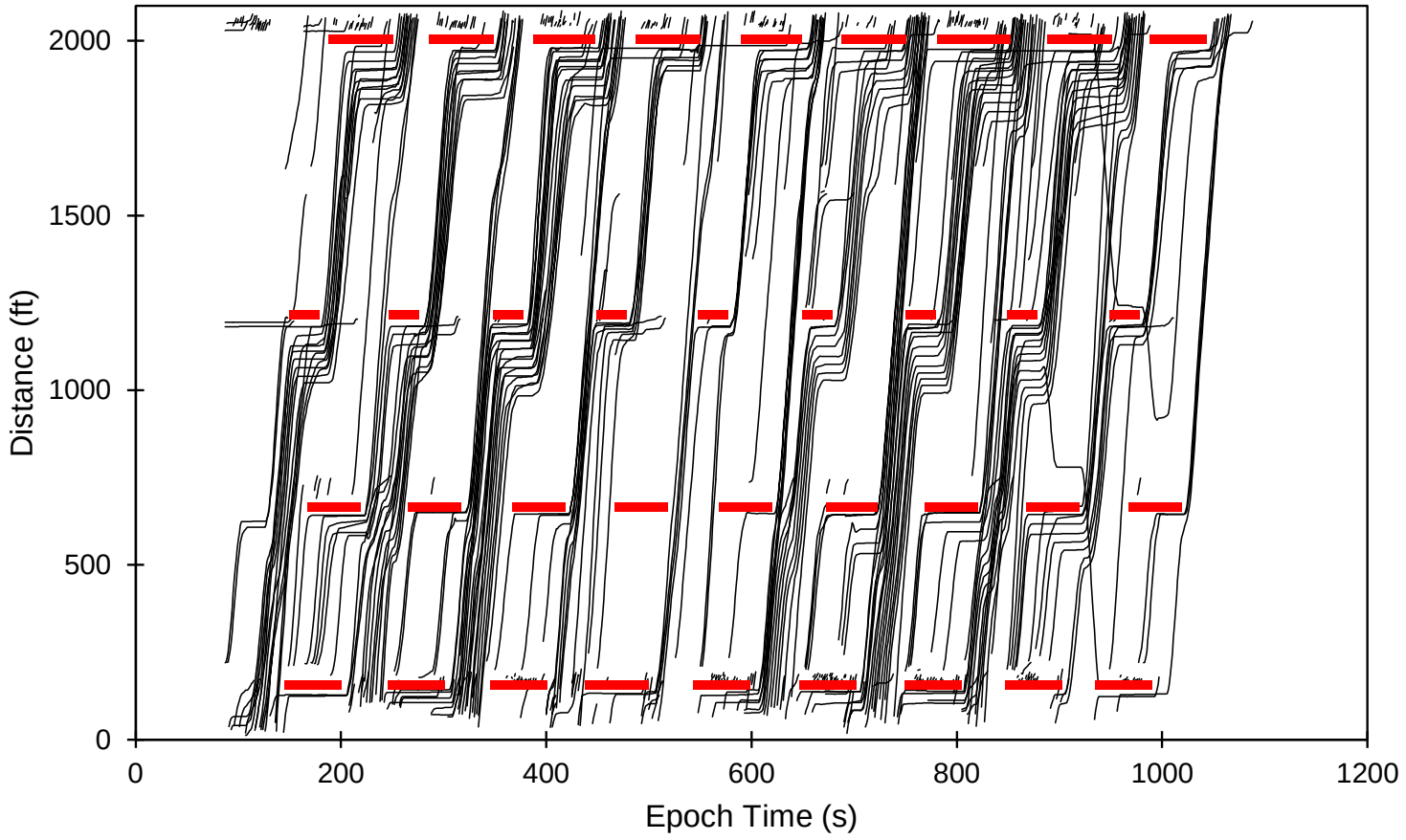


1. Is my communication working?
2. Are my detectors working?
3. Do I have adequate green time on each phase?
4. **Do I have most of my vehicles arriving on green?**

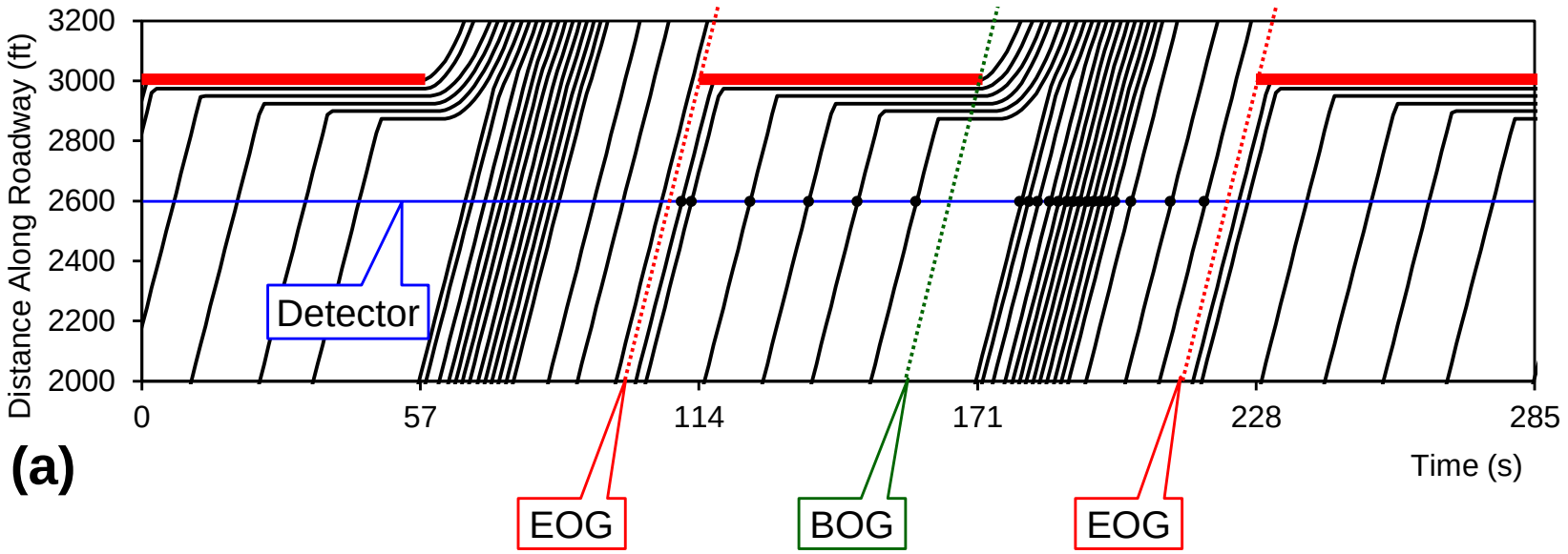
Traditional Approach: Modeling

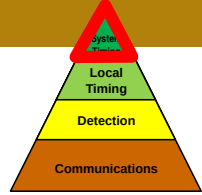


Vehicle Trajectories… (NGSIM Data)



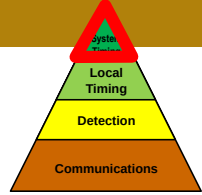
What Can be Measured with Existing Infrastructure?





"Do I Have Most of my Vehicles Arriving on Green?" Coordination Diagram Concept

https://www.youtube.com/watch?v=YhrtTuhcjMw



Coordination Diagram (60 Minutes during the AM Peak)

Start of Red

Arrivals in Green

Vehicle Platoon

Arrivals in Red

Start of Green

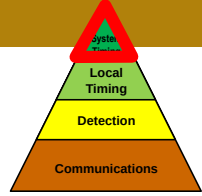
$$P = \frac{N_g}{N}$$

Time In Cycle (s)

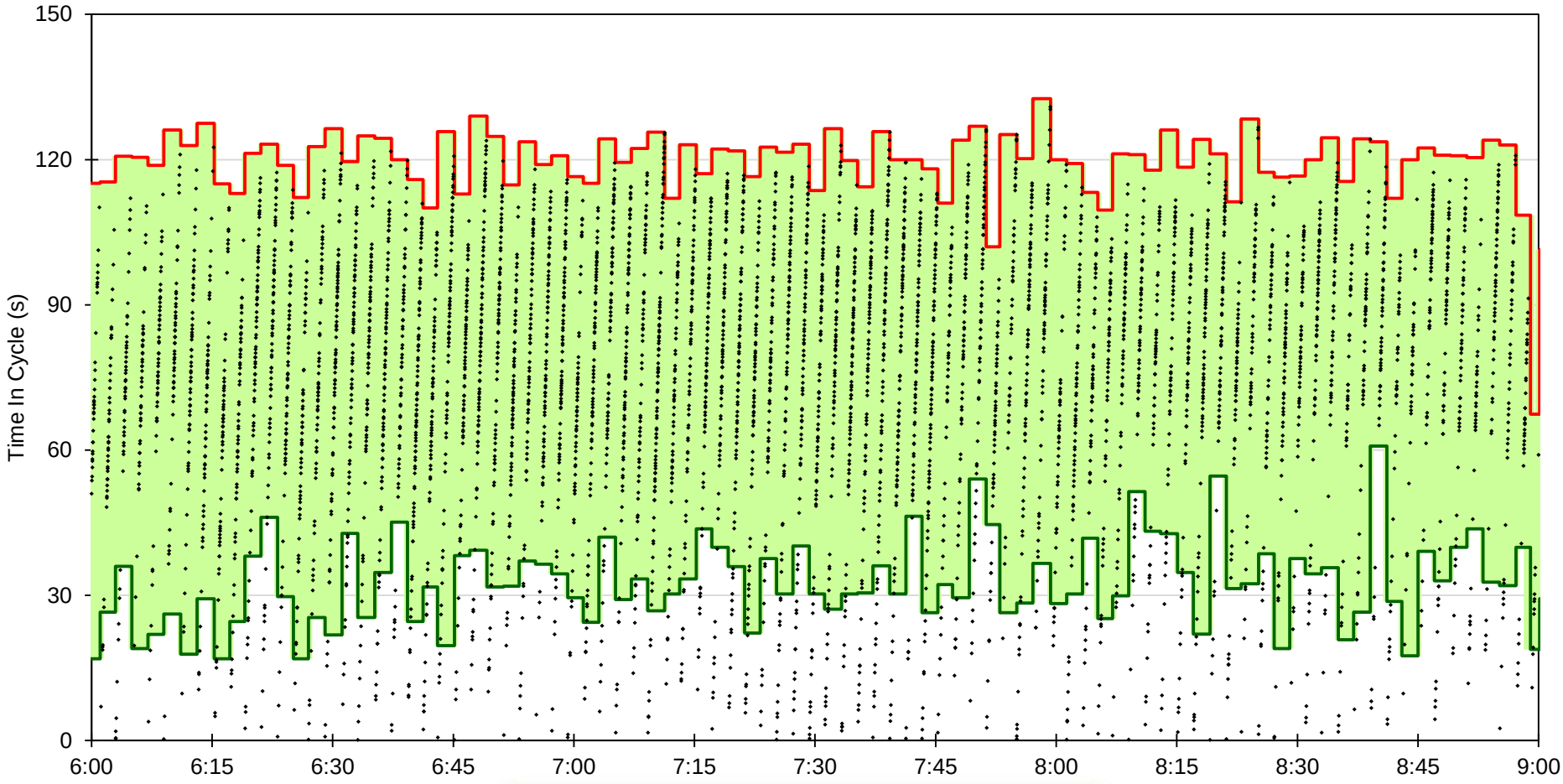
150
120
90
60
30
0

6:00 6:05 6:10 6:15 6:20 6:25 6:30 6:35 6:40 6:45 6:50 6:55 7:00

Day, C.M., D.M. Bullock, H. Li, S.M. Remias, A.M. Hainen, R.S. Freije, A.L. Stevens, J.R. Sturdevant, and T.M. Brennan *Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach*. West Lafayette, Indiana: Purdue University, 2014.

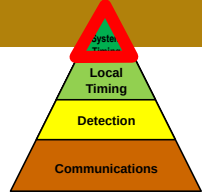


Coordination Diagram (Time of Day Plan … 6:00 to 9:00)

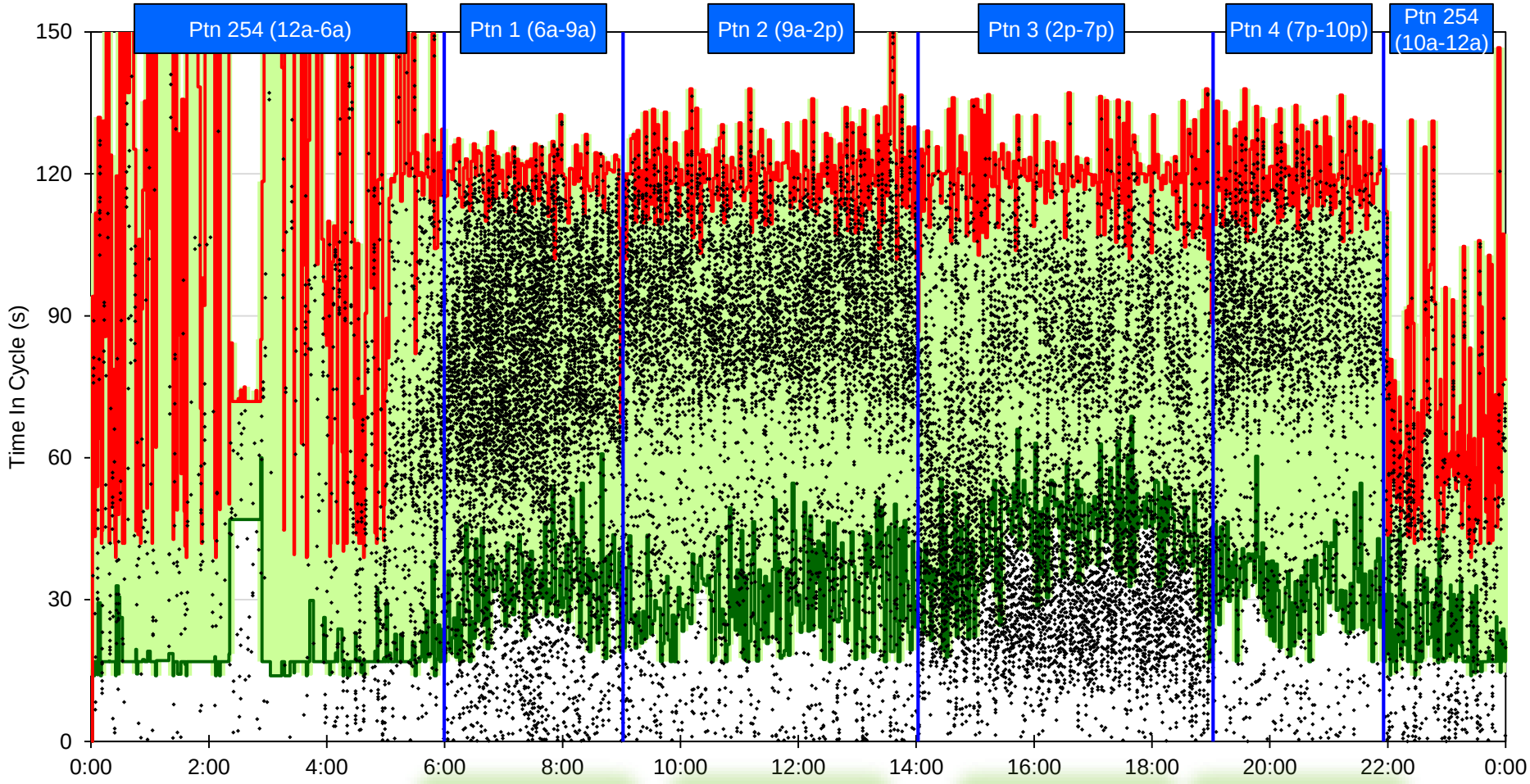


88.6% on Green

Day, C.M., D.M. Bullock, H. Li, S.M. Remias, A.M. Hainen, R.S. Freije, A.L. Stevens, J.R. Sturdevant, and T.M. Brennan *Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach*. West Lafayette, Indiana: Purdue University, 2014.



Coordination Diagram (24 Hours)



88.6% on Green

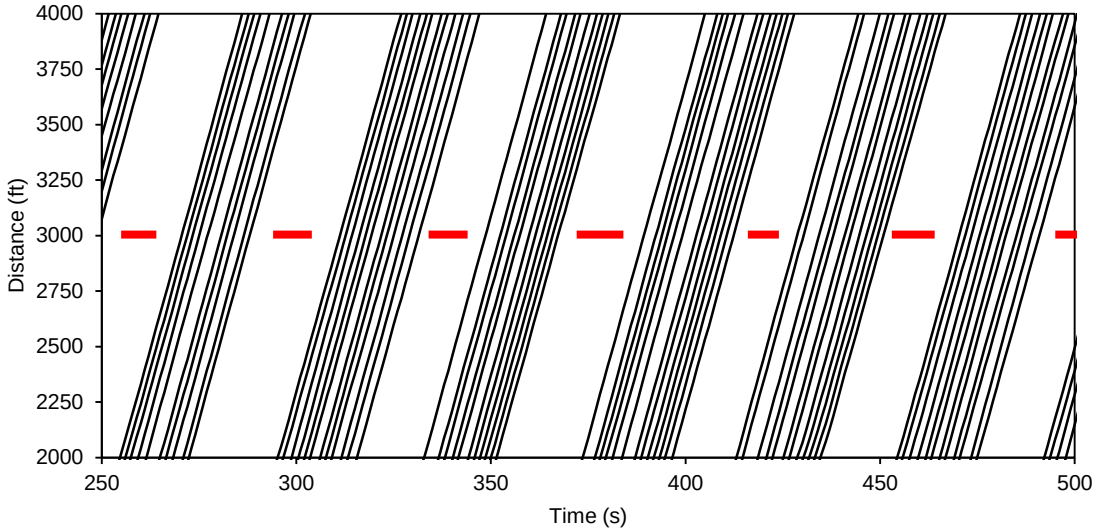
91.6% on Green

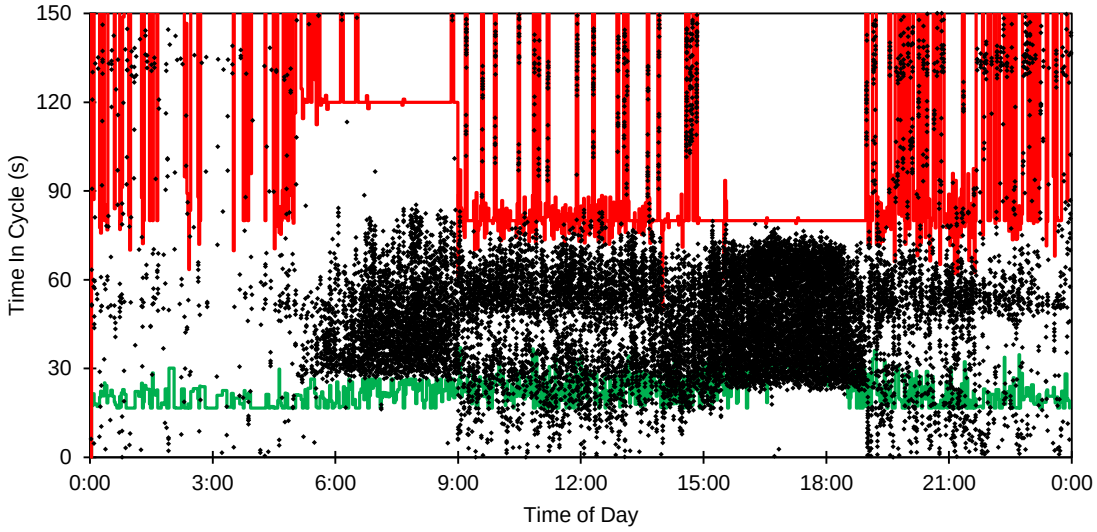
56.6% on Green

91.0% on Green

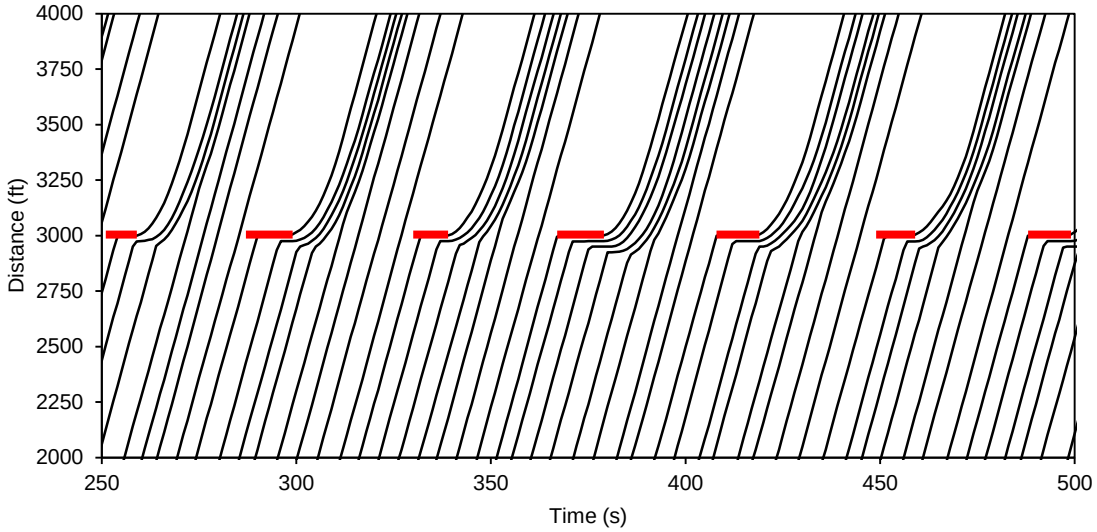
Day, C.M., D.M. Bullock, H. Li, S.M. Remias, A.M. Hainen, R.S. Freije, A.L. Stevens, J.R. Sturdevant, and T.M. Brennan *Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach*. West Lafayette, Indiana: Purdue University, 2014.

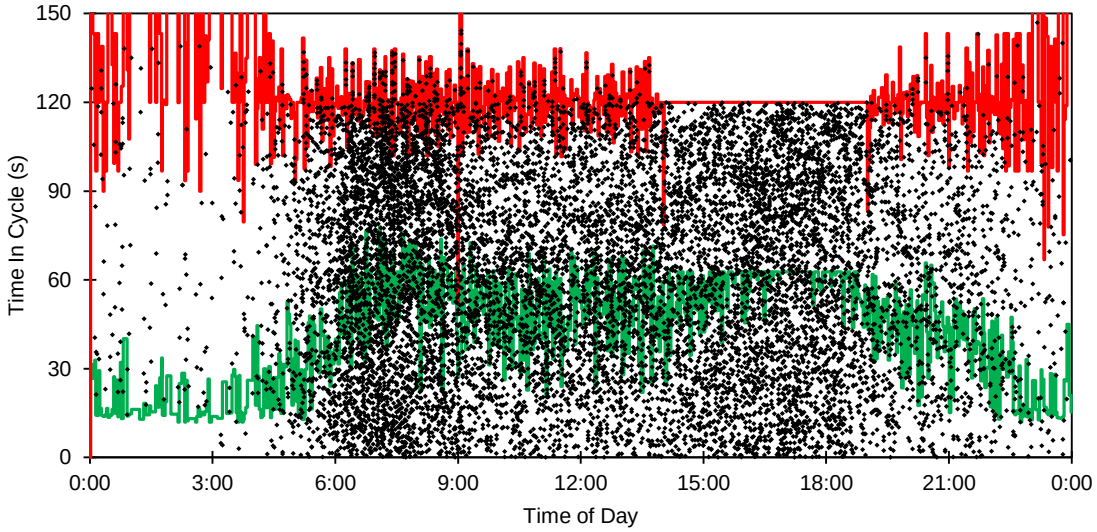
Example #1
Very Good Progression… (Inside Well Timed Diamond Interchange)



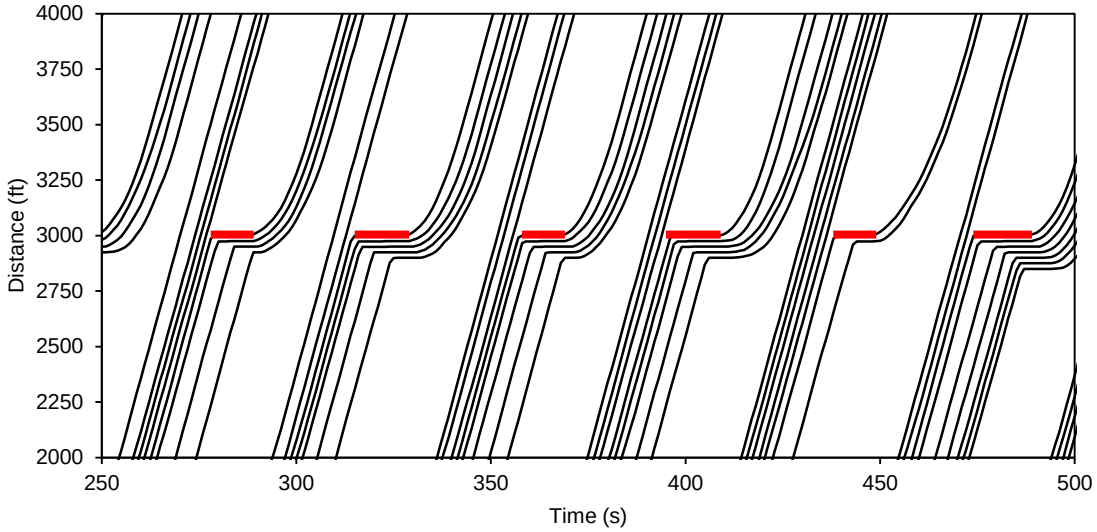


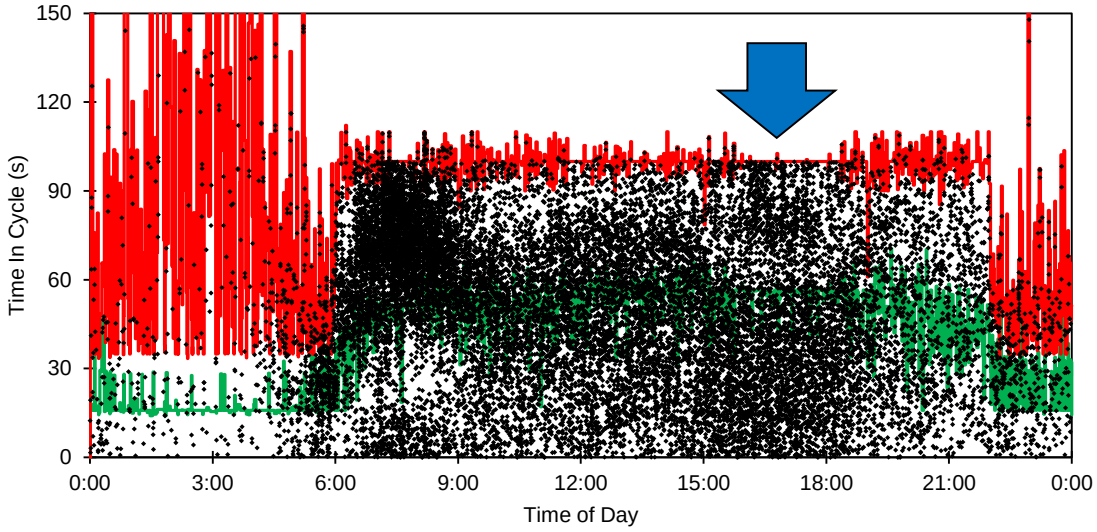
Example #2
Random Arrivals (Entry into a system)



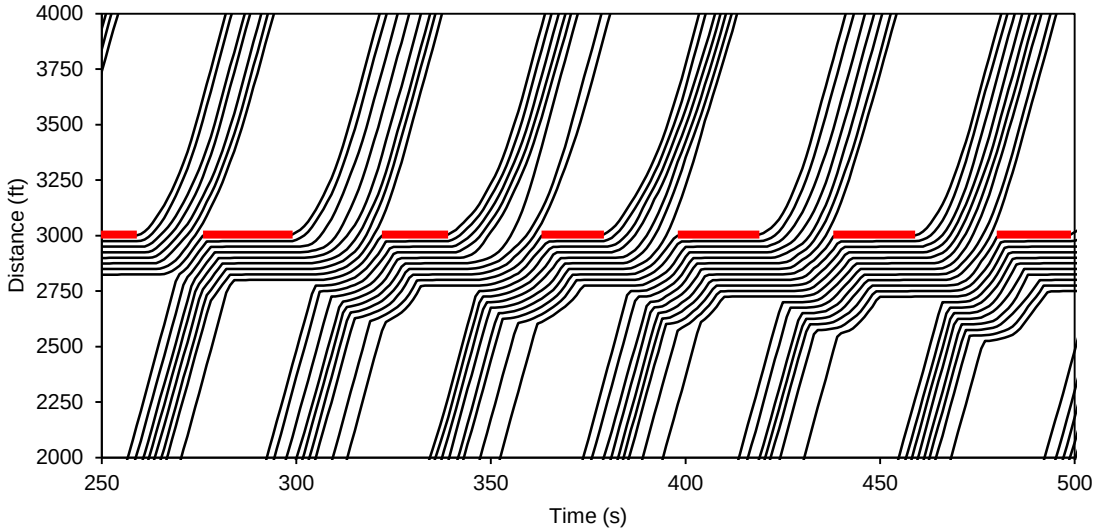


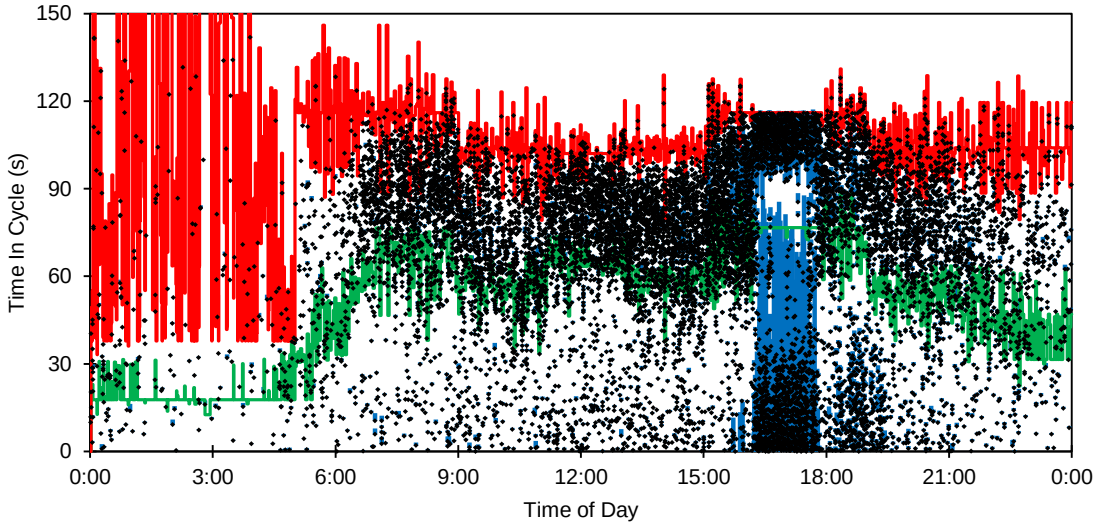
Example #3
Poor Progression



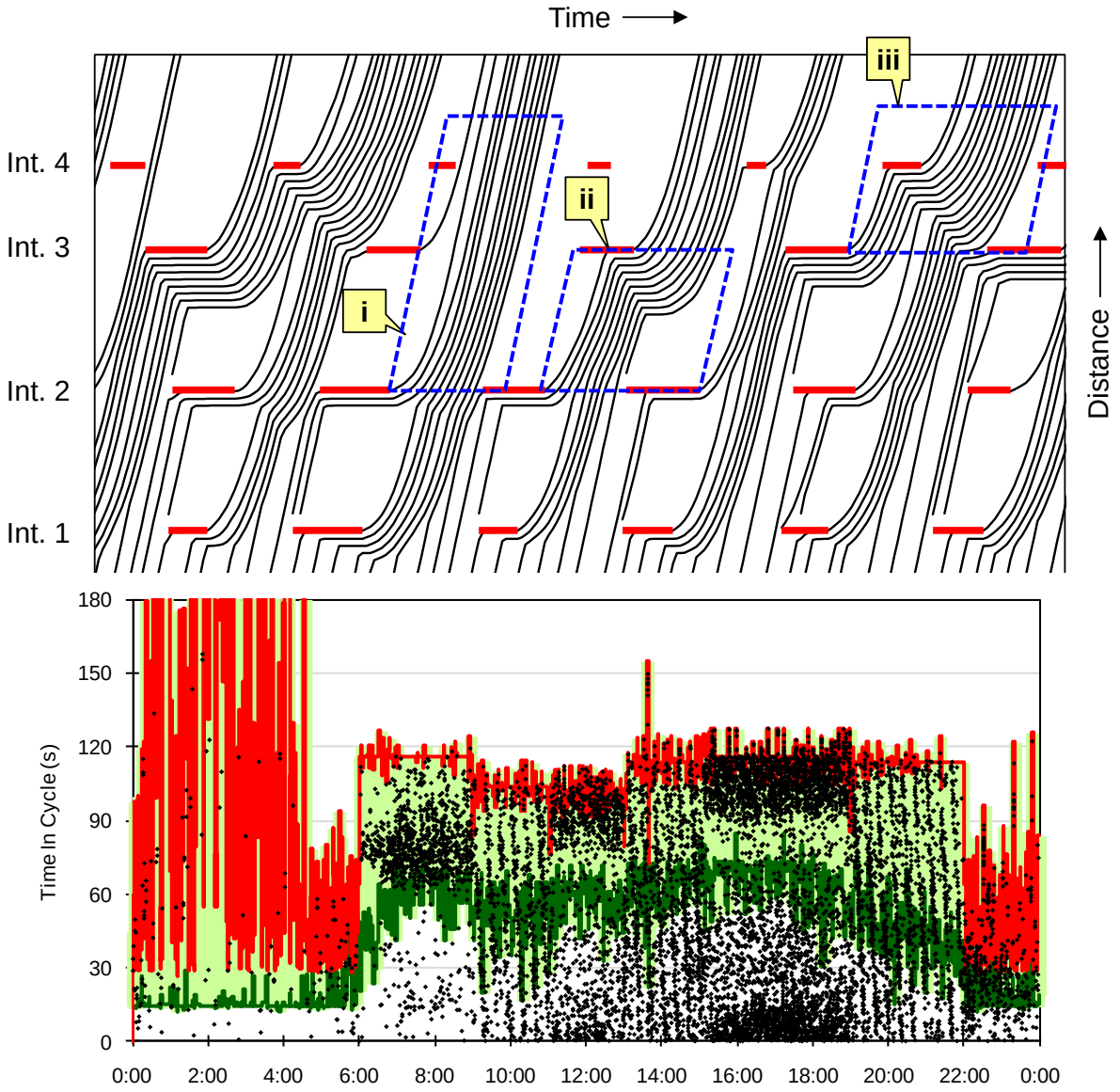


Example #4
Queue over Detector

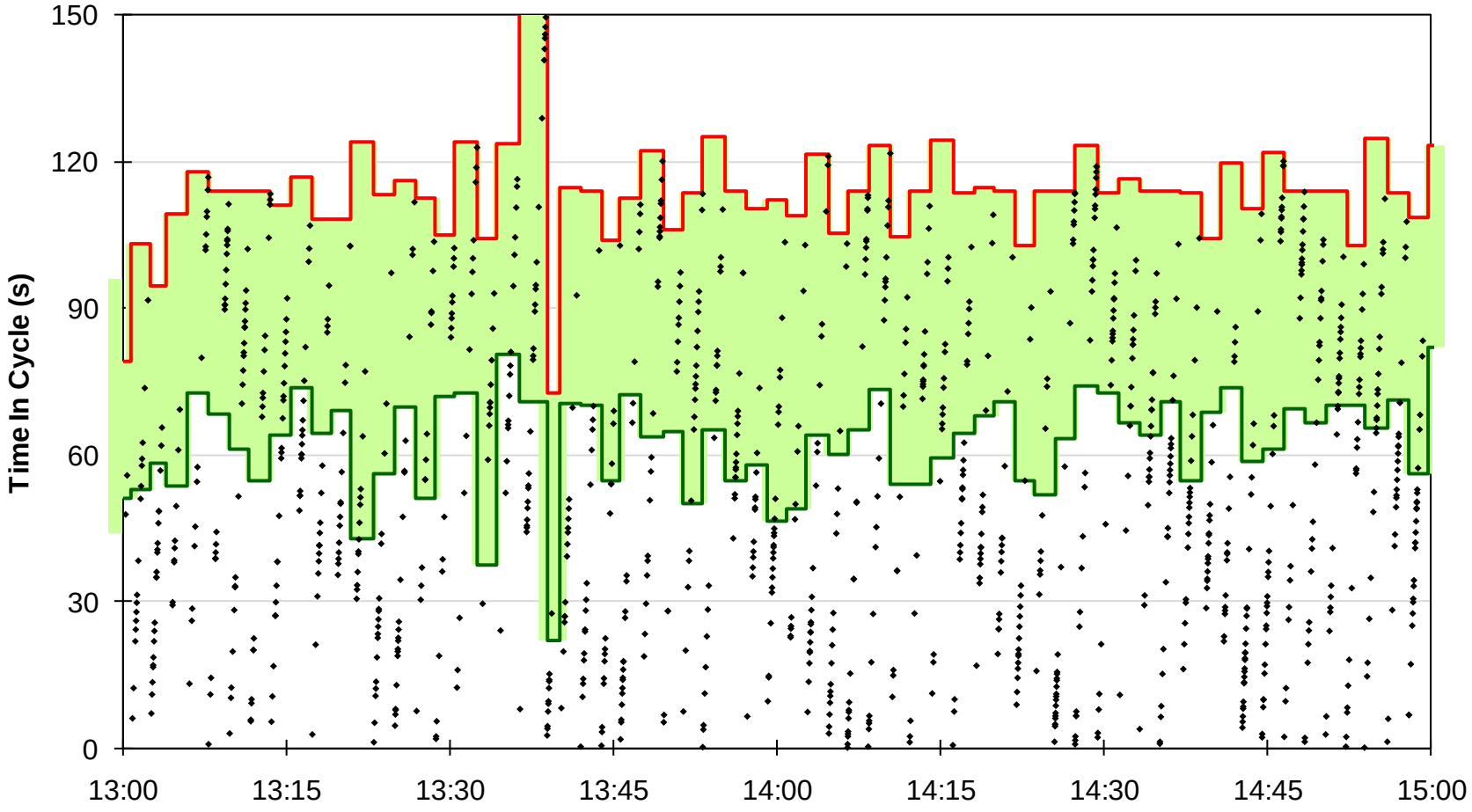




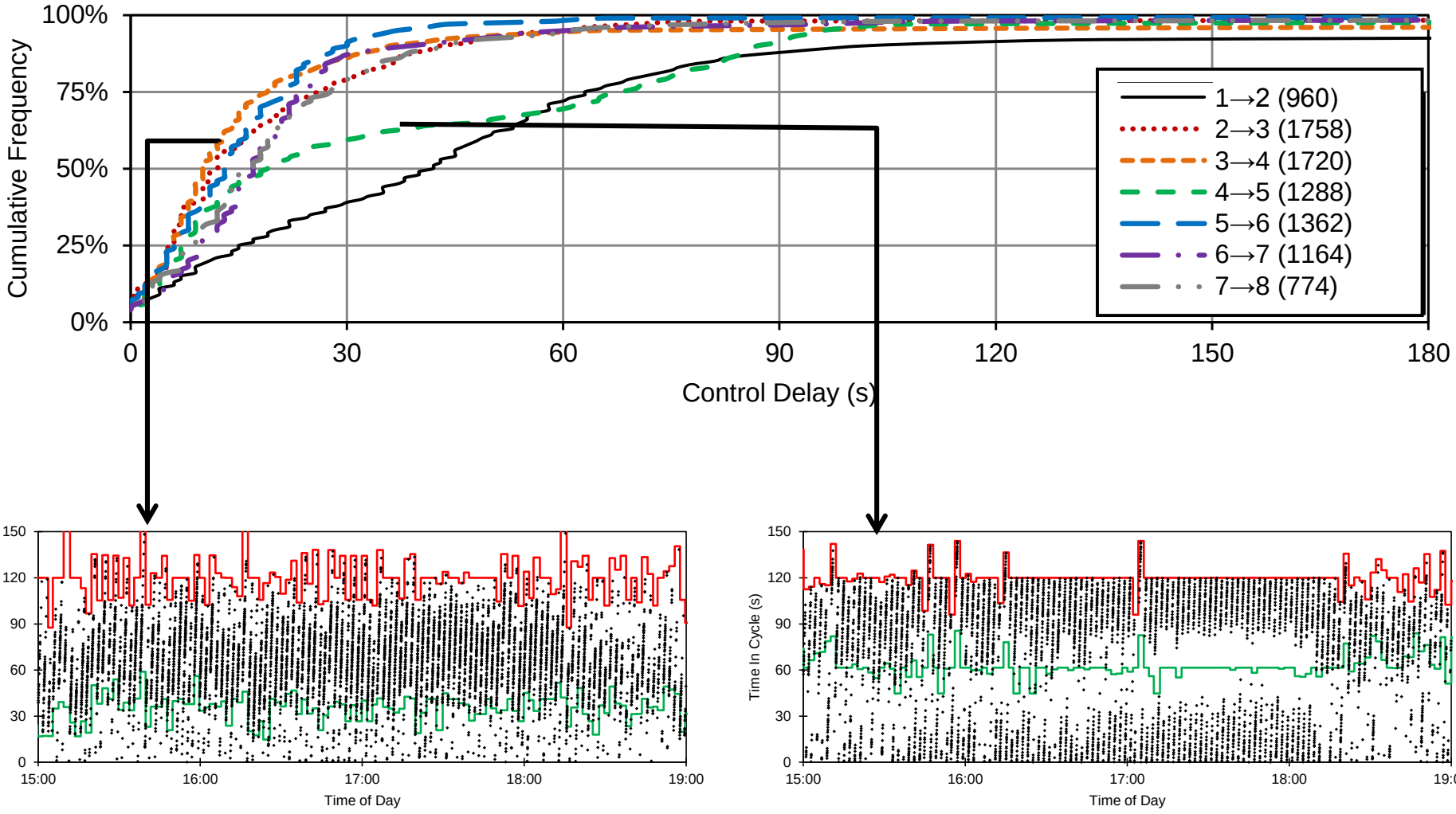
Example #5
Cycle Length Mismatch



Cycle Length Mismatch… Close Up



Return to the Link Based Travel Times…



I-65 Detour

'SHE CAME TO WIN' Purdue-bound blind pole vaulter medals at state meet Sports, 1D

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SUNDAY, MAY 17, 2015 | LAFAYETTE – WEST LAFAYETTE | A GANNETT COMPANY

NIGHTMARE ON INTERSTATE 65

MORE THAN $240 IN COUPONS INSIDE TODAY!

WHAT THEY'RE DOING

OVERSIZE LOAD

CAUTION!

STAGE 1

SPEED LIMIT 45

DETOUR

GETTING AROUND IT

NOISE BARRIERS

STAGE 2

2 years of work to clog Lafayette's major artery

What changes are coming?

Fugitive surrenders

Suspect apprehended without incident after crime spree

USA TODAY

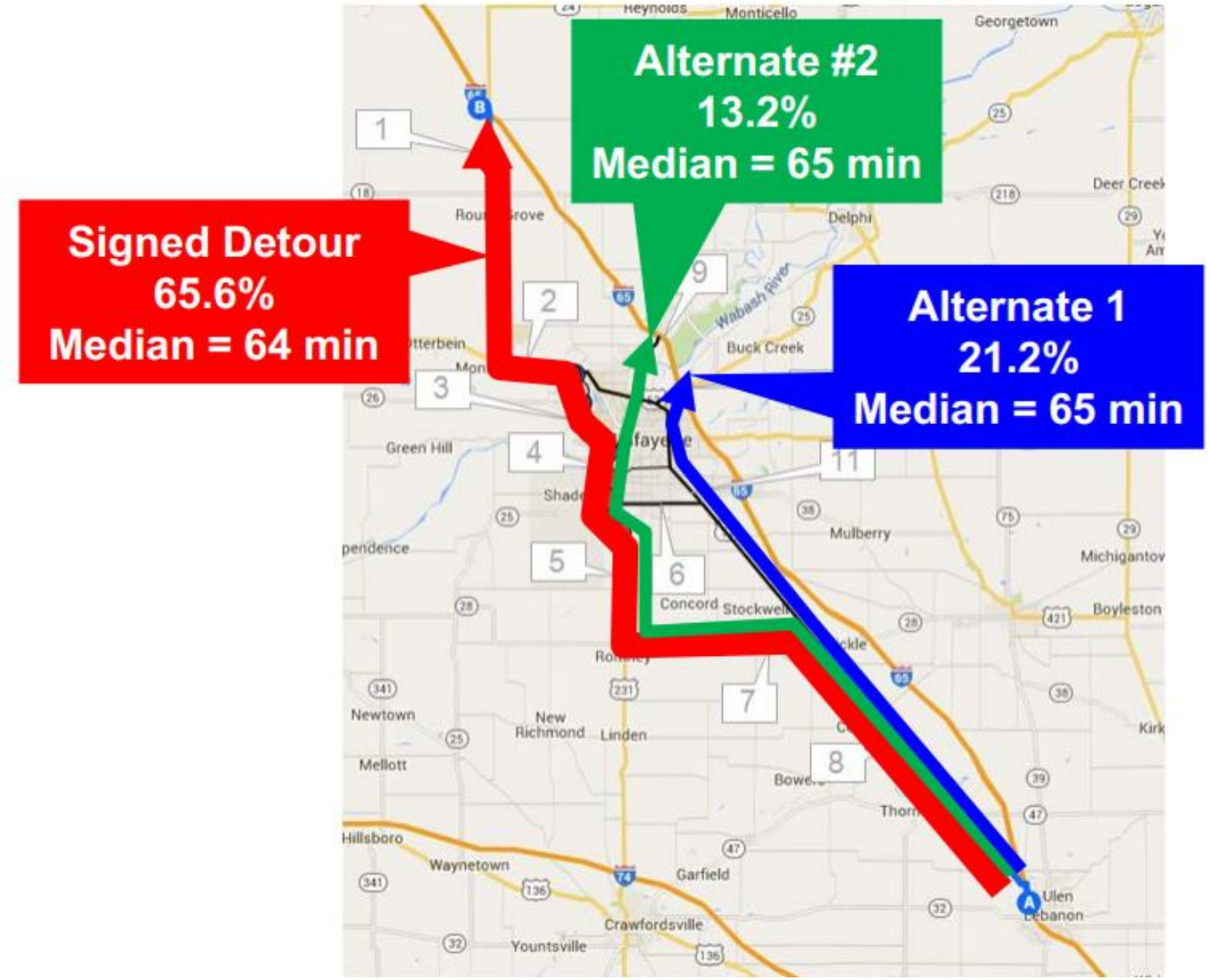
ISIL leader killed

U.S. troops carried out a raid inside eastern Syria. USA TODAY, 1B

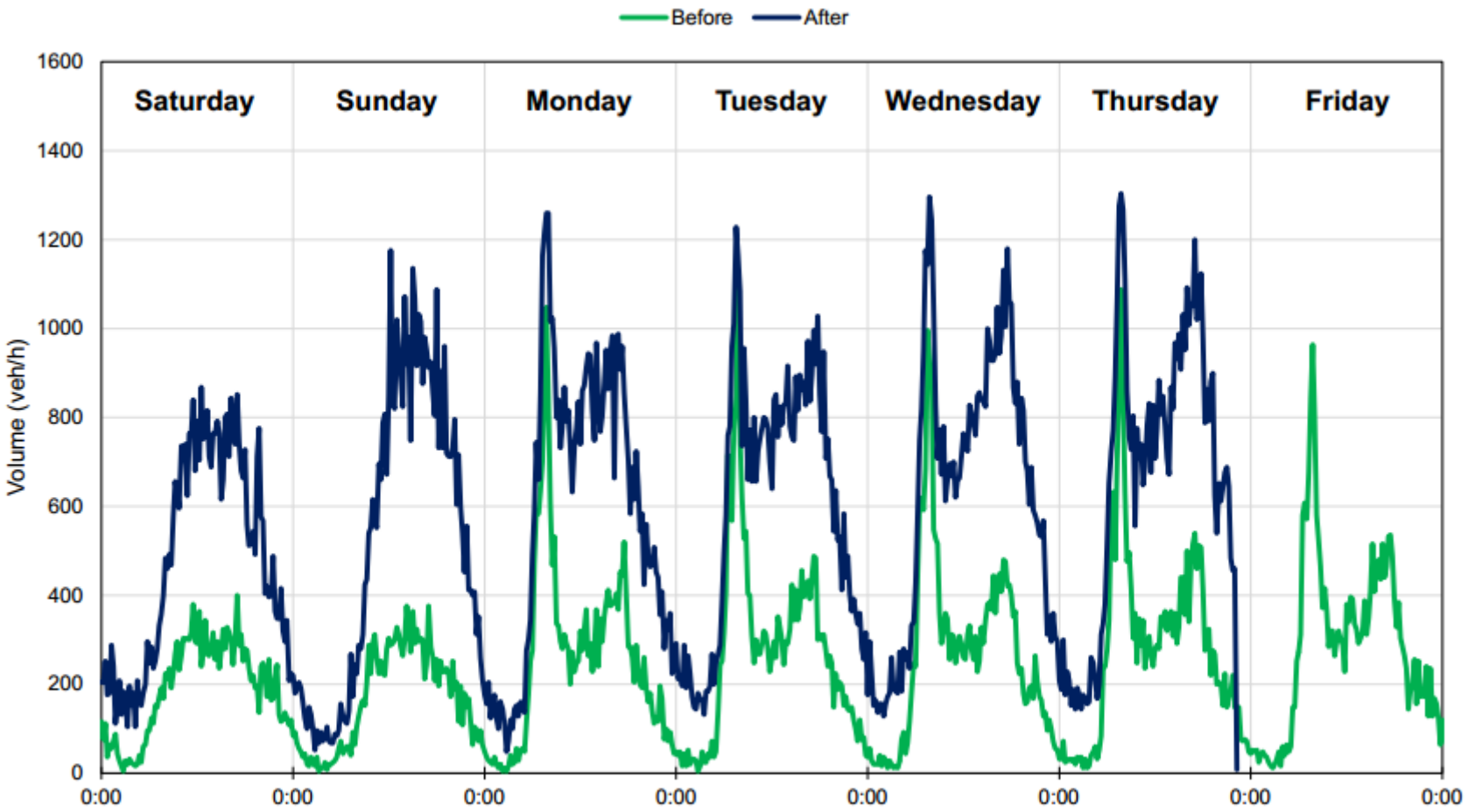
INDEX

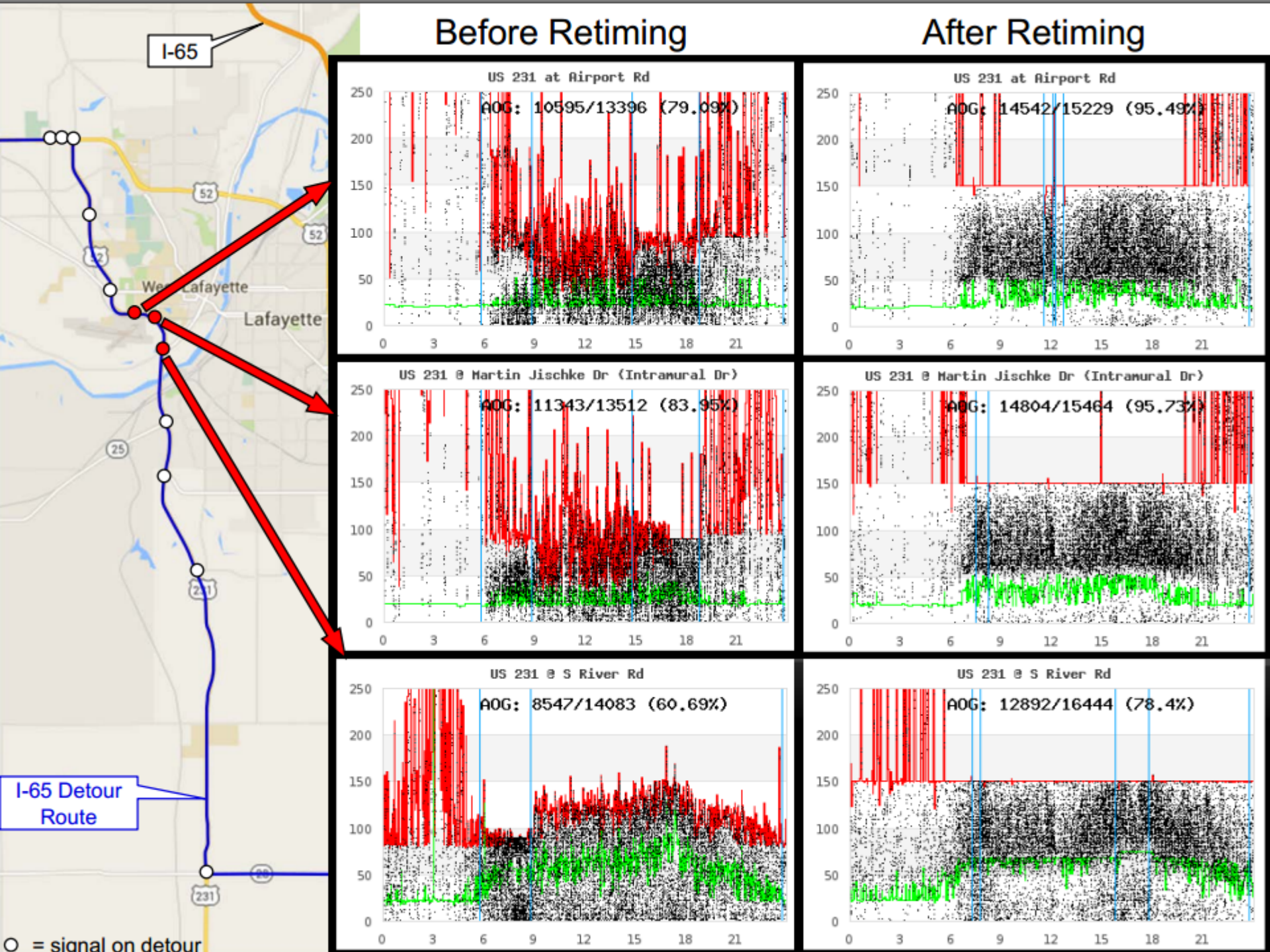
Franciscan EXPRESSCARE

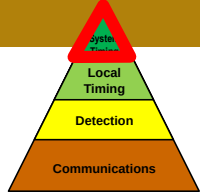
I-65 Detour Route Choice



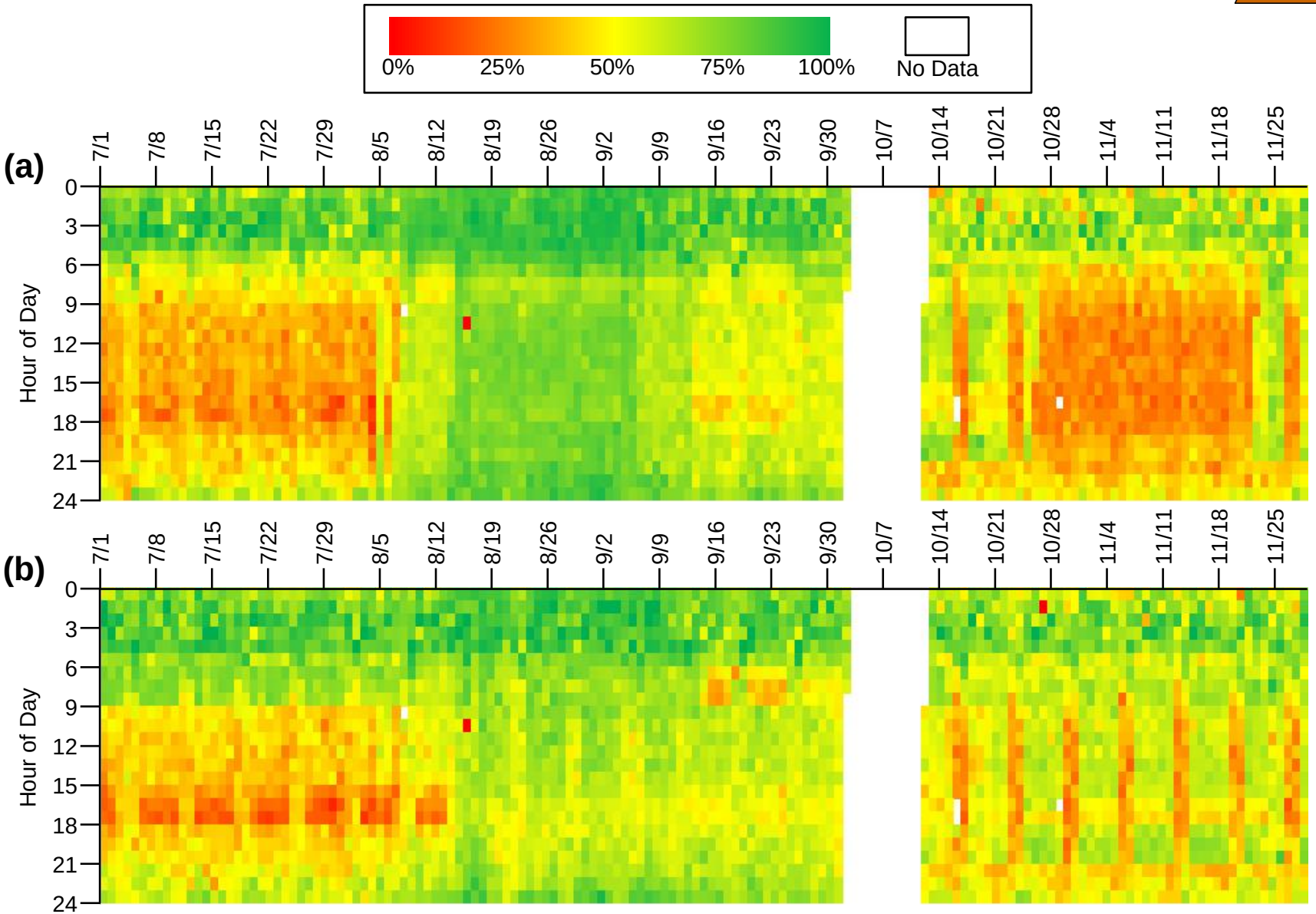
Northbound Volumes – US 231 & River Rd.



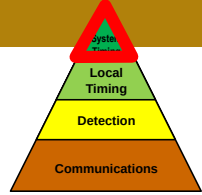

Before Retiming
After Retiming
I-65
52
52
25
231
231
Lafayette
Lafayette
I-65 Detour Route
= signal on detour
US 231 at Airport Rd
AOG: 10595/13396 (79.09%)
US 231 at Airport Rd
AOG: 14542/15229 (95.49%)
US 231 @ Martin Jischke Dr (Intramural Dr)
AOG: 11343/13512 (83.95%)
US 231 @ Martin Jischke Dr (Intramural Dr)
AOG: 14804/15464 (95.73%)
US 231 @ S River Rd
AOG: 8547/14083 (60.69%)
US 231 @ S River Rd
AOG: 12892/16444 (78.4%)
0
50
100
150
200
250
0
3
6
9
12
15
18
21



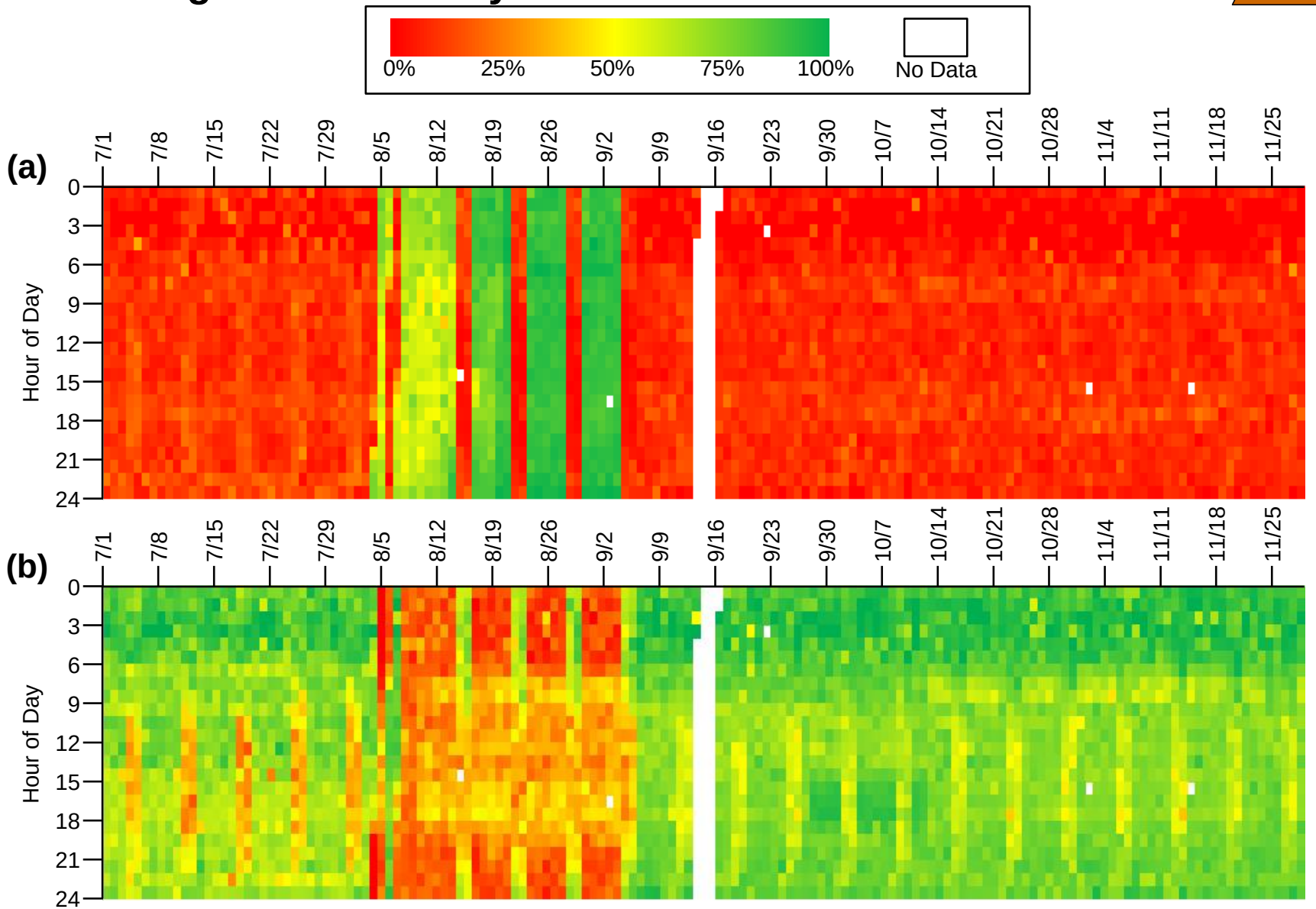
Longitudinal Analysis of Percent on Green
US 231 & River Road



Day, C.M., D.M. Bullock, H. Li, S.M. Lavrenz, W.B. Smith, and J.R. Sturdevant. *Integrating Traffic Signal Performance Measures into Agency Business Processes.* West Lafayette, Indiana: Purdue University, 2016.



Longitudinal Analysis of Percent on Green
US 231 & Sagamore Parkway



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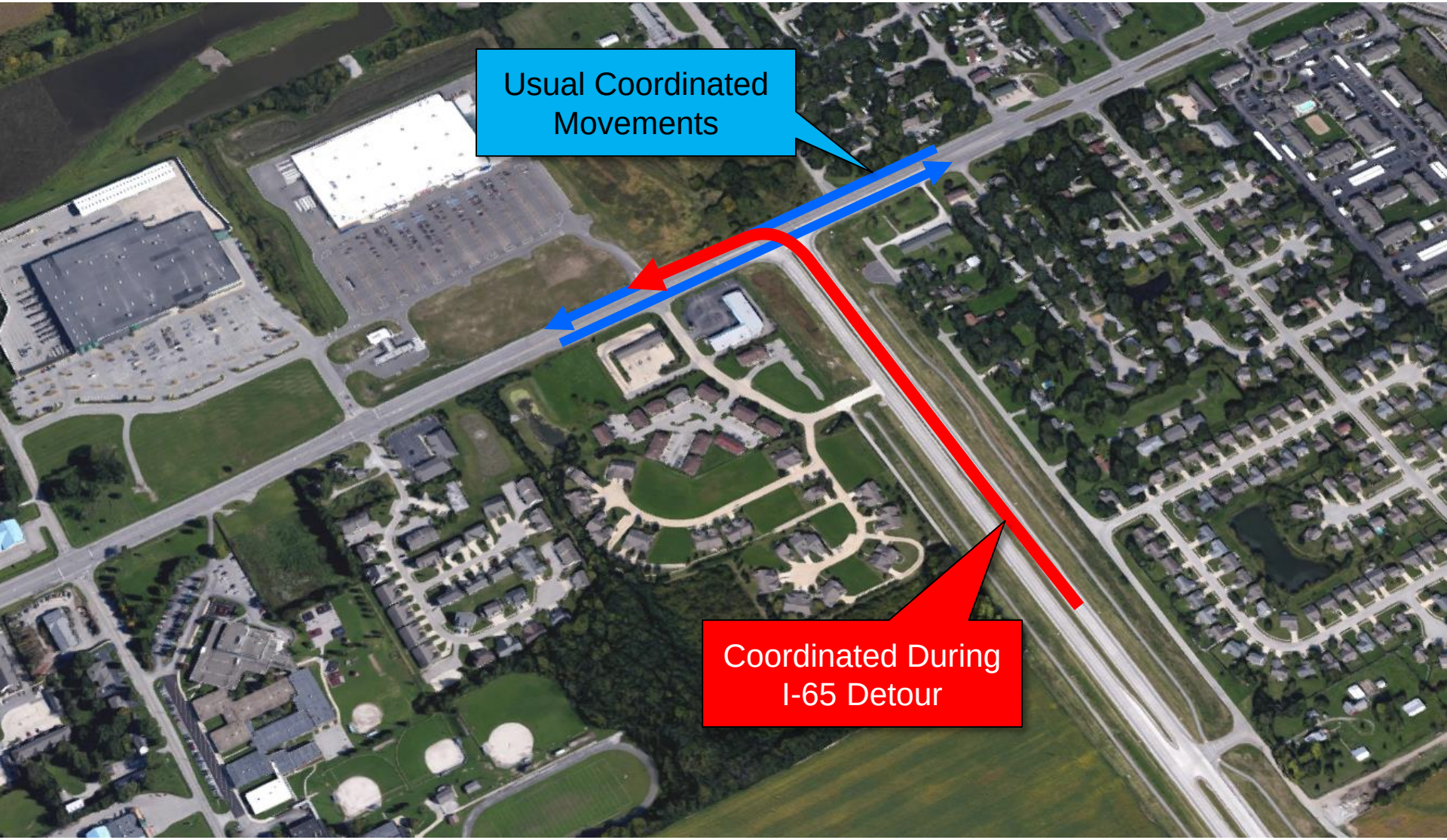
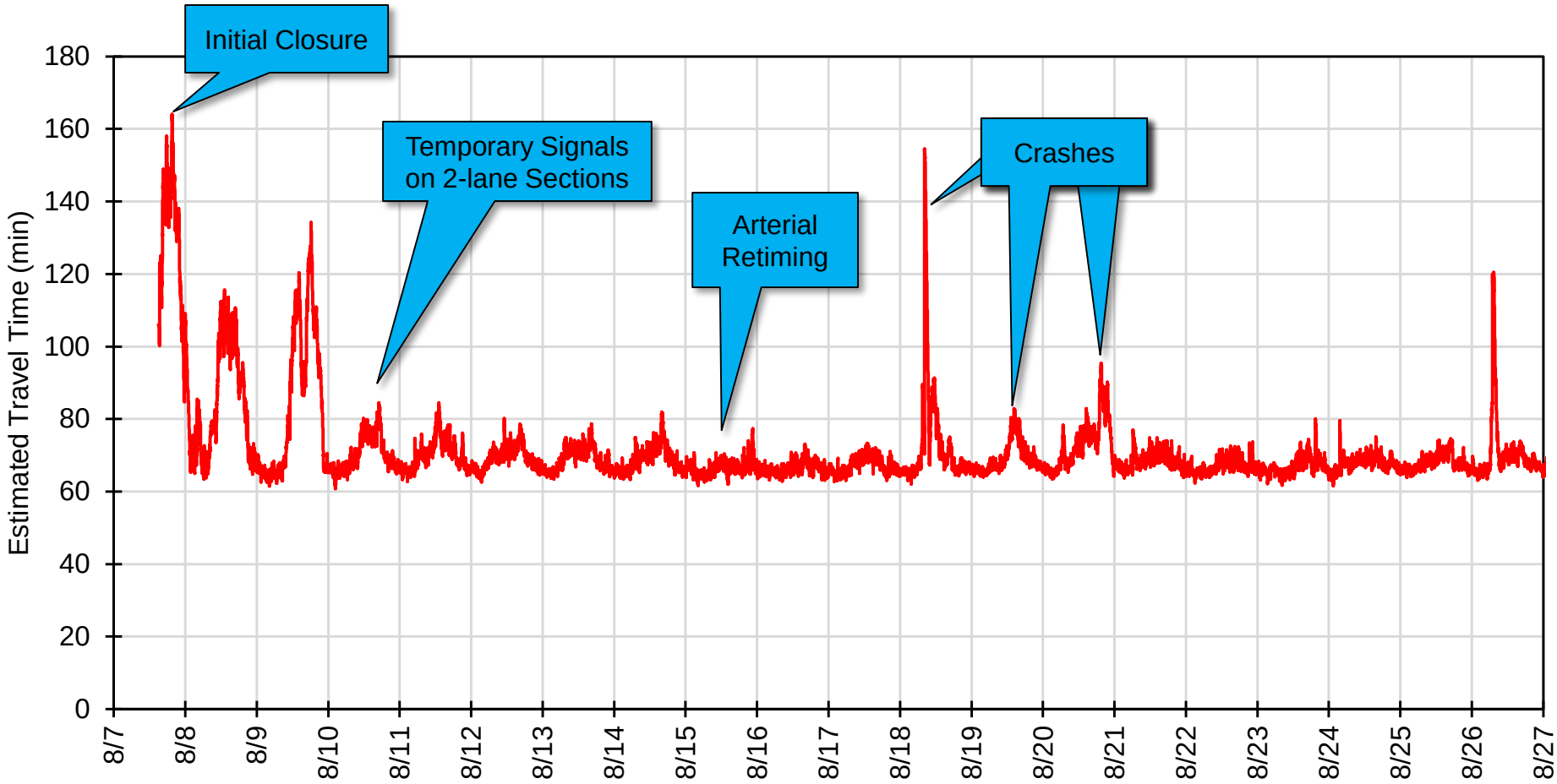
US 231 & Sagamore Parkway

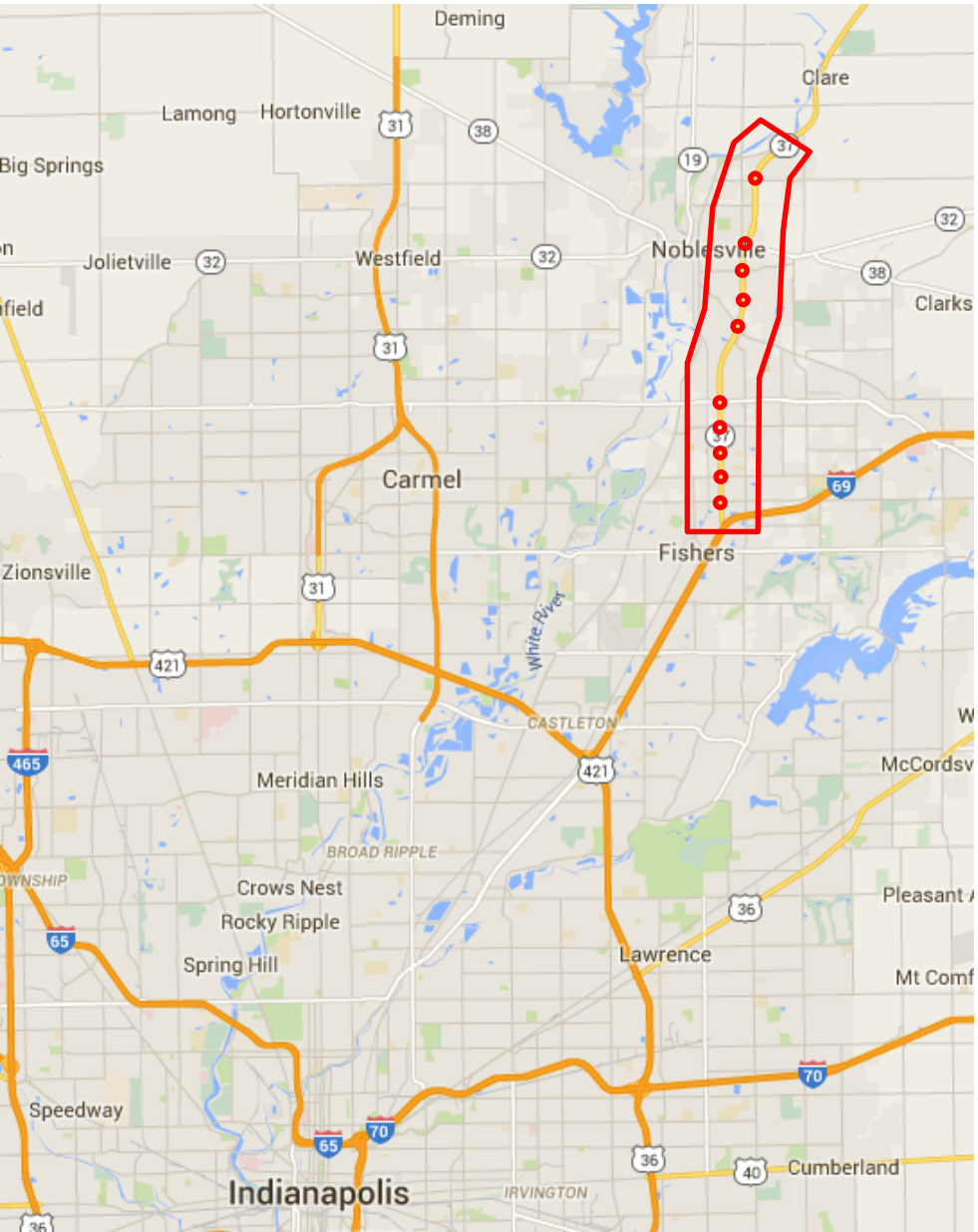


Detour Route Estimated Travel Times from Probe Data



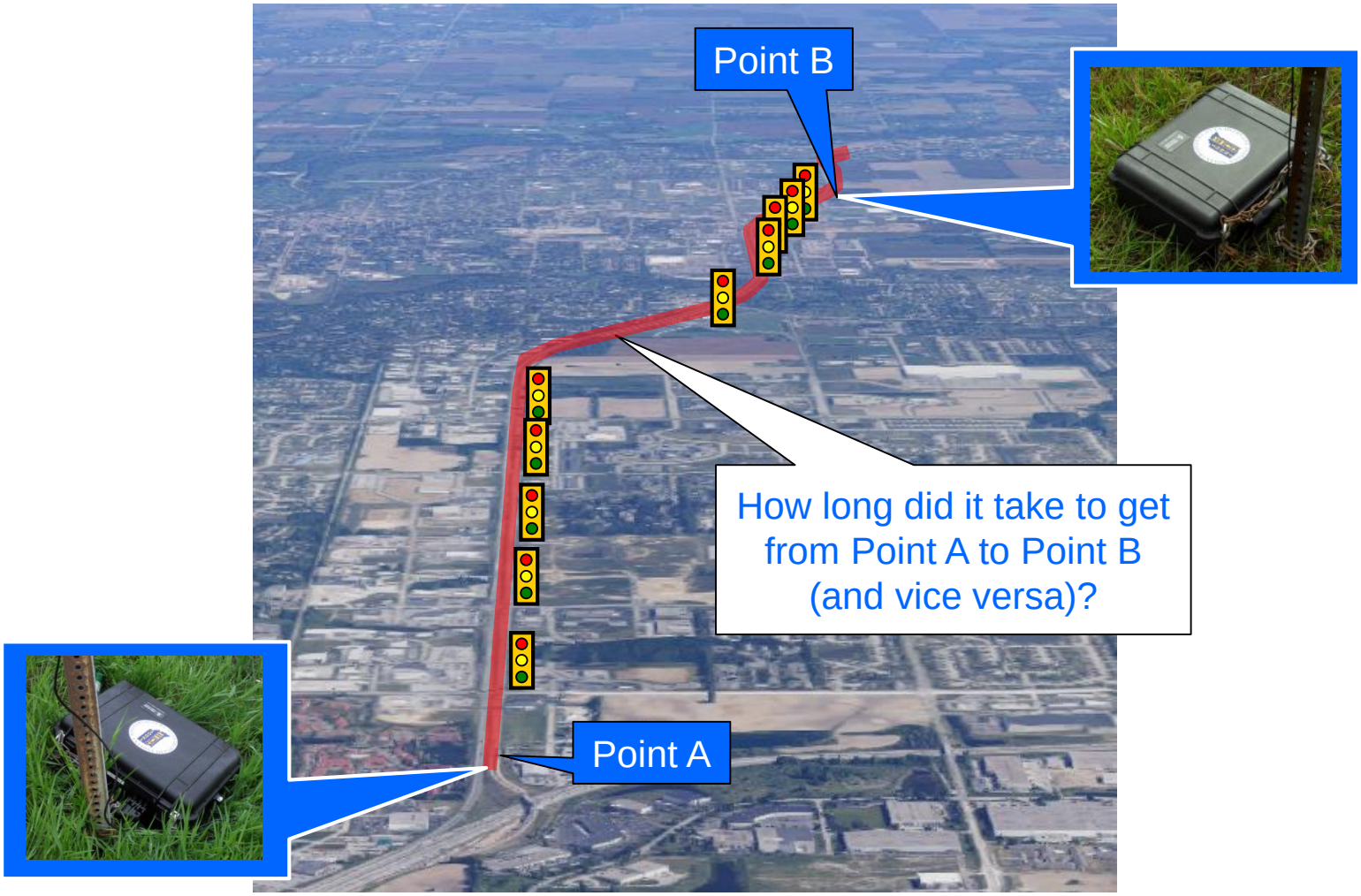
PURDUE UNIVERSITY

SR 37 North Case Study: Location and Timeline

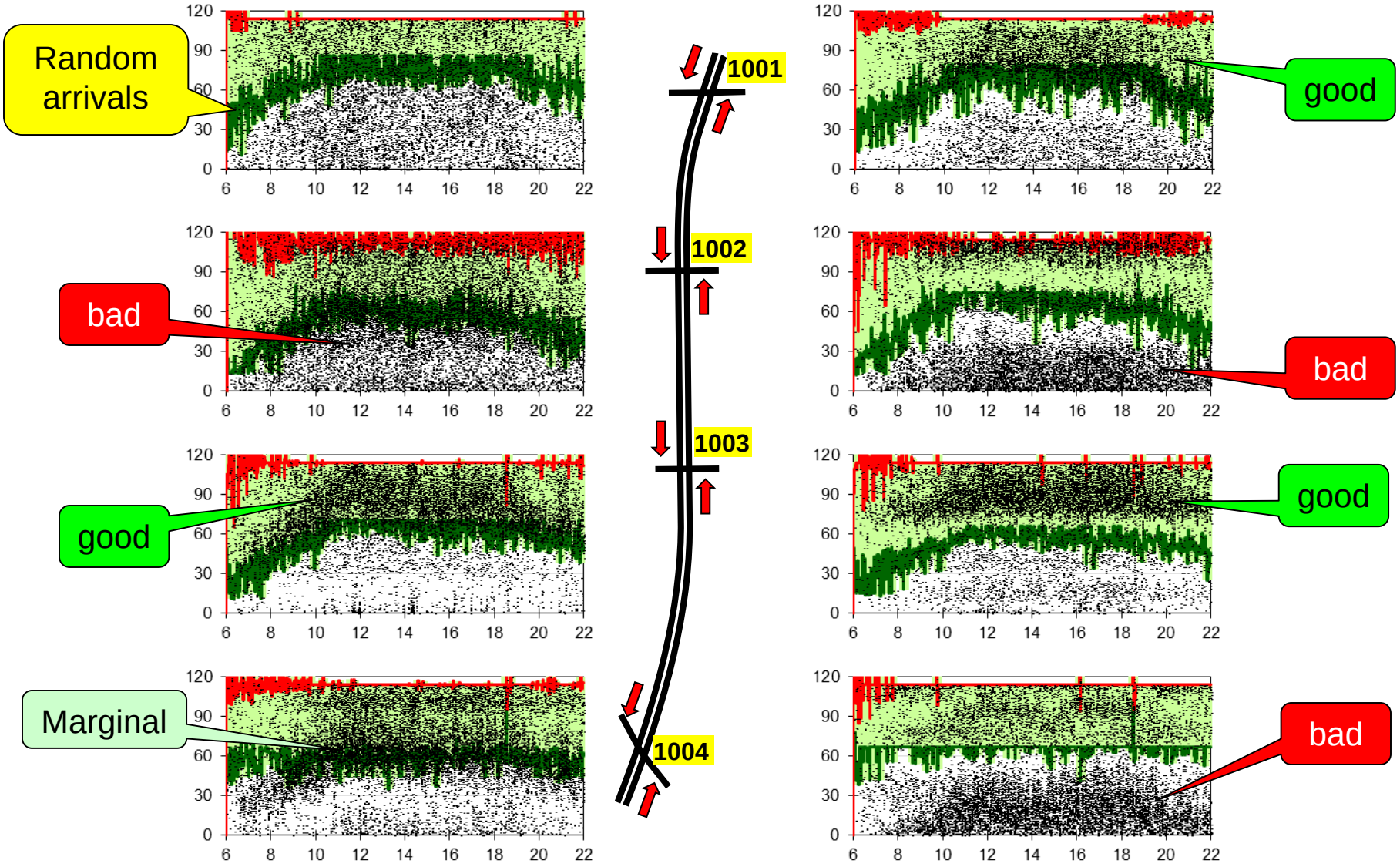


- 2009
  - Trial offset optimization study along 4 intersections on the north end
  - “Quasi-exhaustive search” (ad hoc optimization)
- 2010
  - Better optimization algorithm
  - Full offset optimization along entire corridor
- 2013
  - New intersection added
  - Offsets re-optimized
- 2015
  - Traffic growth of 32% since 2010
  - Offsets re-optimized
- **Evaluation with Bluetooth Travel Time Data**

Outcome Assessment
Probe Data Travel Time Measurement

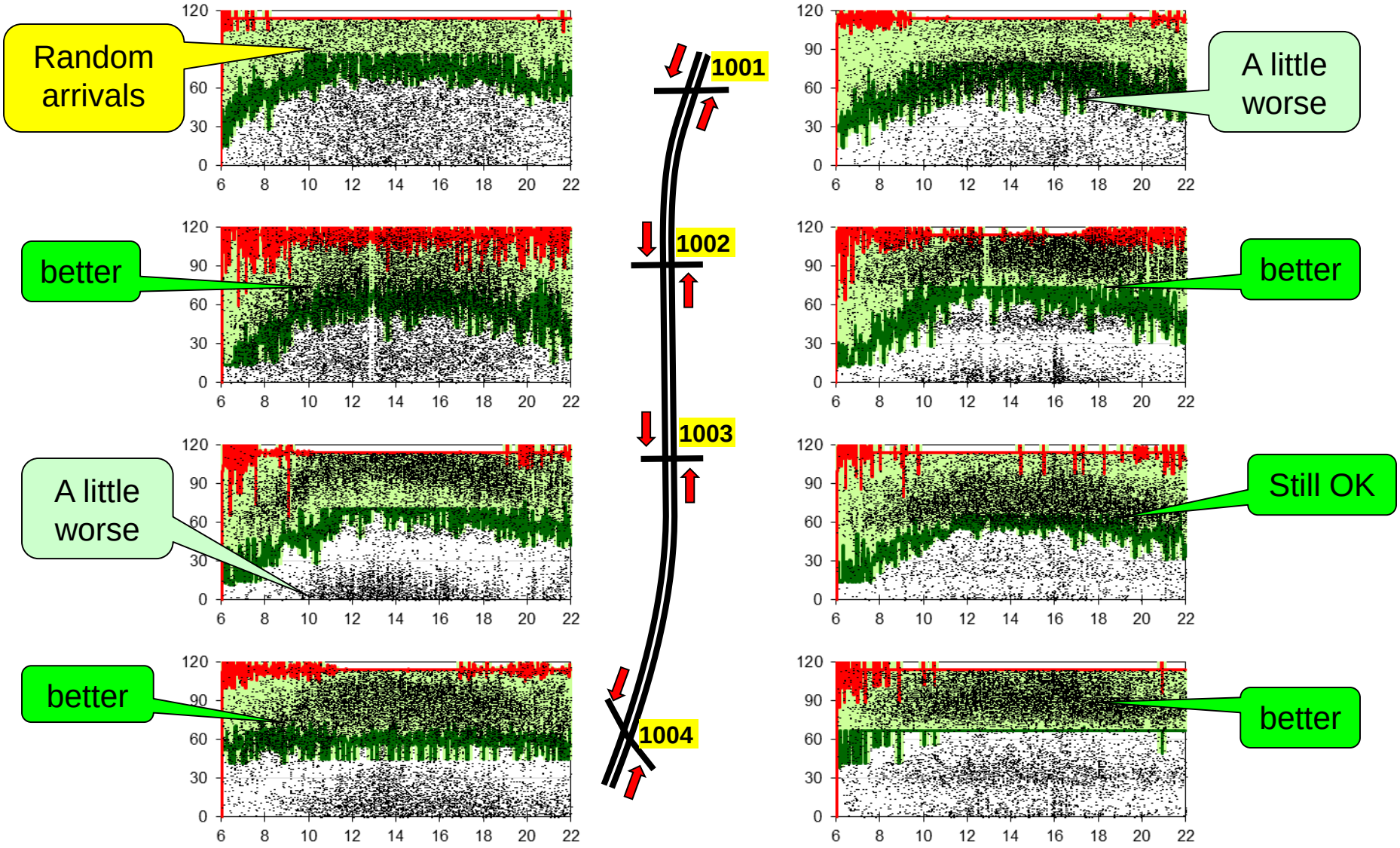


Coordination Diagram: Corridor, Before Retiming
Saturday, 0600-2200



Day, C.M., R. Haseman, H. Premachandra, T.M. Brennan, J.S. Wasson, J.R. Sturdevant, and D.M. Bullock. Evaluation of arterial signal coordination: methodologies for visualizing high-resolution event data and measuring travel time. *Transportation Research Record No. 2192,* 37-49, 2010.

Coordination Diagram: Corridor, After Retiming
Saturday, 0600-2200



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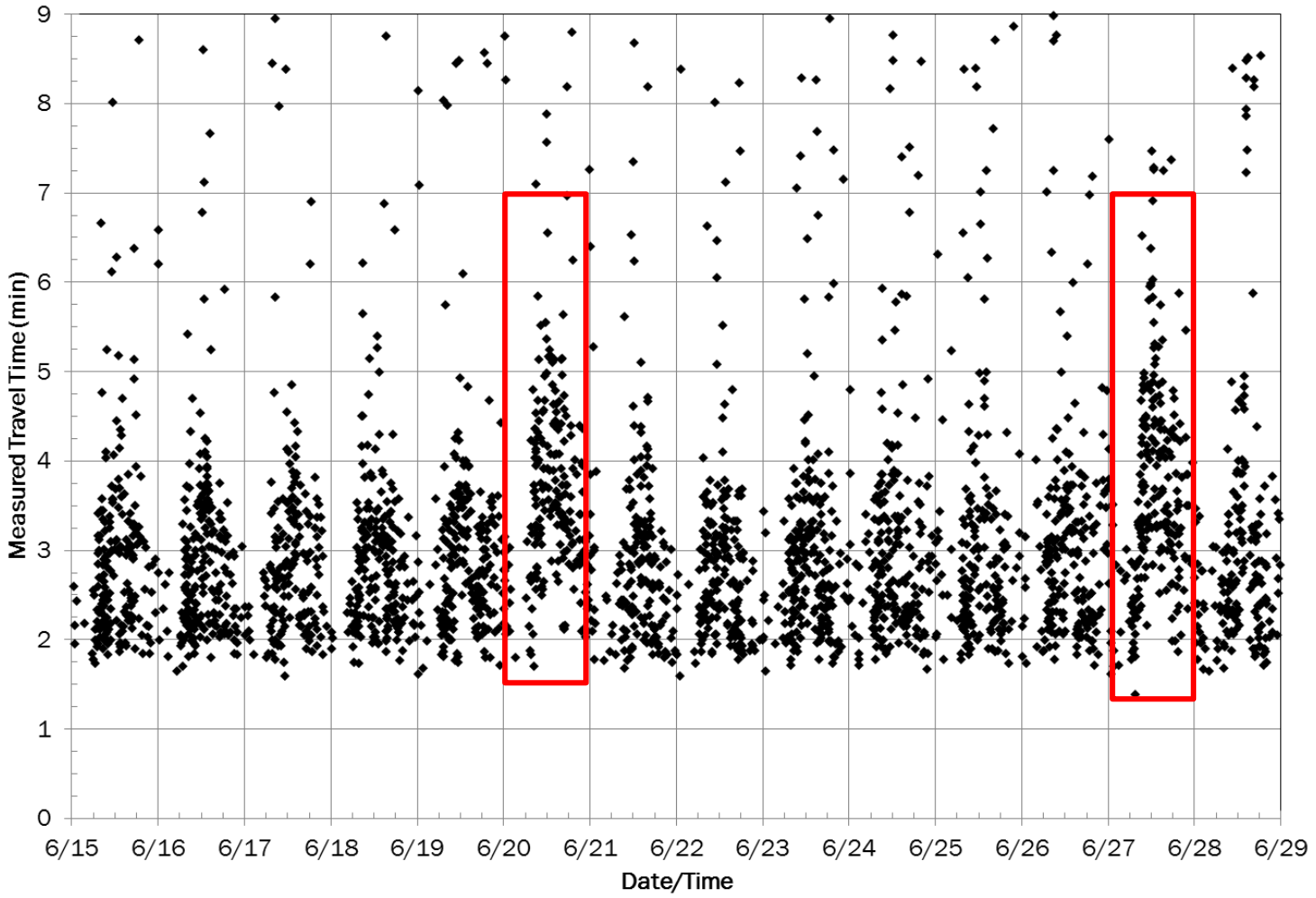
Raw Data: Before Retiming



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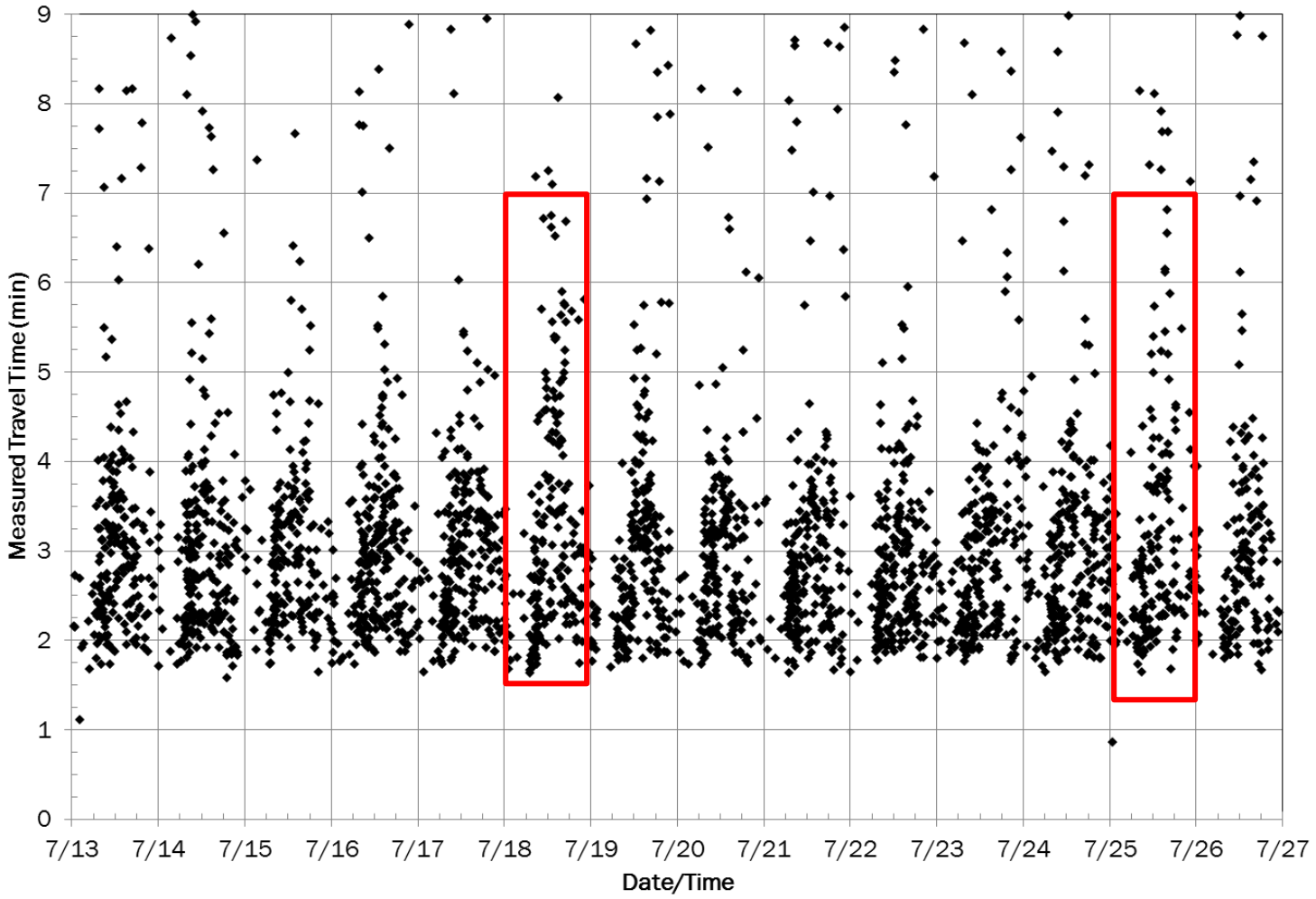
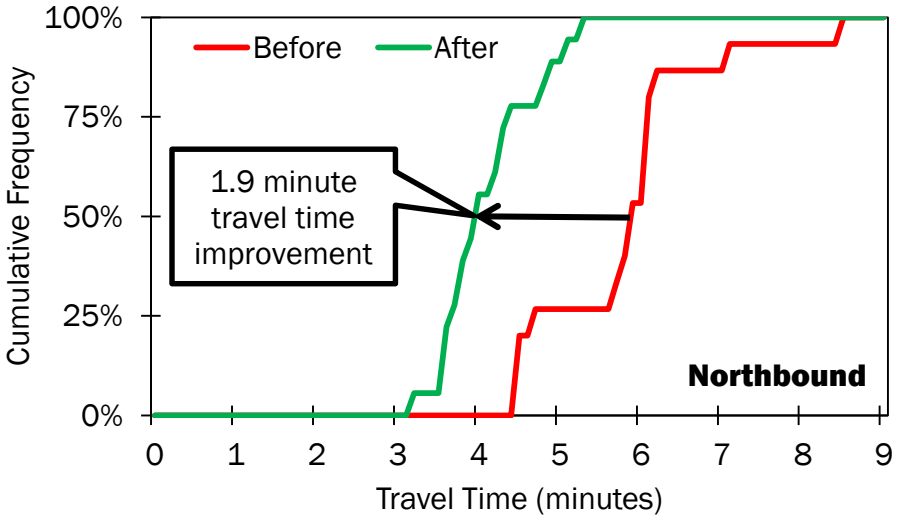
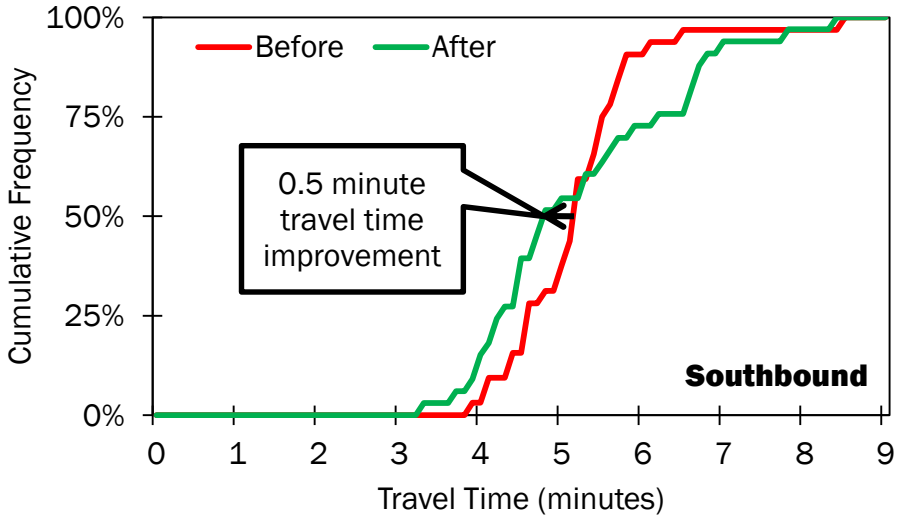
Raw Data: After Retiming



Day, C.M., R. Haseman, H. Premachandra, T.M. Brennan, J.S. Wasson, J.R. Sturdevant, and D.M. Bullock. Evaluation of arterial signal coordination: methodologies for visualizing high-resolution event data and measuring travel time. *Transportation Research Record No. 2192,* 37-49, 2010.

Measured Impact: Before and After
Initial Study in 2009… (Before we had an algorithm)





Optimization with High Res Data
Next – A Systematic Method to Find the Optimal Offsets

- After validating the prediction method, we devised a way to systematically adjust offsets to find an optimal solution…

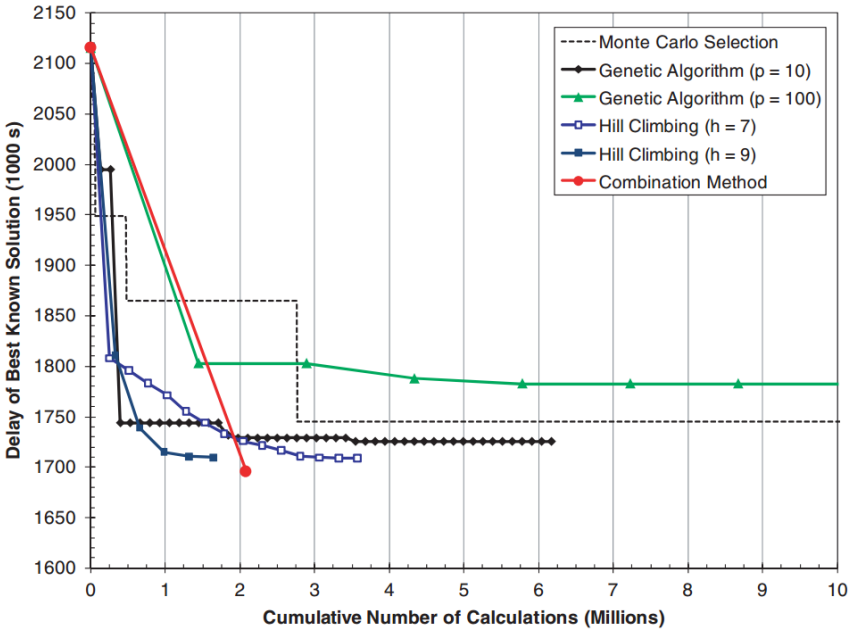


FIGURE 6 Performance of alternative methodologies for offset optimization.

Computational Efficiency of Alternative Algorithms for Arterial Offset Optimization

Christopher M. Day and Darcy M. Bullock

This paper compares the performance of several algorithms for offset optimization. A case study of a five-intersection arterial is presented. Cyclic probability distributions of vehicle arrivals and the probability of green are used to characterize traffic conditions under alternative offsets. Five algorithms for offset optimization were selected for comparison: quasi-exhaustive search, Monte Carlo selection, genetic algorithms, hill climbing, and the combination method. Each algorithm was evaluated with two alternative objectives: minimize delay and maximize vehicle arrivals on green. The relative performances of the algorithms were characterized by the optimality of the solution that they returned, the number of computations needed to execute the algorithm, and the marginal cost of adding an additional intersection to the system. All five algorithms effectively identified optimal or near-optimal offsets within the solution space. Hill climbing was more efficient than genetic algorithms, but the optimality of the solutions from both types was similar. The combination method found the most optimal offsets, with efficiency similar to that of hill climbing. The combination method is recommended for arterial offset optimization because of its deterministic computational performance for identifying optimized offset timing plans.

The selection of offsets in traffic signal timing plans is critical for establishing vehicle progression. At present, traffic engineers rely on a rather small group of software programs for designing or adapting signal timing plans, which rely on their own internally hard-coded algorithms. Although there is a considerable literature comparing the performance of those software packages against each other and proposed methods, less attention has been paid to the relative performance of the internal algorithms. This paper explicitly considers the performance of alternative algorithms in an identical traffic model.

Recently, the introduction of online data collection into traffic signal controller firmware has enabled signal events to be logged in real time at the highest possible time resolution (*1*). This paper describes a methodology for offset optimization with high resolution controller data and compares the performance of alternative algorithms for optimizing offsets in that model. A quasi-exhaustive search, Monte Carlo selection, the combination method, hill climbing, and genetic algorithms (GAs) are compared. The paper concludes with a recommendation that the combination method be used to optimize offsets where possible because of its computational efficiency and robust performance.

Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47906. Corresponding author: D. M. Bullock, darcy@purdue.edu.

Transportation Research Record: Journal of the Transportation Research Board, No. 2259, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 37–47.
DOI: 10.3141/2259-04

BACKGROUND

Offset optimization can be described as a mathematical optimization problem in which the adjustable parameters are the offsets and the objective is to minimize or maximize a performance measure that is a complex function of those parameters. In a network of n signals, the number of possible offset combinations is generally $(C/r)^{n-1}$, where C is the cycle length (s), and r is the resolution (s) of the search. The complexity of the problem increases exponentially with n, making it essential to adopt efficient optimization techniques. Table 1 lists advantages and disadvantages of a variety of mathematical techniques for the offset optimization problem for delay minimization (*14*).

The quasi-exhaustive search and Monte Carlo selection are basic numerical strategies for sampling a large solution space. A quasi-exhaustive search is an enumerative search using a value of r that makes $(C/r)^{n-1}$ scenarios feasibly calculable. Monte Carlo selection samples the solution space by random selection of parameters over many iterations. As more iterations are accumulated, the best known parameter combination continues to improve. However, no knowledge of the performance of past parameters is used to aid the selection of new ones. Heuristic optimization methods leverage the performance of past iterations. In this paper, hill climbing and GAs are considered.

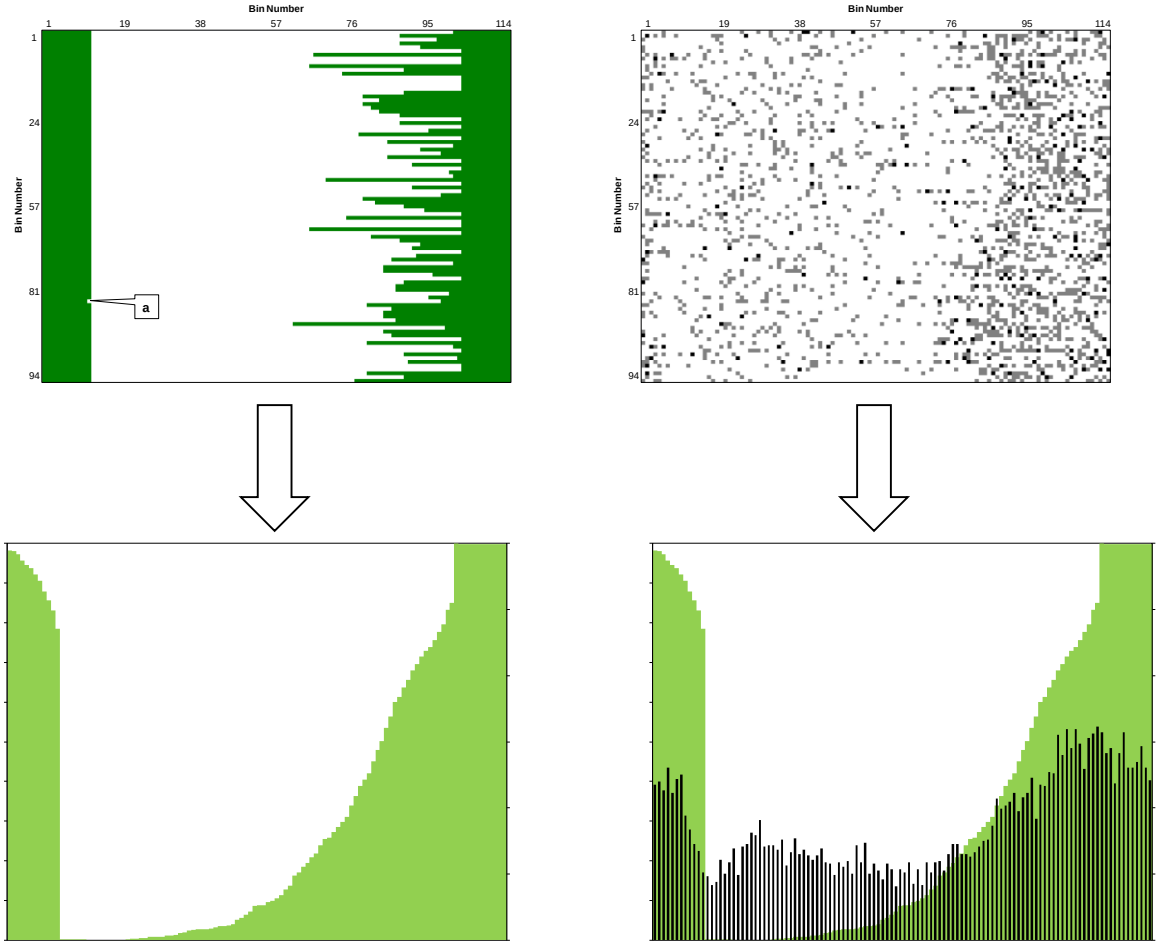
- In hill climbing, a vector of hill climb increments is applied to each offset; the most optimal increment is retained (*3*). This is carried out for one intersection at a time in an iterative loop that repeats until the system performance cannot be improved further.
- In GAs, the parameters are encoded as genetic sequences and are manipulated in a simulation of the behavior of DNA during reproduction (*15*). The first generation is a population of randomly generated parameters. Subsequent generations are created from the fittest members of previous generations, with random changes introduced during crossover and mutation, interpreted as manipulation of the encoded parameters. An extensive review is presented by Kesur (*10*). Foy et al. (*4*) first used GA in signal timing design; numerous subsequent implementations compare GA against other optimization methods in a variety of applications with favorable results (e.g., *5–9*). Thus, GA appears to have potential for future software implementation. GA has been implemented in recent versions of TRANSYT.

The combination method leverages information about the network topology to optimize offsets (*11*, *12*). Parallel combinations of links (such as a pair of one-way links that share endpoints) are combined by adding up their individual delay–offset relationships. Series combinations are limited enumerative searches that optimize a single offset. As subsequent series combinations accumulate, previously optimized link flows are held constant by adjusting the combined offsets as a group to accommodate the newly combined link. The final combination

Day, C.M. and D.M. Bullock. Computational efficiency of alternative algorithms for arterial offset optimization. *Transportation Research Record No. 2259*, 37-47, 2011.

Link Pivot Algorithm…
Consider Flow Profiles -- Another Way to View the Same Data…

- Either PCDs or cyclic flow profiles can be used with Link Pivot



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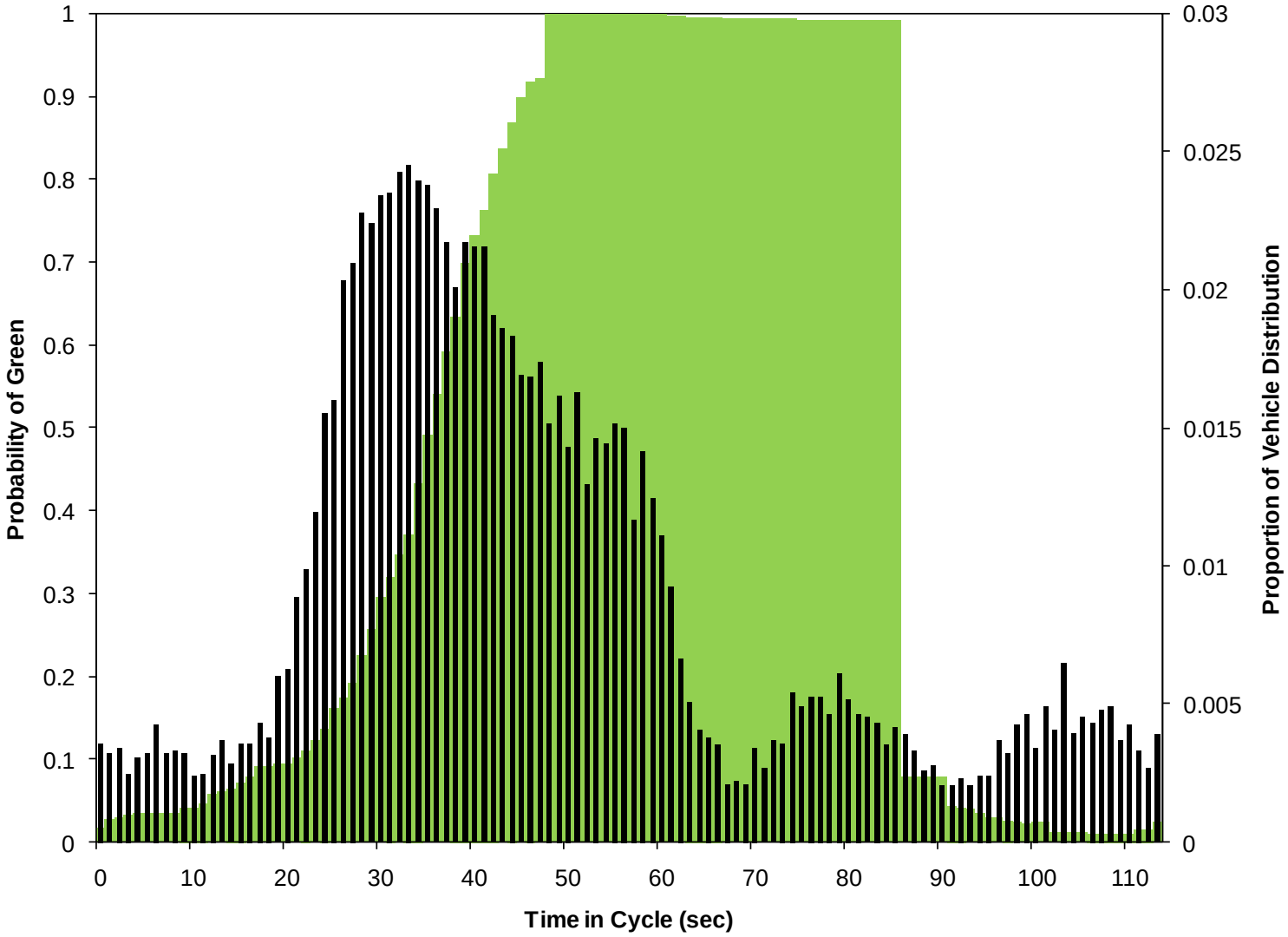
Model



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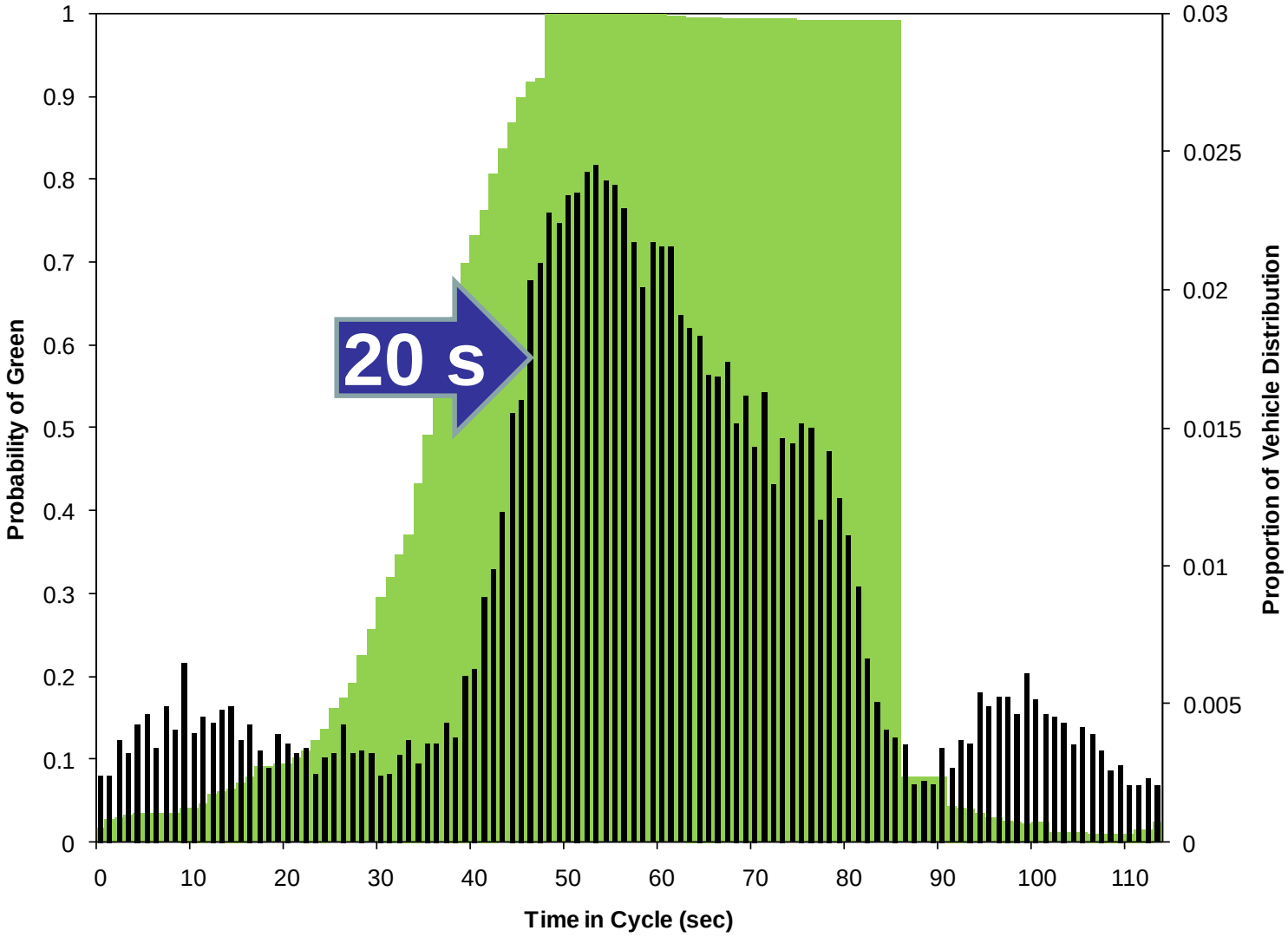
Model – Subtract 20 Seconds



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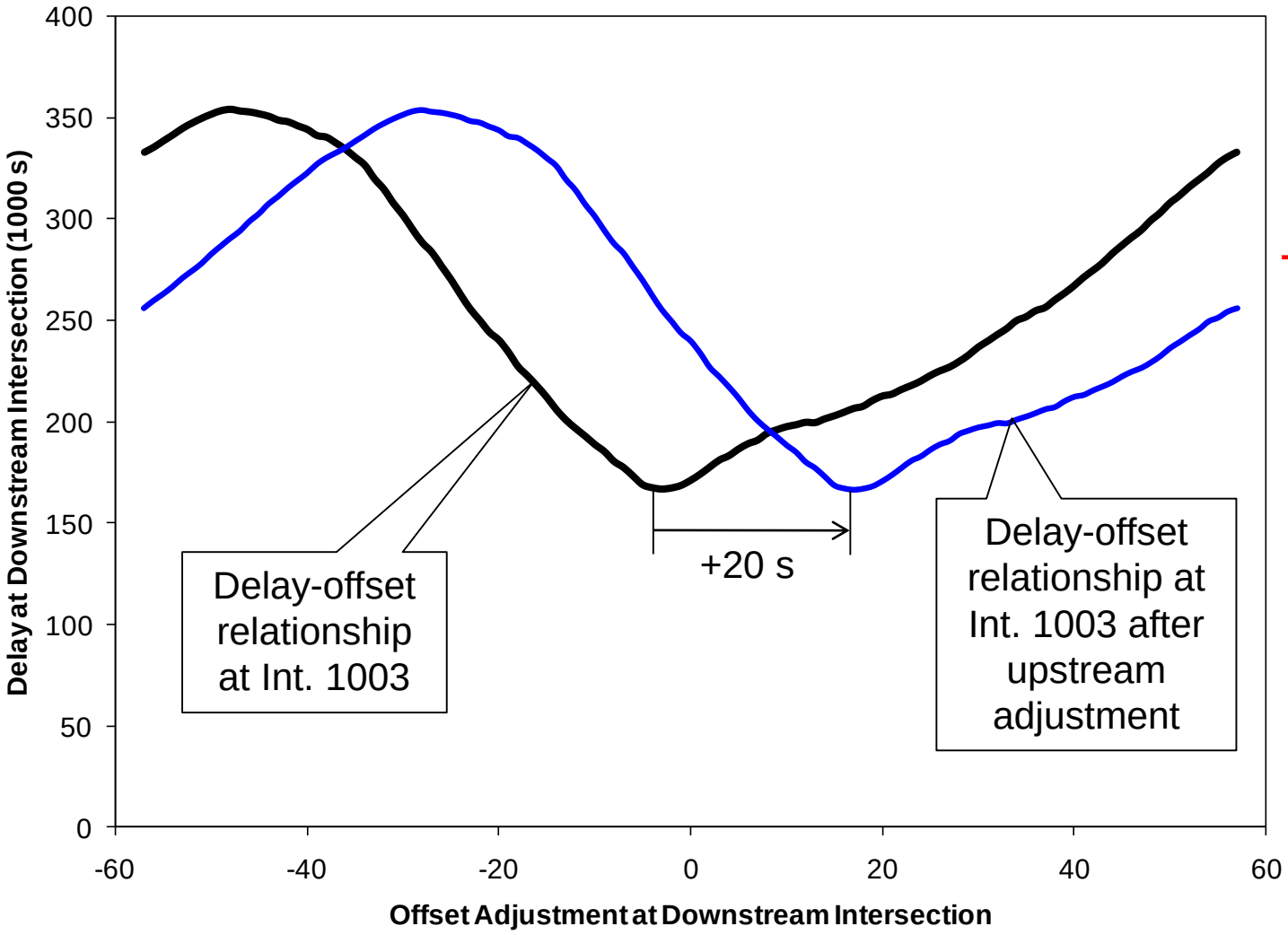
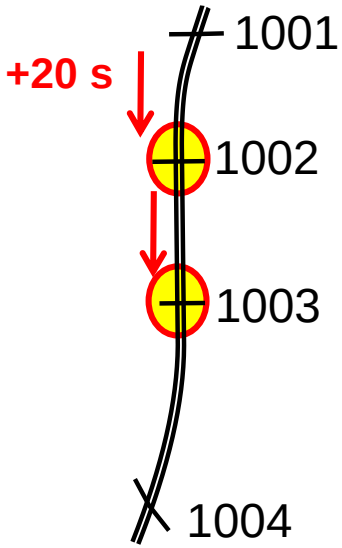
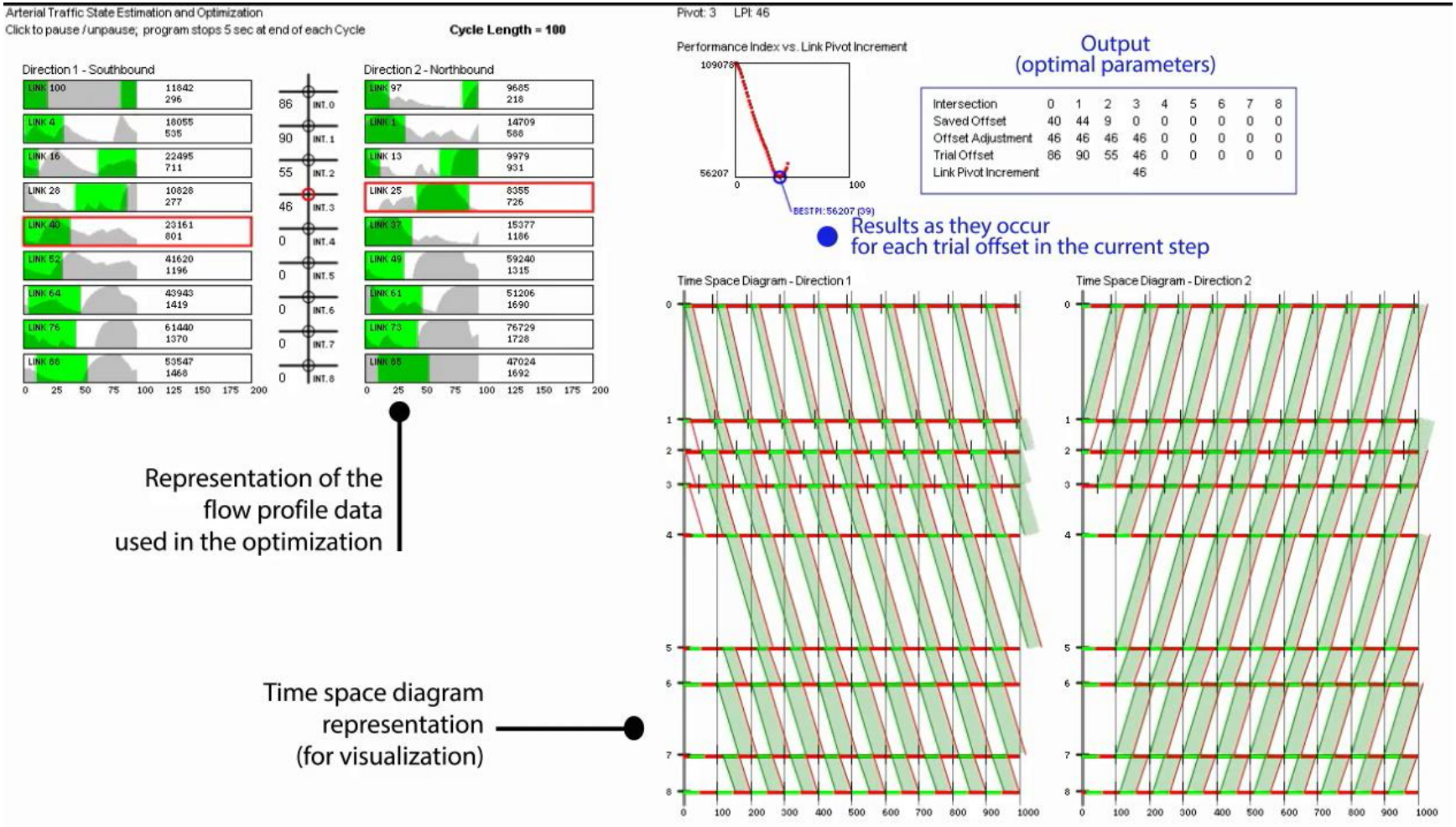
Link Pivot – Basic Conceptual Principle





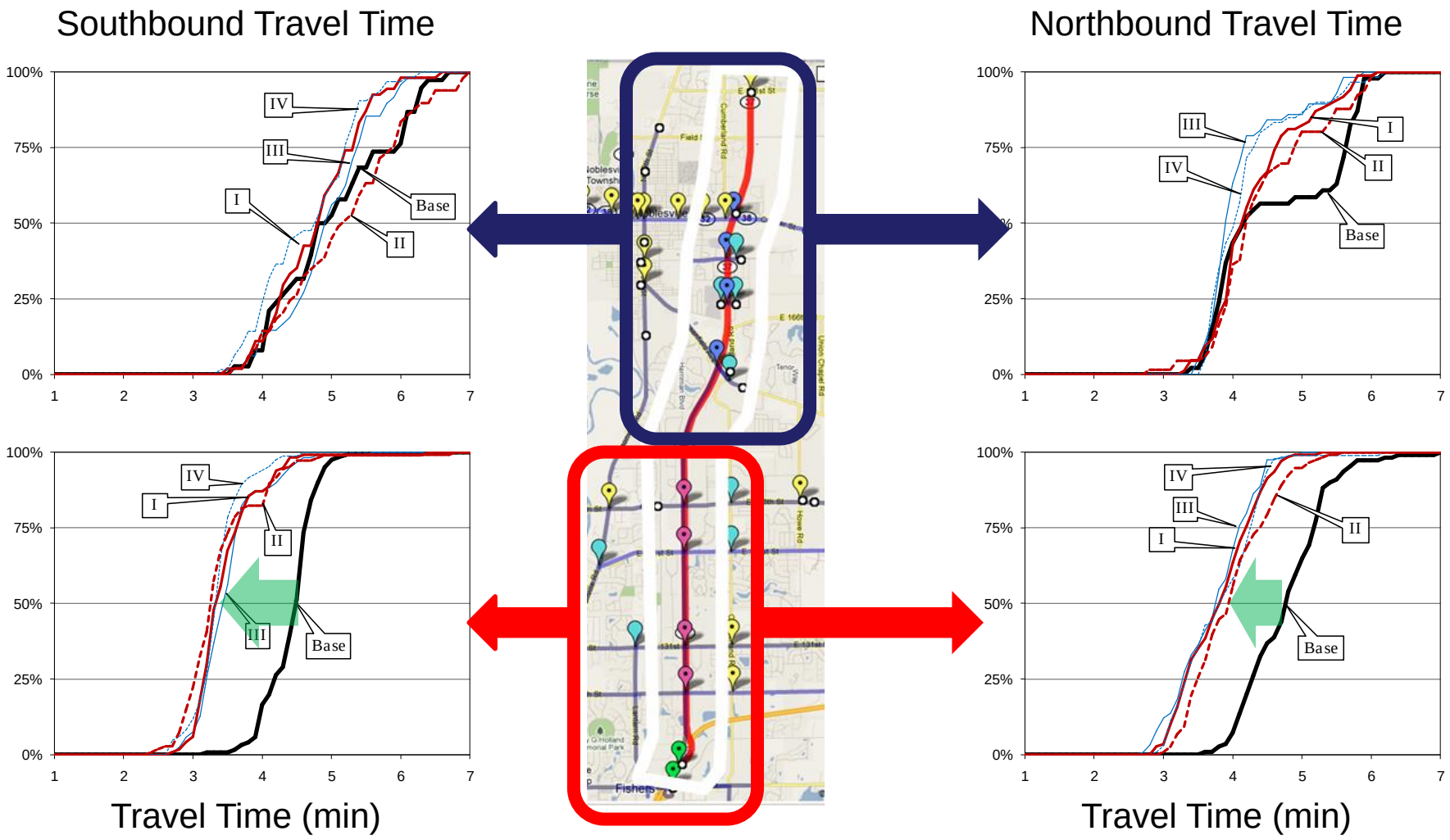
Day, C.M. and D.M. Bullock. Computational efficiency of alternative algorithms for arterial offset optimization. *Transportation Research Record No. 2259*, 37-47, 2011.

Link Pivot Animation



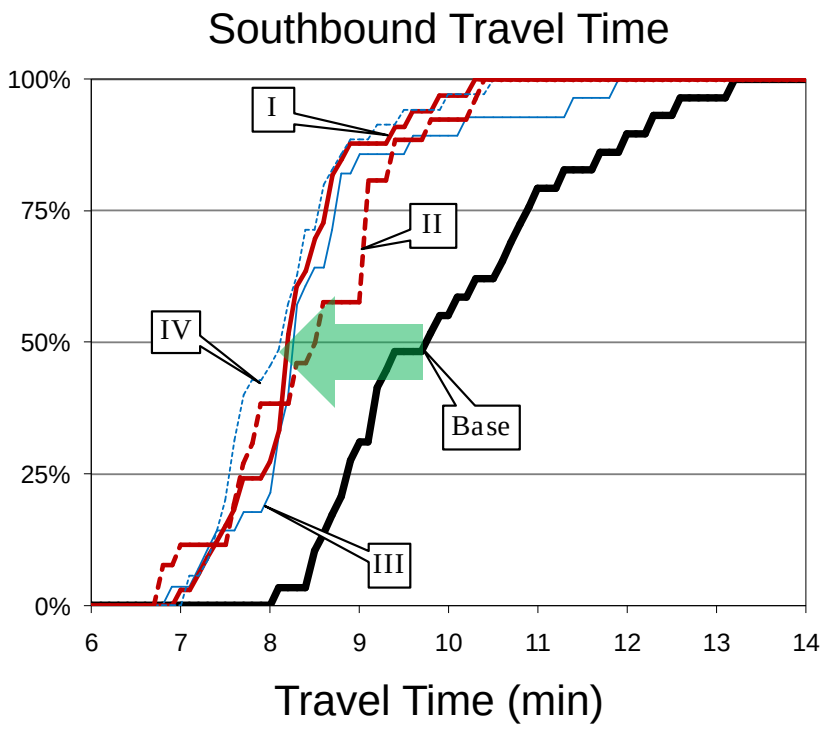
https://www.youtube.com/watch?v=Yf1ZtDA8Edw

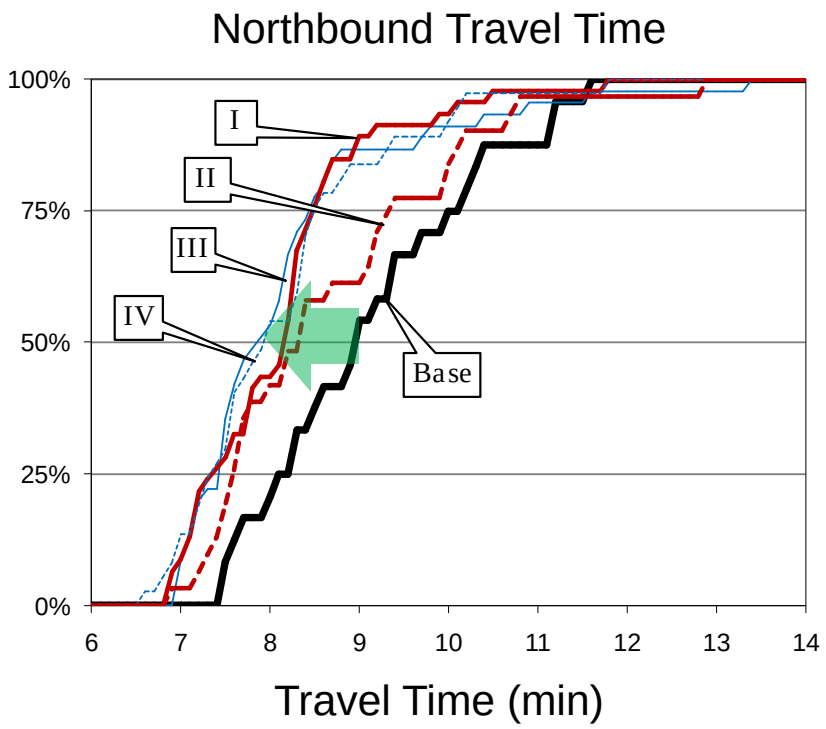
2010: Expanded Deployment from 4 to 8 Intersections (and we fully developed the algorithm)



Day, C.M., T.M. Brennan, A.M. Hainen, S.M. Remias, H. Premachandra, J.R. Sturdevant, G. Richards, J.S. Wasson, and D.M. Bullock. Reliability, flexibility, and environmental impact of alternative objective functions for arterial offset optimization. *Transportation Research Record No. 2259,* 8-22, 2011.

2010: Testing Outcomes for Different Optimization Objectives…





I. Min Delay
II. Min Delay / Stops
III. Max Arrivals on Green
IV. Max Arrivals on Green with Added Queue Clearance Time

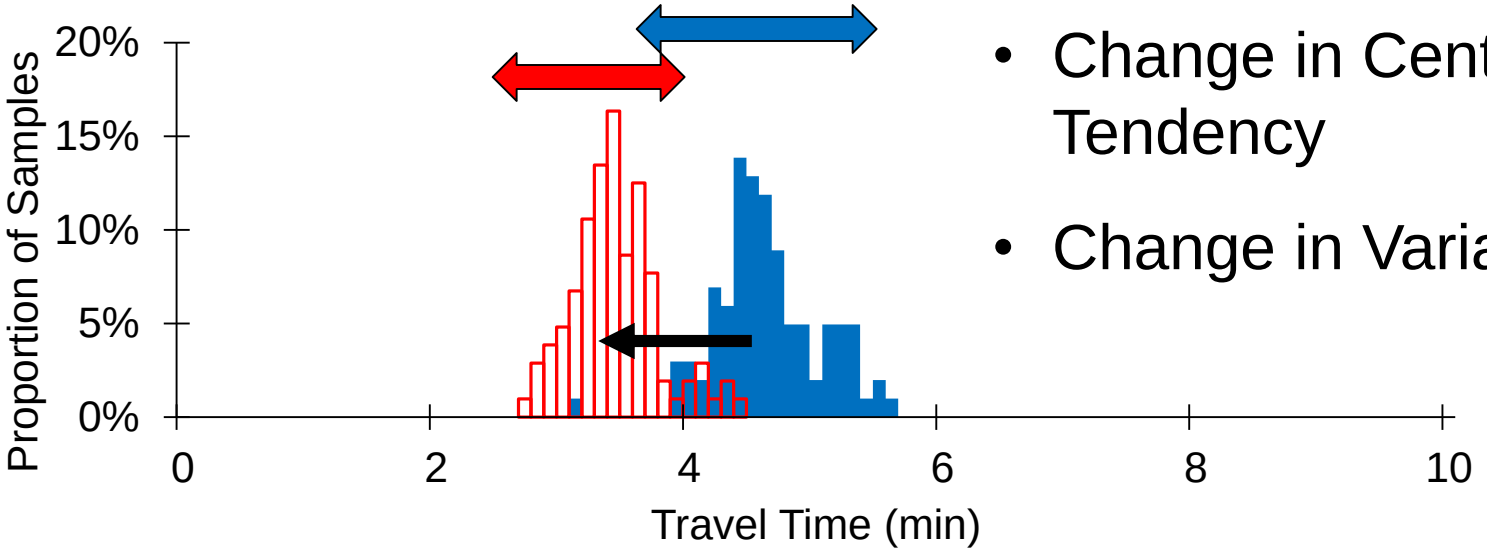
Day, C.M., T.M. Brennan, A.M. Hainen, S.M. Remias, H. Premachandra, J.R. Sturdevant, G. Richards, J.S. Wasson, and D.M. Bullock. Reliability, flexibility, and environmental impact of alternative objective functions for arterial offset optimization. *Transportation Research Record No. 2259,* 8-22, 2011.

Monetization of Changes in Travel Time Based on Median Values… 2010 Saturdays

Objective		Daily					Annual		
		Total Time Saved (veh-min)	CO_2 Emission Reduction (tons)	CO_2 Savings	User Benefits	Multi-plier	CO_2 Emission Reduction (tons)	CO_2 Savings	User Benefits
(a) System 1, Northern Section									
I	Min Delay	5032	0.71	$16	$1,697	52	37	$810	$88,233
II	Min Delay and Stops	3813	0.54	$12	$1,286	52	28	$614	$66,864
III	Max N_q	1760	0.25	$5	$593	52	13	$283	$30,855
IV	Alt. Max N_q	7883	1.11	$24	$2,658	52	58	$1,268	$138,229
(b) System 2, Southern Section									
I	Min Delay	24386	3.43	$75	$8,223	52	178	$3,924	$427,614
II	Min Delay and Stops	25327	3.56	$78	$8,541	52	185	$4,075	$444,111
III	Max N_q	25147	3.54	$78	$8,480	52	184	$4,046	$440,962
IV	Alt. Max N_q	26338	3.70	$81	$8,882	52	193	$4,238	$461,845
(c) System 1 and System 2, Arterial									
I	Min Delay	29418	4.14	$91	$9,920	52	215	$4,733	$515,847
II	Min Delay and Stops	29140	4.10	$90	$9,826	52	213	$4,689	$510,976
III	Max N_q	26907	3.78	$83	$9,073	52	197	$4,329	$471,817
IV	Alt. Max N_q	34221	4.81	$106	$11,540	52	250	$5,506	$600,073

Day, C.M., T.M. Brennan, A.M. Hainen, S.M. Remias, H. Premachandra, J.R. Sturdevant, G. Richards, J.S. Wasson, and D.M. Bullock. Reliability, flexibility, and environmental impact of alternative objective functions for arterial offset optimization. *Transportation Research Record No. 2259,* 8-22, 2011.

Revisiting the Idea … Quantifying Changes in User Costs
1. Characterizing Changes in Travel Time AND Reliability



- Change in Central Tendency
- Change in Variability

Median travel time isn't the only thing we care about!

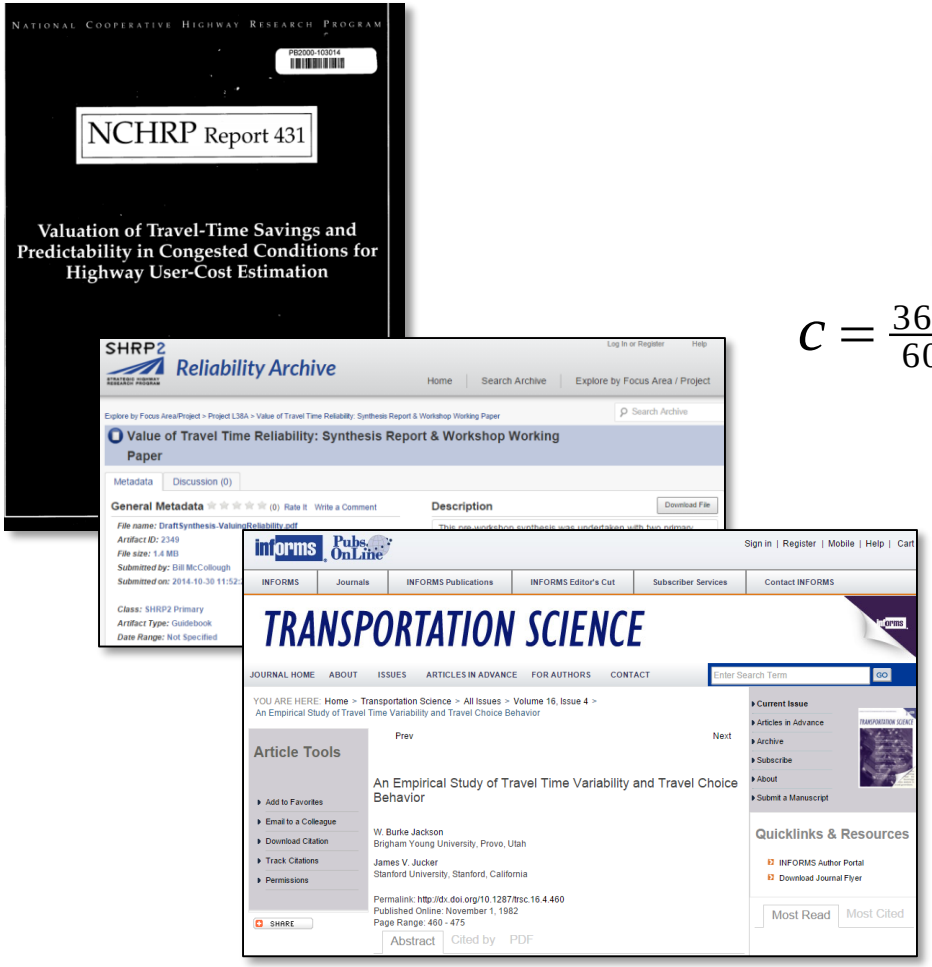
Lavrenz, S.M., C.M. Day, W.B. Smith, J.R. Sturdevant, and D.M. Bullock. Assessing longitudinal arterial performance traffic signal retiming outcomes. Transportation Research Record, in press, 2016.

Revisiting the Idea … Quantifying Changes in User Costs
2. Monetizing Changes in Travel Time

volume v, occupancy o, unit value of travel time u, conversion factor k

T_{avg} = average travel time

T_{std} = standard deviation of travel time



Passenger cars

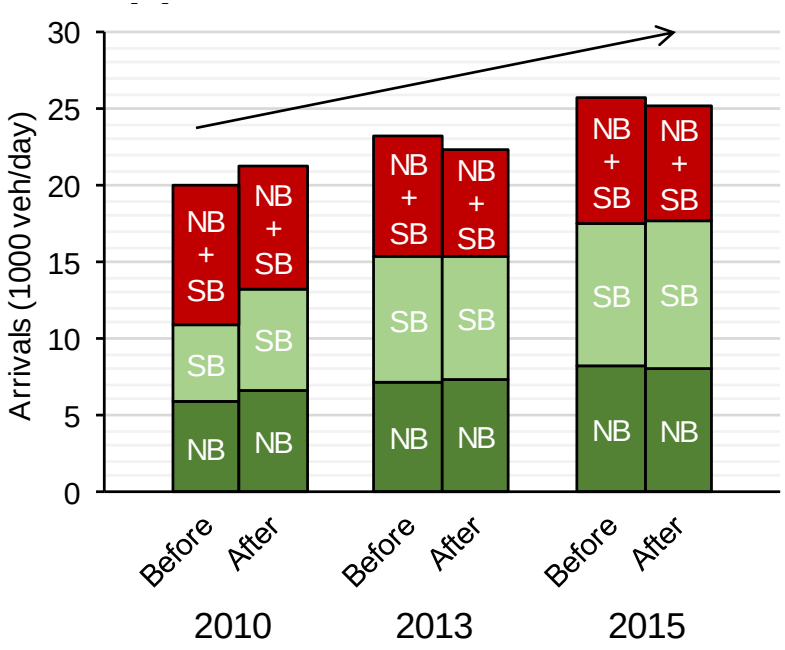
$$c = \frac{364}{60} \cdot (T_{avg} v_{pc} o_{pc} u_{pc} + k_{pc} T_{std} v_{pc} o_{pc} u_{pc} + T_{avg} v_{hv} u_{hv} + k_{hv} T_{std} v_{hv} u_{hv})$$

Heavy vehicles

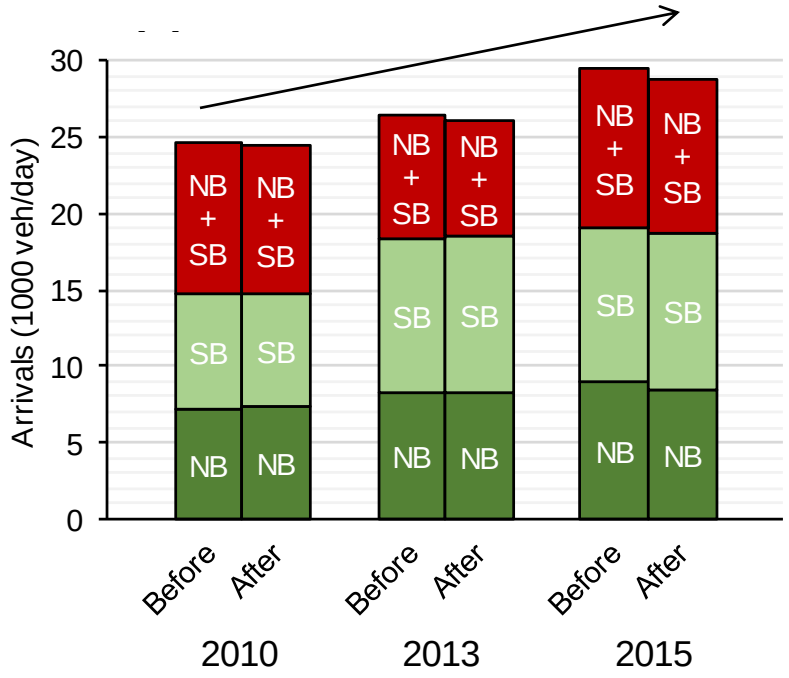
Lavrenz, S.M., C.M. Day, W.B. Smith, J.R. Sturdevant, and D.M. Bullock. Assessing longitudinal arterial performance traffic signal retiming outcomes. Transportation Research Record, in press, 2016.

Volumes and Arrivals on Green, Per Year…

Volumes Increased by 36%



Saturday

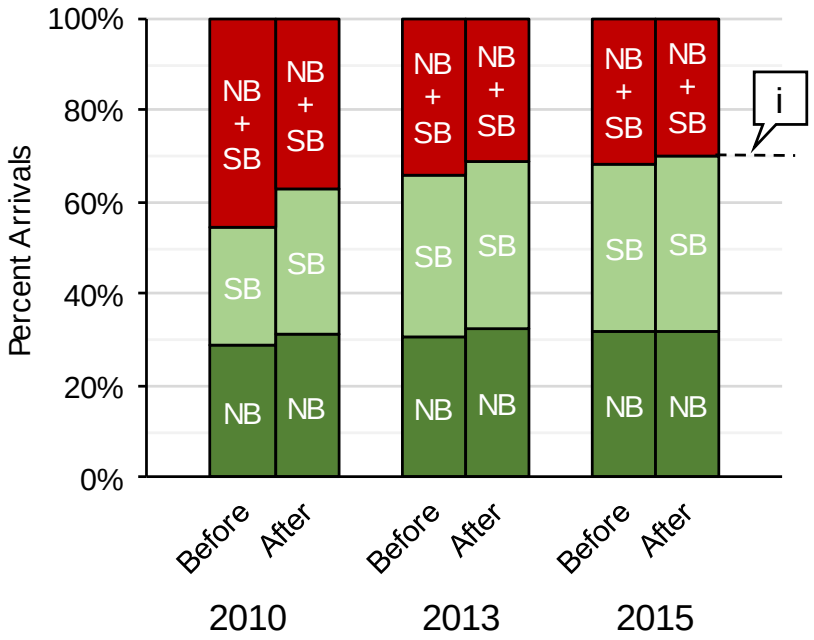


Monday-Friday

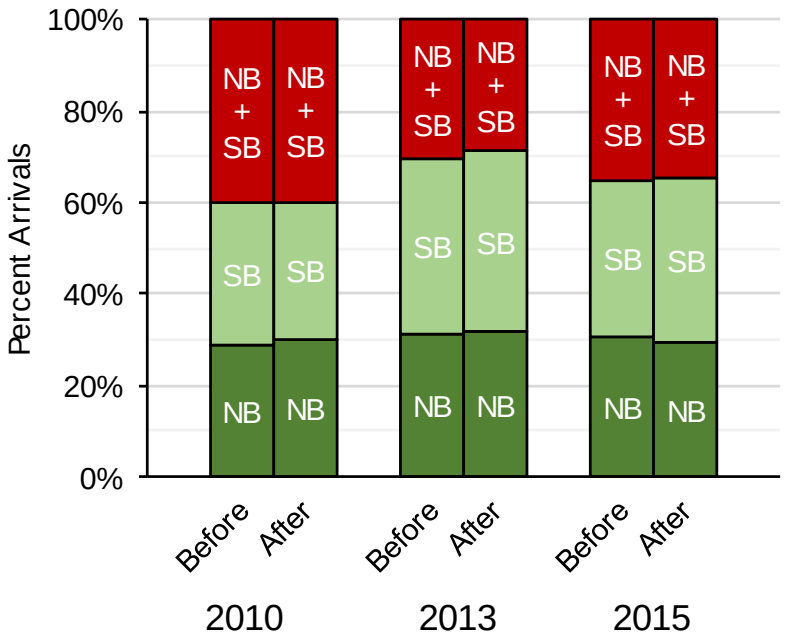
Lavrenz, S.M., C.M. Day, W.B. Smith, J.R. Sturdevant, and D.M. Bullock. Assessing longitudinal arterial performance traffic signal retiming outcomes. Transportation Research Record, in press, 2016.

Arrivals on Green, Per Year…

Improvement on Each Iteration…



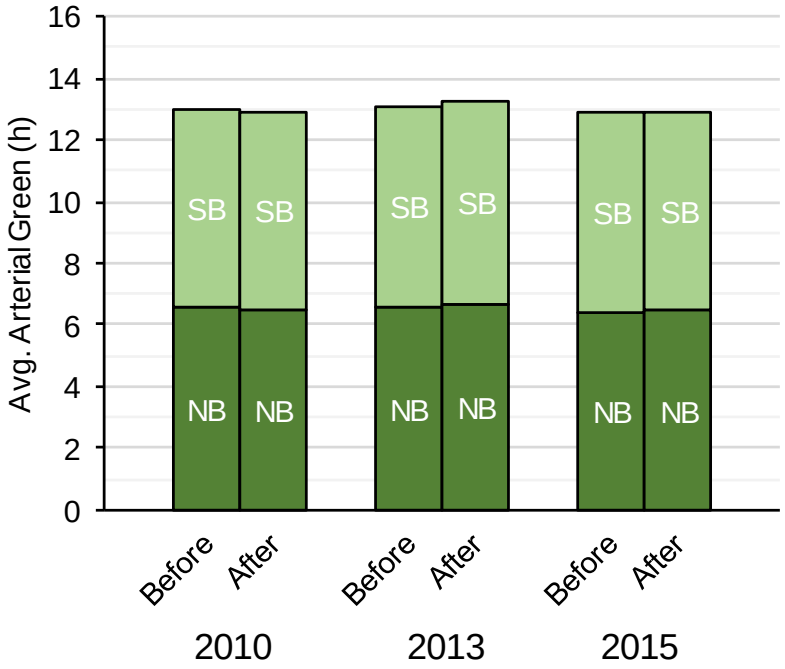
Saturday



Monday-Friday

Lavrenz, S.M., C.M. Day, W.B. Smith, J.R. Sturdevant, and D.M. Bullock. Assessing longitudinal arterial performance traffic signal retiming outcomes. Transportation Research Record, in press, 2016.

Arterial Green Times, Per Year…
(We didn't have to increase the bandwidth to obtain the results)



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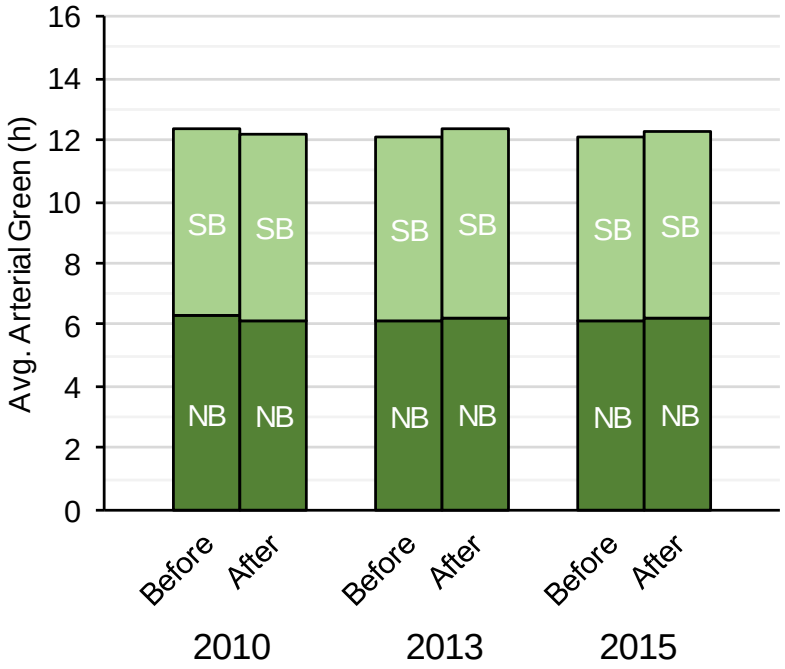
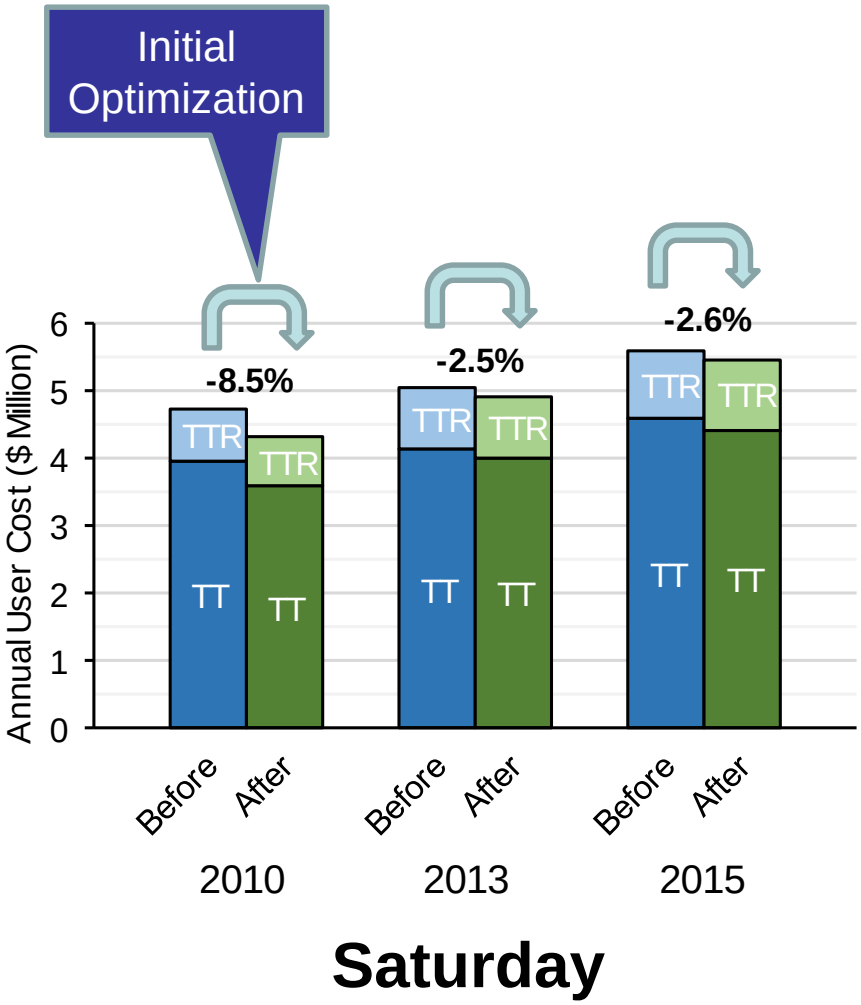


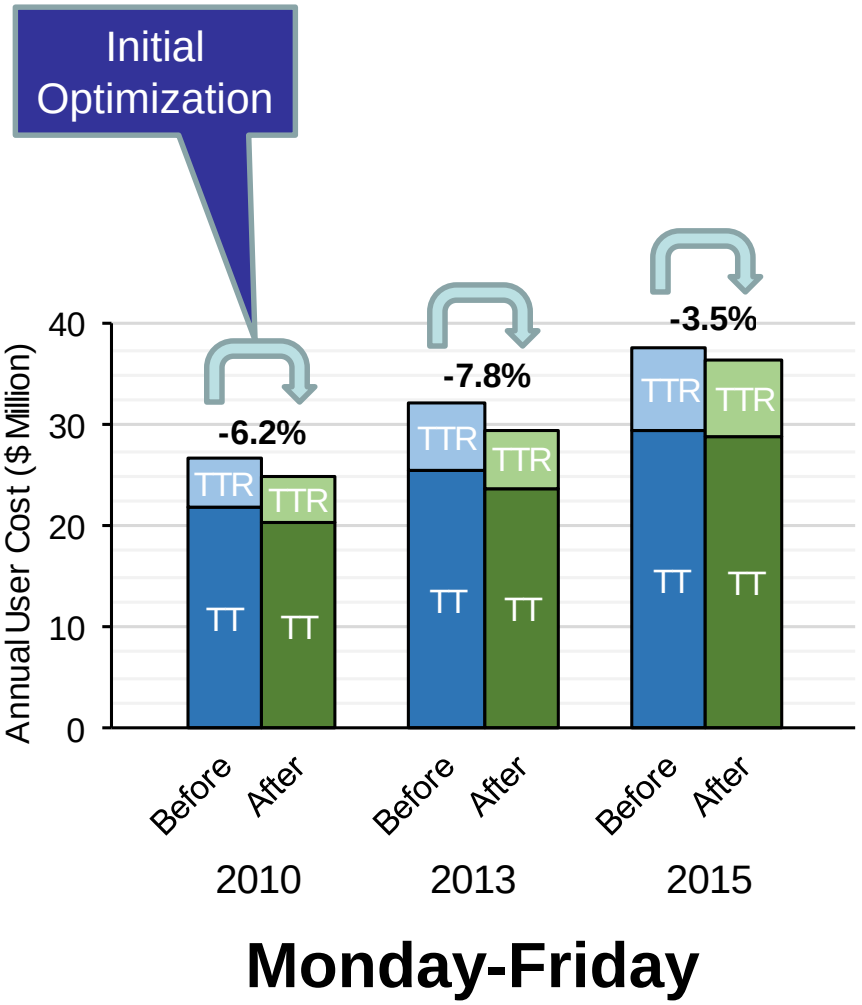
Monday-Friday

Lavrenz, S.M., C.M. Day, W.B. Smith, J.R. Sturdevant, and D.M. Bullock. Assessing longitudinal arterial performance traffic signal retiming outcomes. Transportation Research Record, in press, 2016.

User Costs By Year



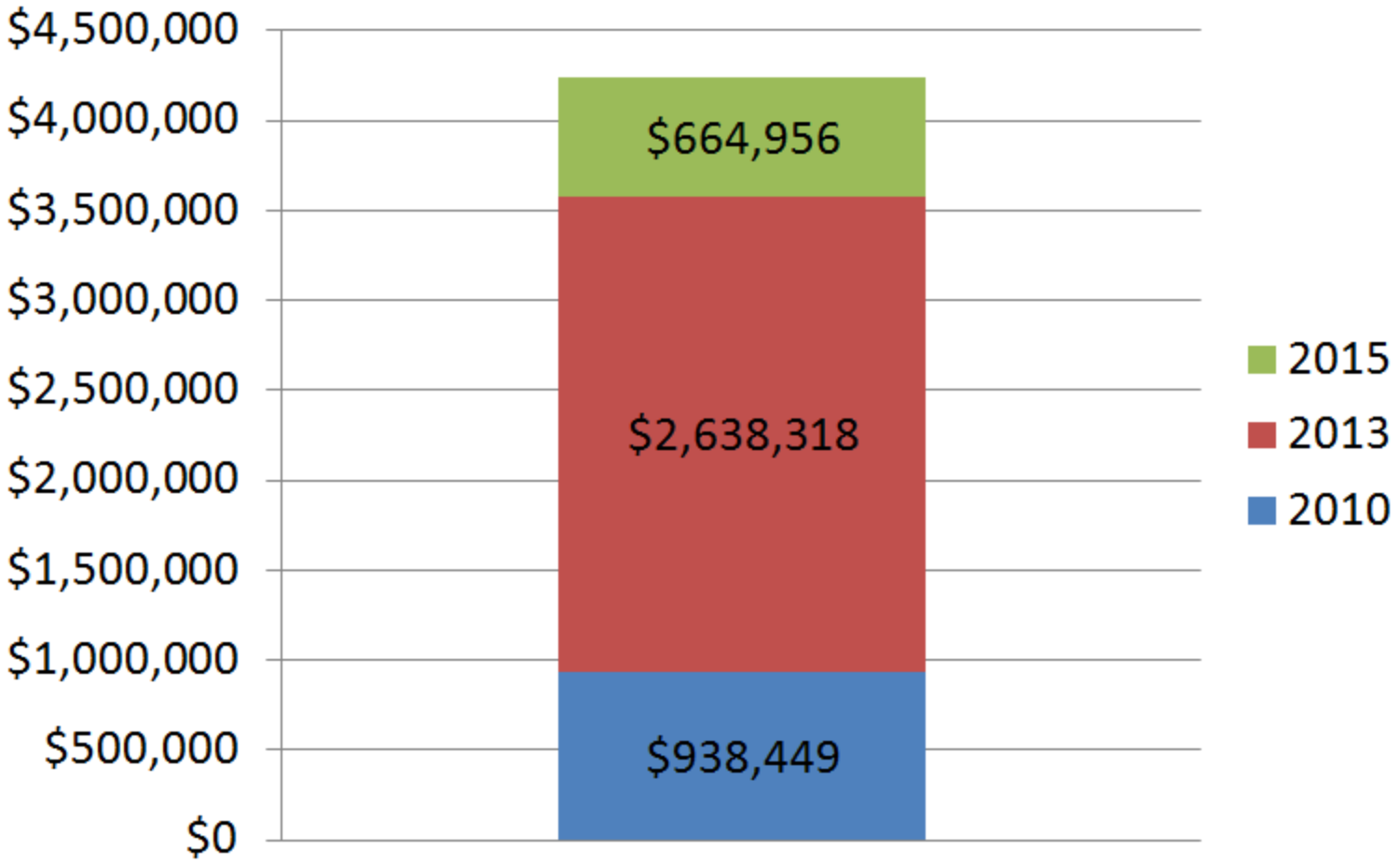
Saturday



Monday-Friday

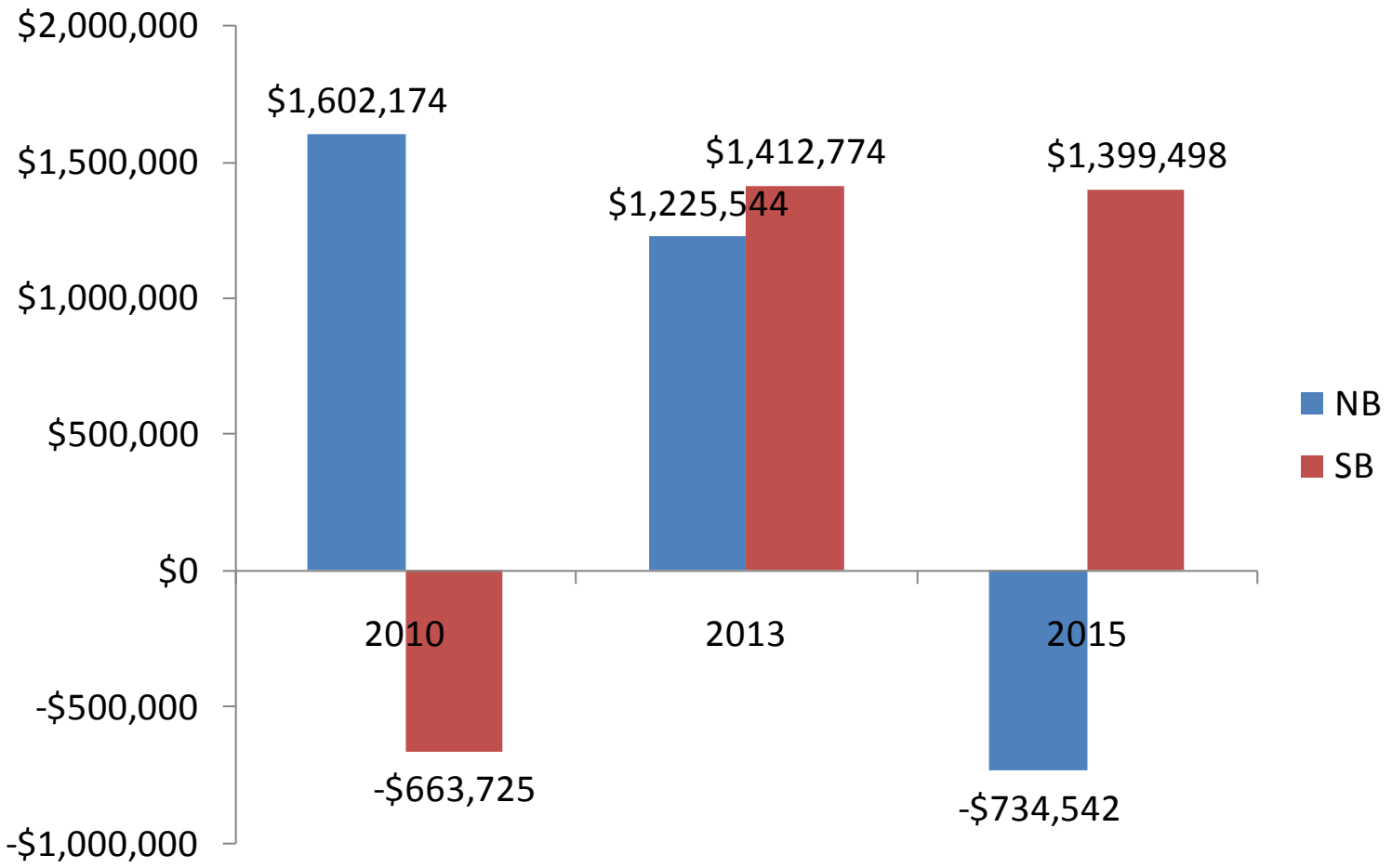
Lavrenz, S.M., C.M. Day, W.B. Smith, J.R. Sturdevant, and D.M. Bullock. Assessing longitudinal arterial performance traffic signal retiming outcomes. Transportation Research Record, in press, 2016.

Total User Benefit by Year…



Lavrenz, S.M., C.M. Day, W.B. Smith, J.R. Sturdevant, and D.M. Bullock. Assessing longitudinal arterial performance traffic signal retiming outcomes. Transportation Research Record, in press, 2016.

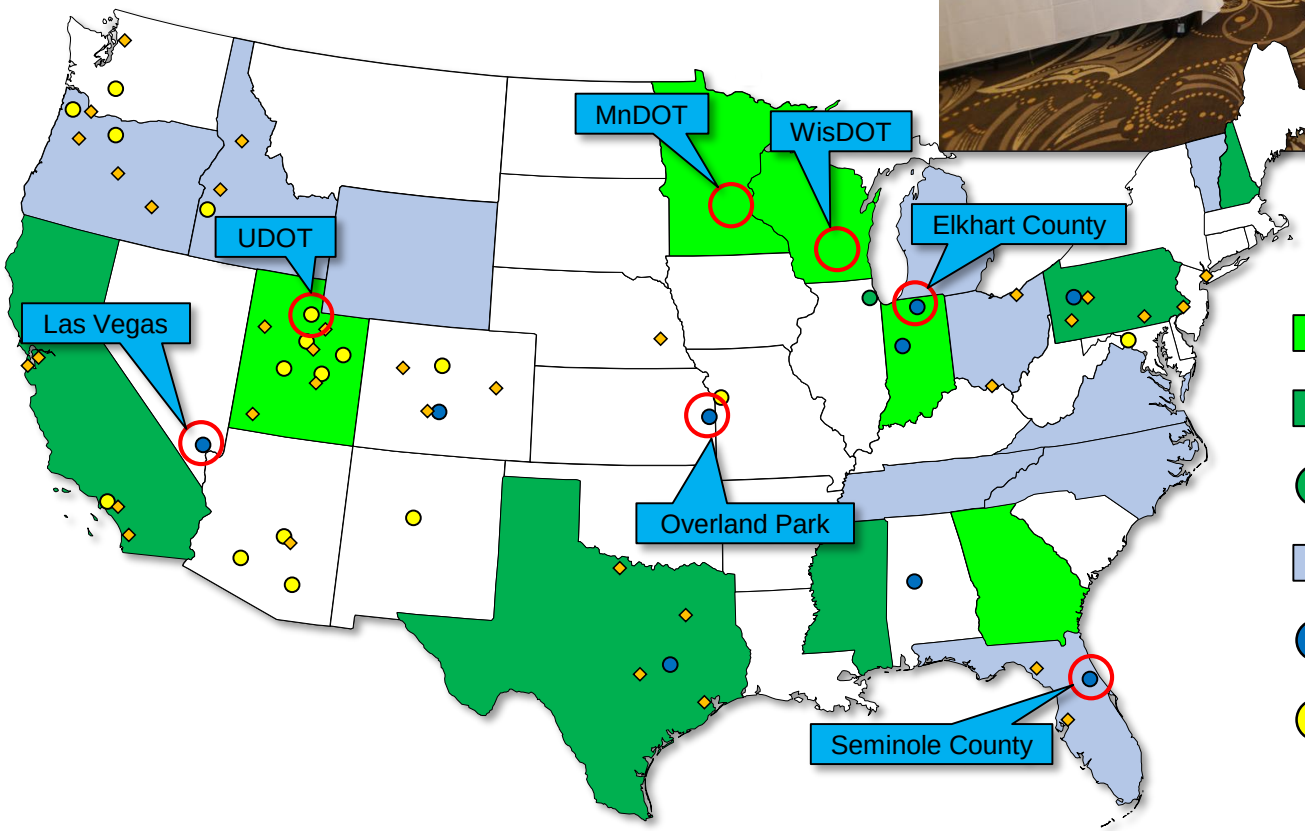
Total User Benefit Broken Down by Year and Direction... Opportunities to Explore Optimization Process Further



Lavrenz, S.M., C.M. Day, W.B. Smith, J.R. Sturdevant, and D.M. Bullock. Assessing longitudinal arterial performance traffic signal retiming outcomes. Transportation Research Record, in press, 2016.

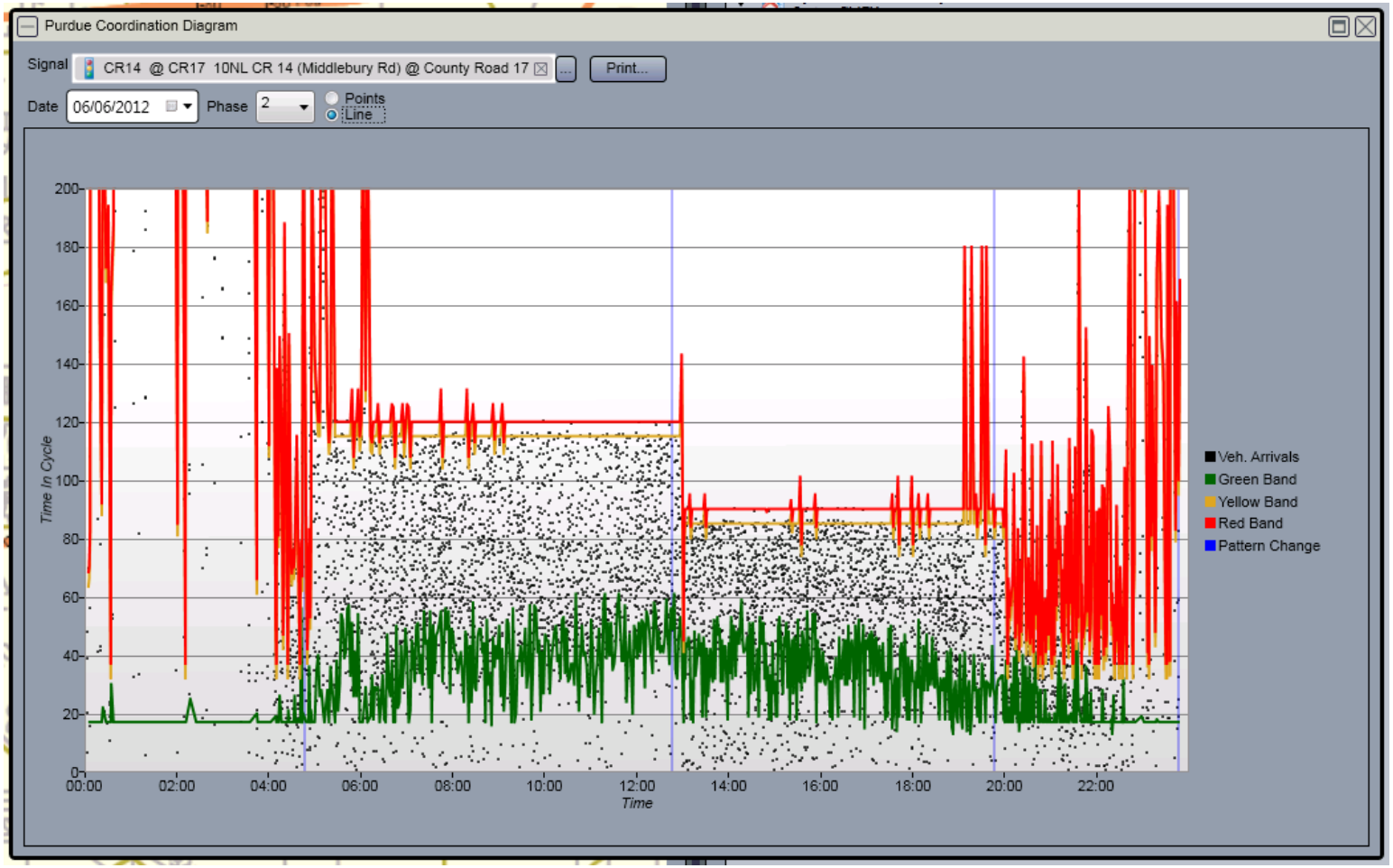
Selected Example Implementations from around the US…

SPM Workshop,
Salt Lake City, Jan. 2016



- State DOT w/ SPM
- Other PFS State DOT
- PFS Local Agency
- States at Workshop
- Local Agency w/ SPM
- Local at Workshop
- Private Sector Workshop Participant

2011 - Elkhart County (Indiana) Highway Department Centracs System



Example Implementations…
From 2016 Workshop: Utah DOT

UDOT Keeping Utah Moving

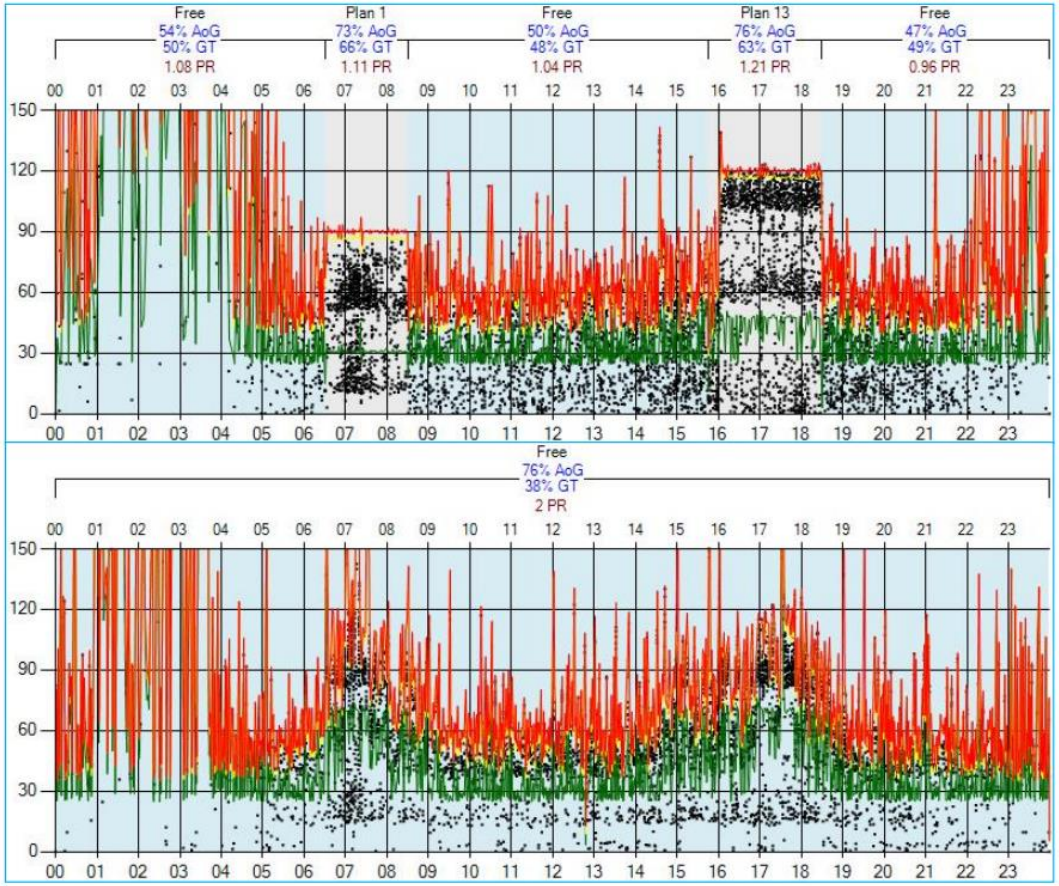
AASHTO Innovation Initiative

Purdue Coordination Diagram – WB at Slave (downstream)

Before: 2/18/15

Coordination in AM and PM peak

Full Day AoG: 60%



After: 11/4/15

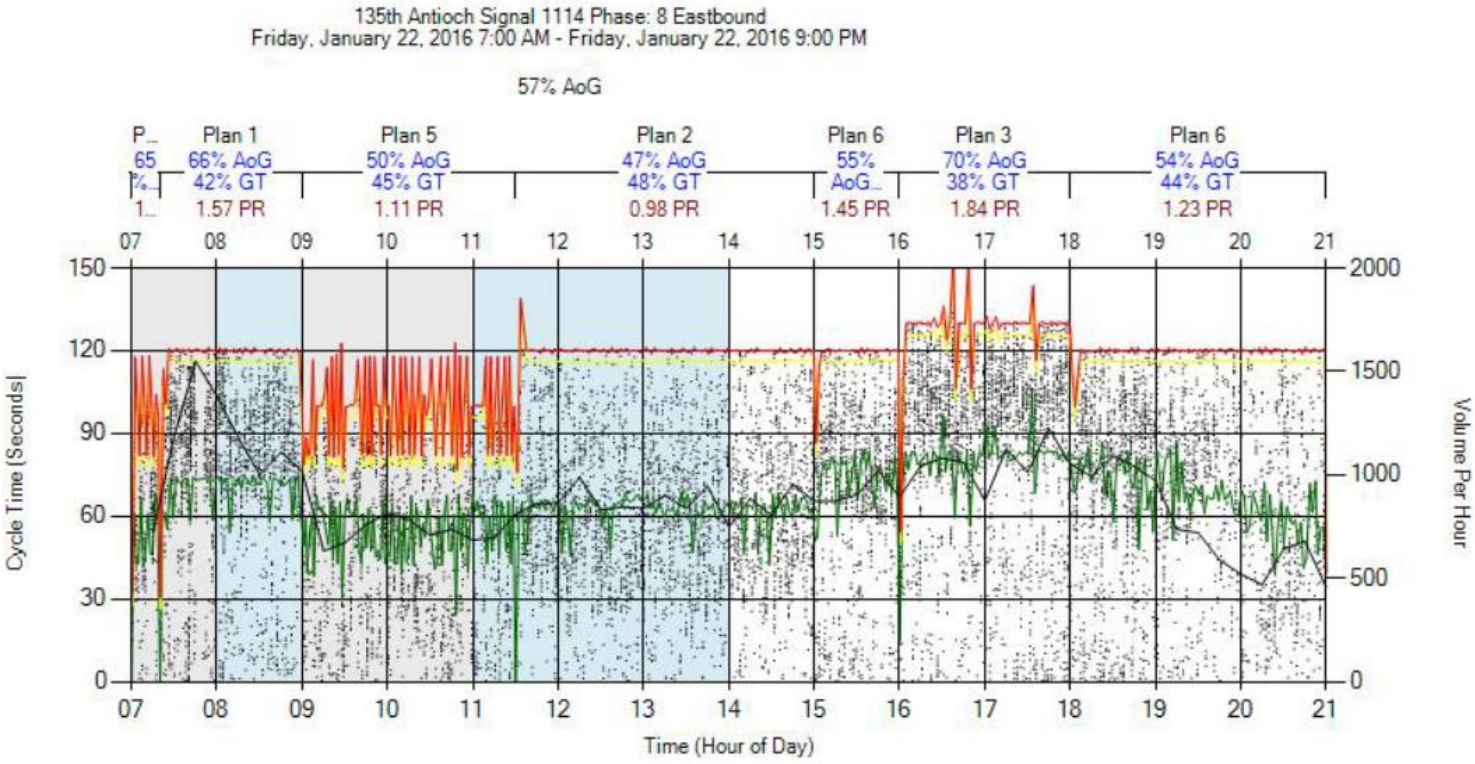
No time-base coordination

Full Day AoG: 76%

Real-Time Adaptive with Peer-to-Peer Logic

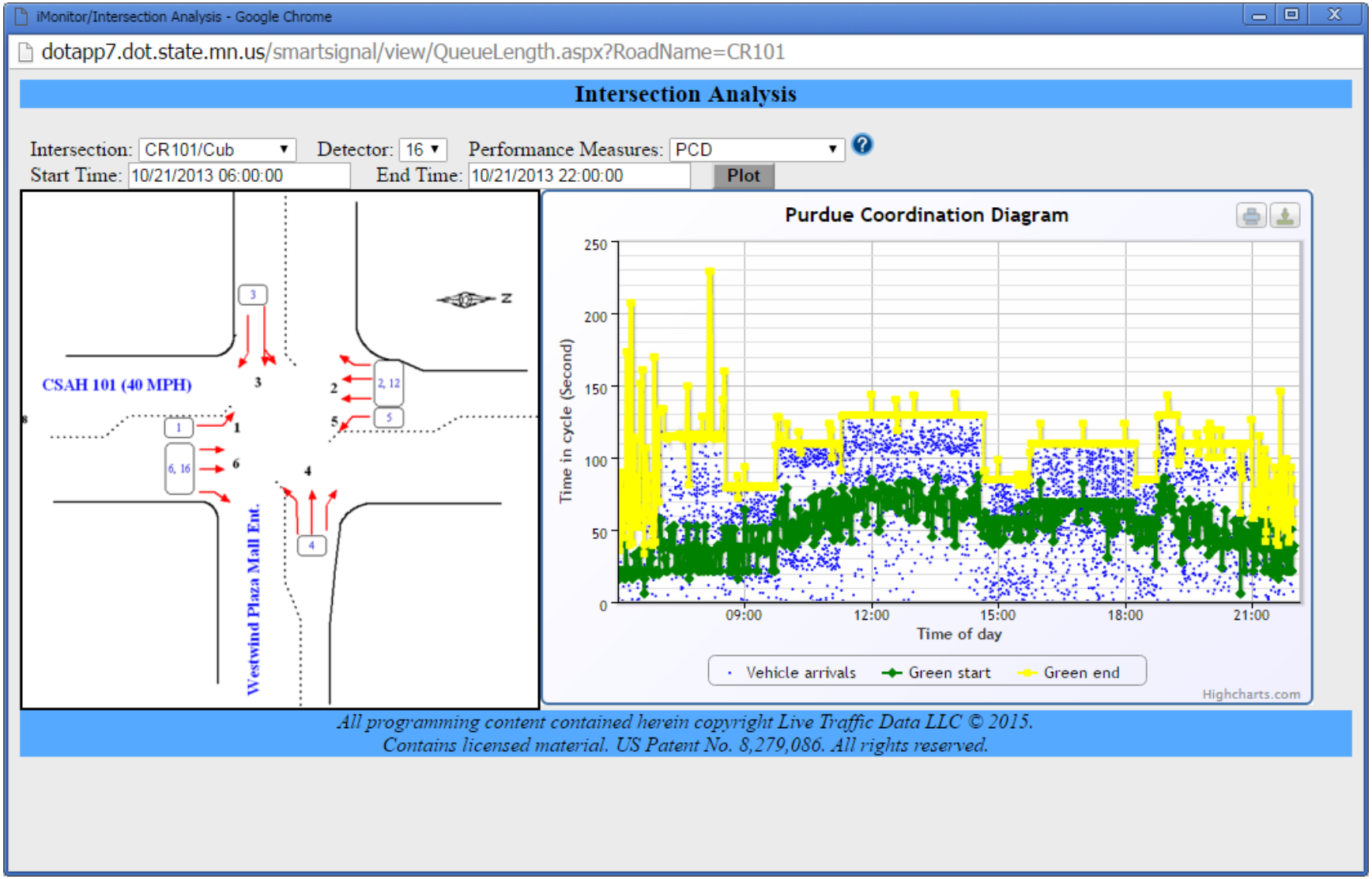
http://docs.lib.purdue.edu/atspmw/2016/Presentations/9

Example Implementations…
From 2016 Workshop: Overland Park, KS

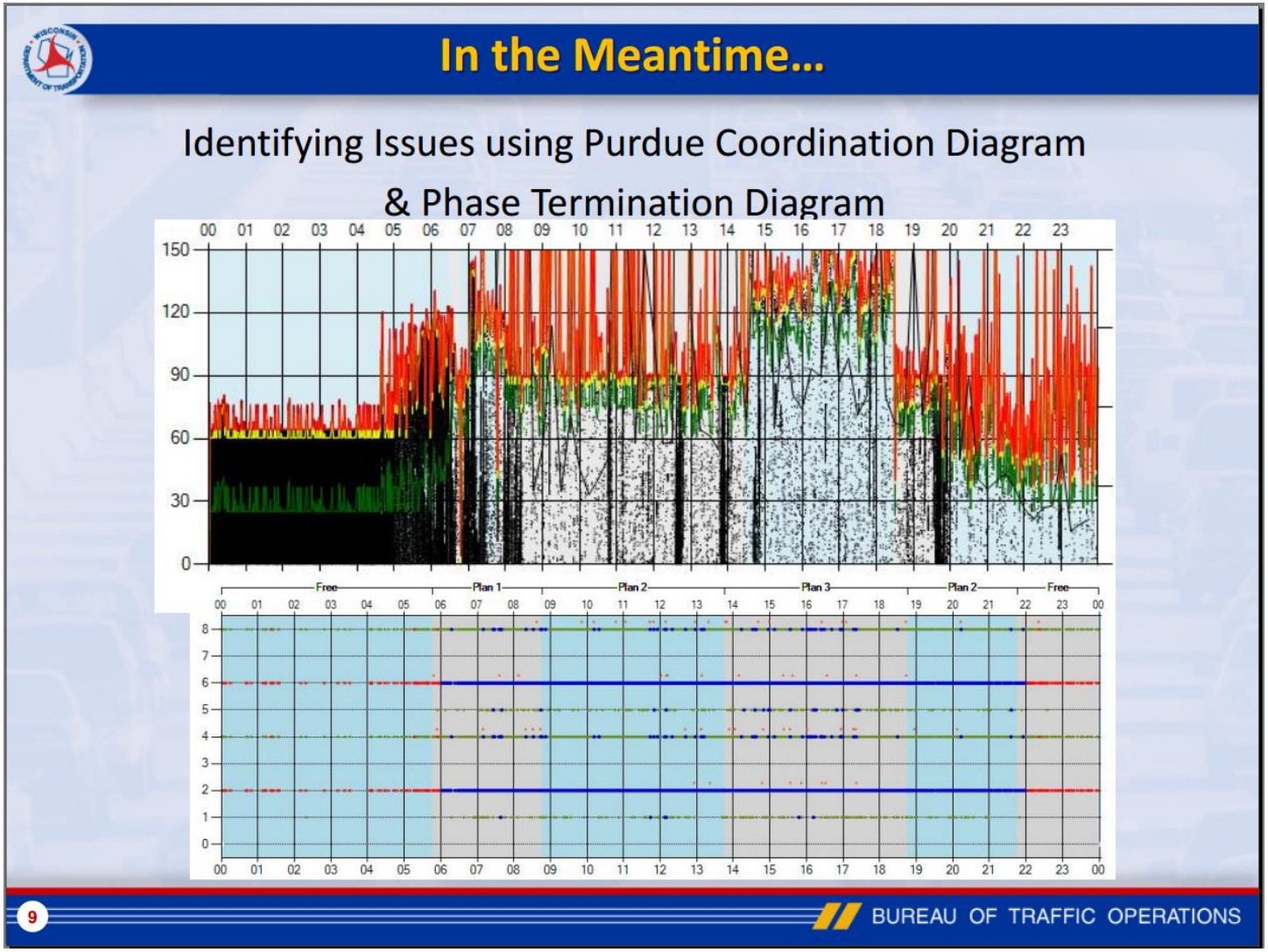


http://docs.lib.purdue.edu/atspmw/2016/Presentations/12

Example Implementations…
PCDs in the Minnesota SMART-SIGNAL System



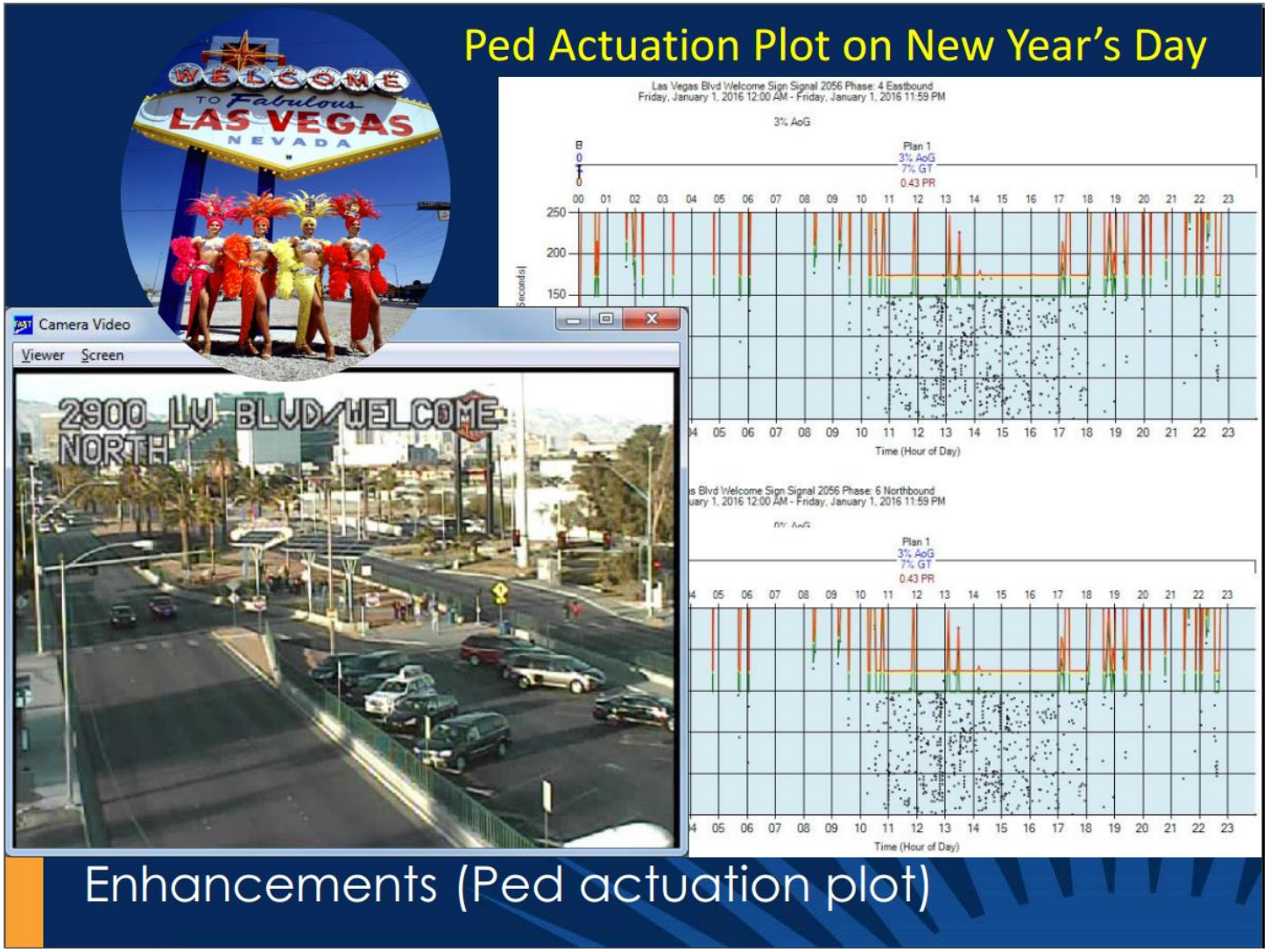
Example Implementations…
From 2016 Workshop: Wisconsin DOT



Evidence of detector error

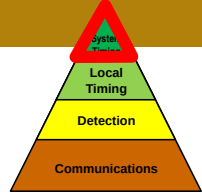
http://docs.lib.purdue.edu/atspmw/2016/Presentations/18

Example Implementations…
From 2016 Workshop: Las Vegas/NVFast – Ped Actuations



Replace vehicle detections with ped button actuation times

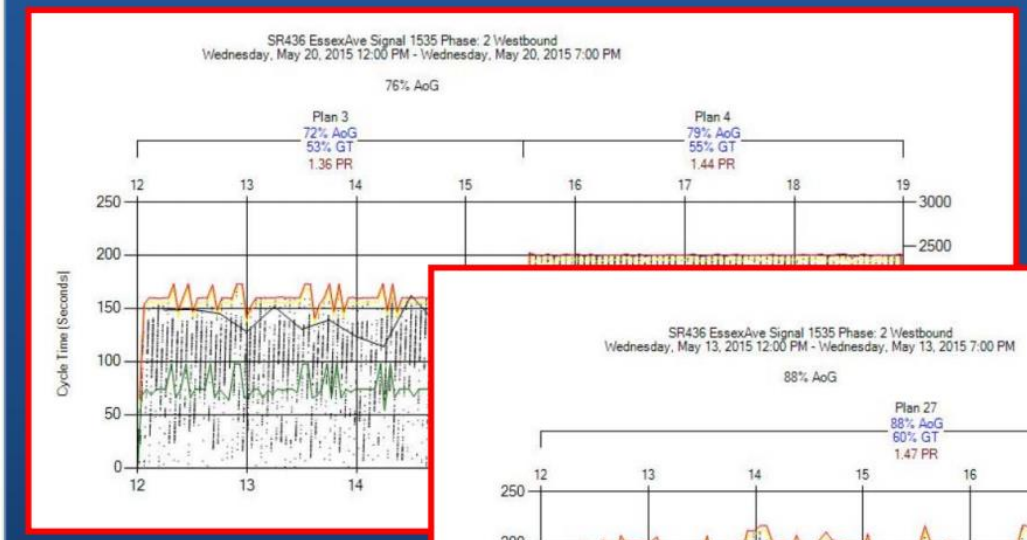
http://docs.lib.purdue.edu/atspmw/2016/Presentations/13

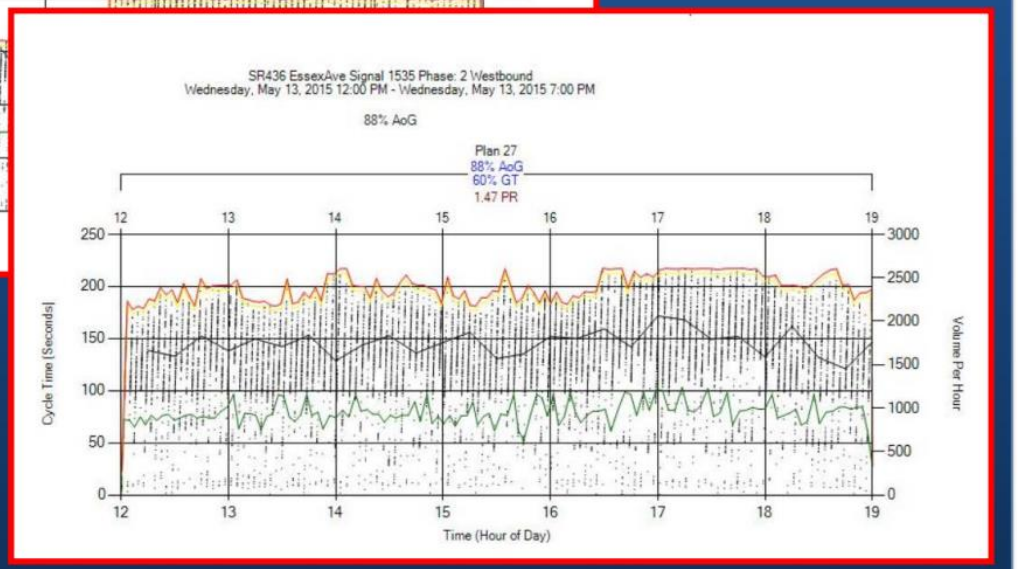


Example Implementations…
From 2016 Workshop: Seminole County, Florida

Case Study/Use #4 – Before/After (On/Off) Studies

SEMINOLE COUNTY
FLORIDA'S NATURAL CHOICE





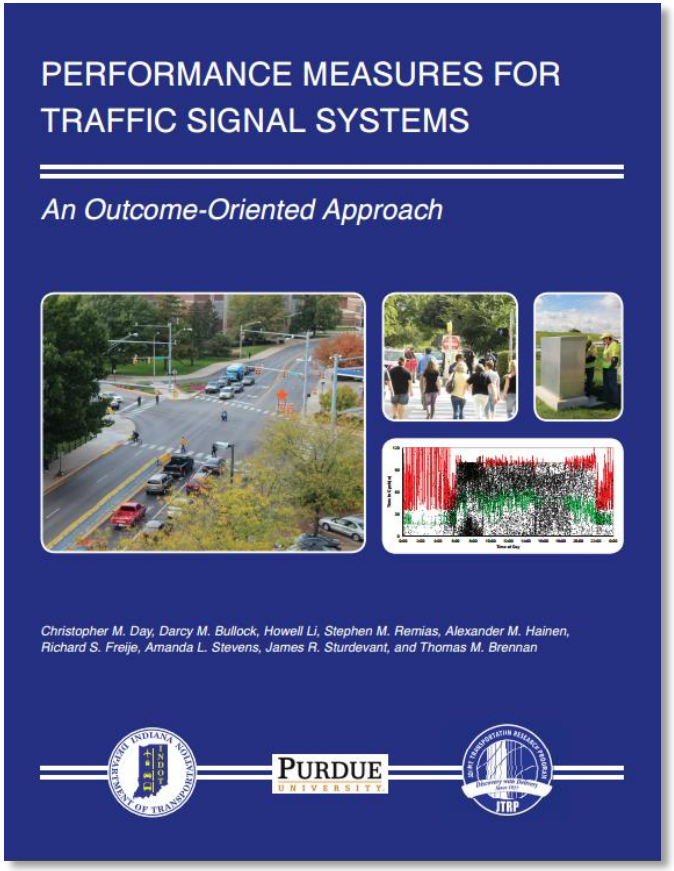
Coordination Diagram with Adaptive Control

http://docs.lib.purdue.edu/atspmw/2016/Presentations/14

Summary

- Need for Performance Measures
- What Probe Data provides
- What High Resolution Data provides
  - Communications
  - Detection
  - Allocation of Capacity (Green Time)
    - Split Monitor
    - Split Failure Detection
    - Regional and Longitudinal Analysis
  - Performance measures for Quality of Progression
    - Coordination Diagram concept
    - Examples
    - I-65 Detour
    - SR 37 Case Study
    - Implementation Examples

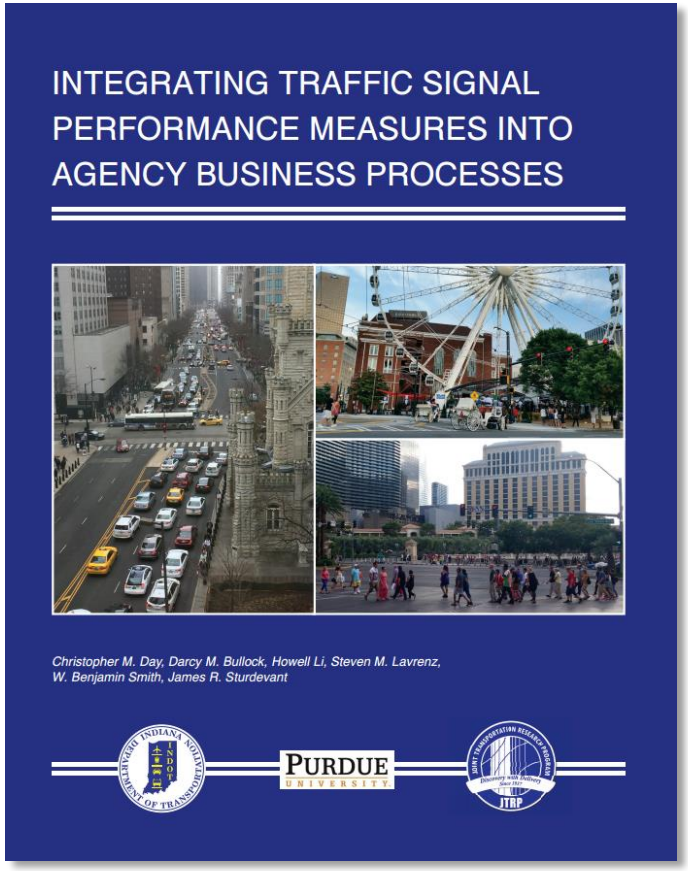
Pooled Fund Study Products (FHWA, Purdue, and Agency Partners)



"Volume 1"

On Defining Performance Measures

Download at:
http://tinyurl.com/signalmoe

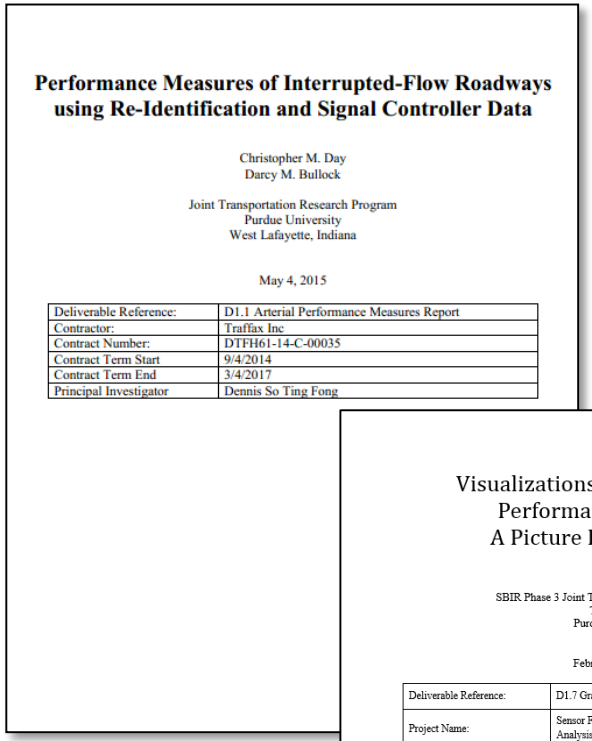


"Volume 2"

On Using Performance Measures

Download at:
http://tinyurl.com/signalmoe2

Traffax/Purdue SBIR Project Products (FHWA Sponsored)



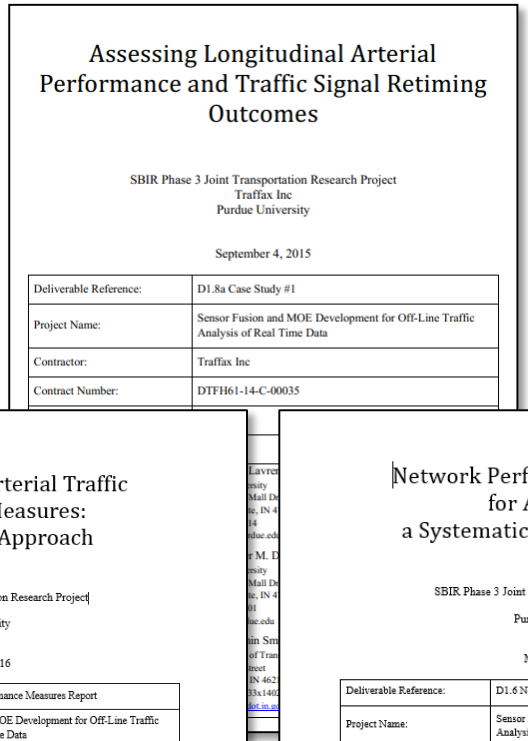
Performance Measures of Interrupted-Flow Roadways using Re-Identification and Signal Controller Data

Christopher M. Day
Darcy M. Bullock

Joint Transportation Research Program
Purdue University
West Lafayette, Indiana

May 4, 2015

Deliverable Reference:	D1.1 Arterial Performance Measures Report
Contractor:	Traffax Inc
Contract Number:	DTFH61-14-C-00035
Contract Term Start	9/4/2014
Contract Term End	3/4/2017
Principal Investigator	Dennis So Ting Fong

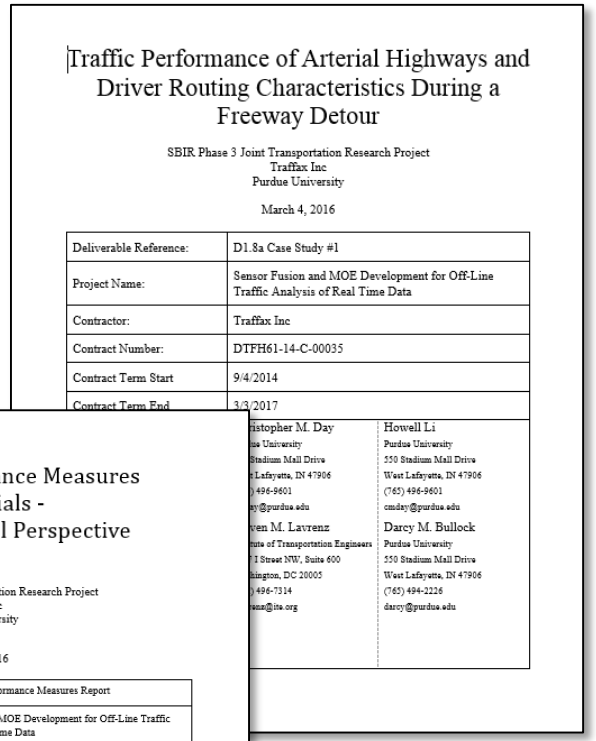


Assessing Longitudinal Arterial Performance and Traffic Signal Retiming Outcomes

SBIR Phase 3 Joint Transportation Research Project
Traffax Inc
Purdue University

September 4, 2015

Deliverable Reference:	D1.8a Case Study #1
Project Name:	Sensor Fusion and MOE Development for Off-Line Traffic Analysis of Real Time Data
Contractor:	Traffax Inc
Contract Number:	DTFH61-14-C-00035

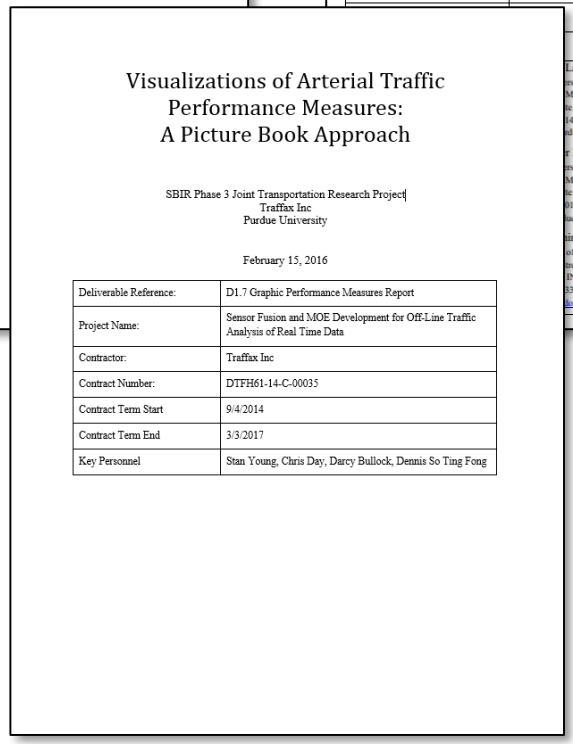


Traffic Performance of Arterial Highways and Driver Routing Characteristics During a Freeway Detour

SBIR Phase 3 Joint Transportation Research Project
Traffax Inc
Purdue University

March 4, 2016

Deliverable Reference:	D1.8a Case Study #1
Project Name:	Sensor Fusion and MOE Development for Off-Line Traffic Analysis of Real Time Data
Contractor:	Traffax Inc
Contract Number:	DTFH61-14-C-00035
Contract Term Start	9/4/2014
Contract Term End	3/3/2017

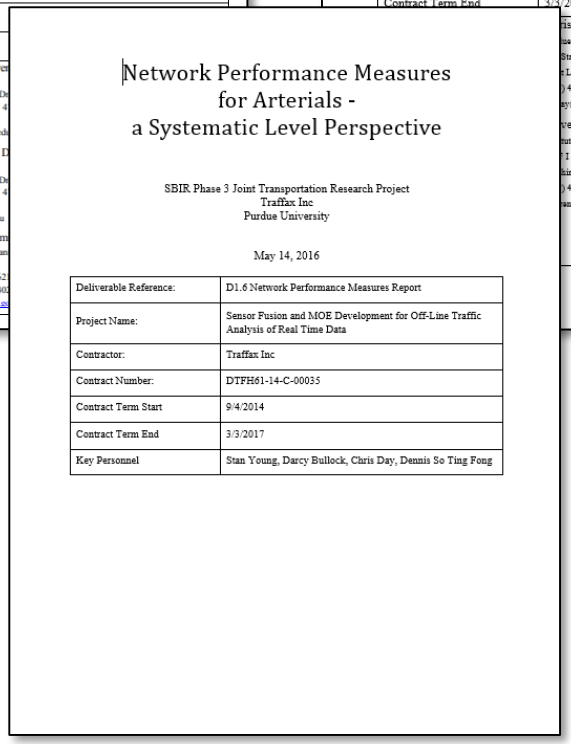


Visualizations of Arterial Traffic Performance Measures: A Picture Book Approach

SBIR Phase 3 Joint Transportation Research Project
Traffax Inc
Purdue University

February 15, 2016

Deliverable Reference:	D1.7 Graphic Performance Measures Report
Project Name:	Sensor Fusion and MOE Development for Off-Line Traffic Analysis of Real Time Data
Contractor:	Traffax Inc
Contract Number:	DTFH61-14-C-00035
Contract Term Start	9/4/2014
Contract Term End	3/3/2017
Key Personnel	Stan Young, Chris Day, Darcy Bullock, Dennis So Ting Fong



Network Performance Measures for Arterials - a Systematic Level Perspective

SBIR Phase 3 Joint Transportation Research Project
Traffax Inc
Purdue University

May 14, 2016

Deliverable Reference:	D1.6 Network Performance Measures Report
Project Name:	Sensor Fusion and MOE Development for Off-Line Traffic Analysis of Real Time Data
Contractor:	Traffax Inc
Contract Number:	DTFH61-14-C-00035
Contract Term Start	9/4/2014
Contract Term End	3/3/2017
Key Personnel	Stan Young, Darcy Bullock, Chris Day, Dennis So Ting Fong

Leveraging Multi-Source Real-Time Data for Arterial Performance Measurement

– Case Study in City of Tucson, Arizona

Yao-Jan Wu, Ph.D., P.E.
Assistant Professor
Department of Civil Engineering And Engineering Mechanics
The University of Arizona, Tucson, AZ

May. 1, 2016

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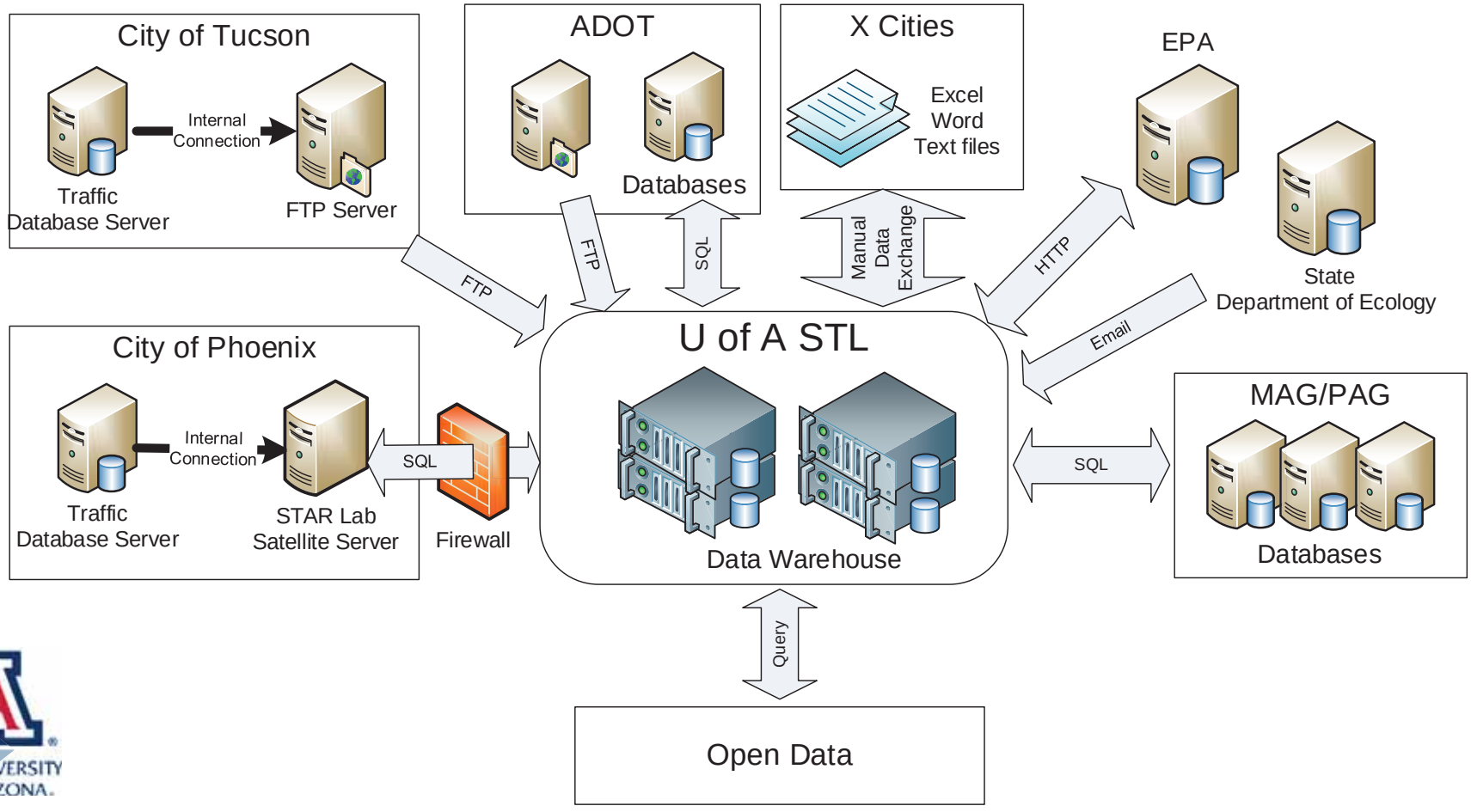
Vision:
Open Big Data / Open Research

Integrated Solutions for the Region



Simple Solution?

Outline

- Multi-source Traffic Data
  - Bluetooth-Based
  - Probe Vehicle-Based
  - Video-Based (Optical)
  - Signal Timing

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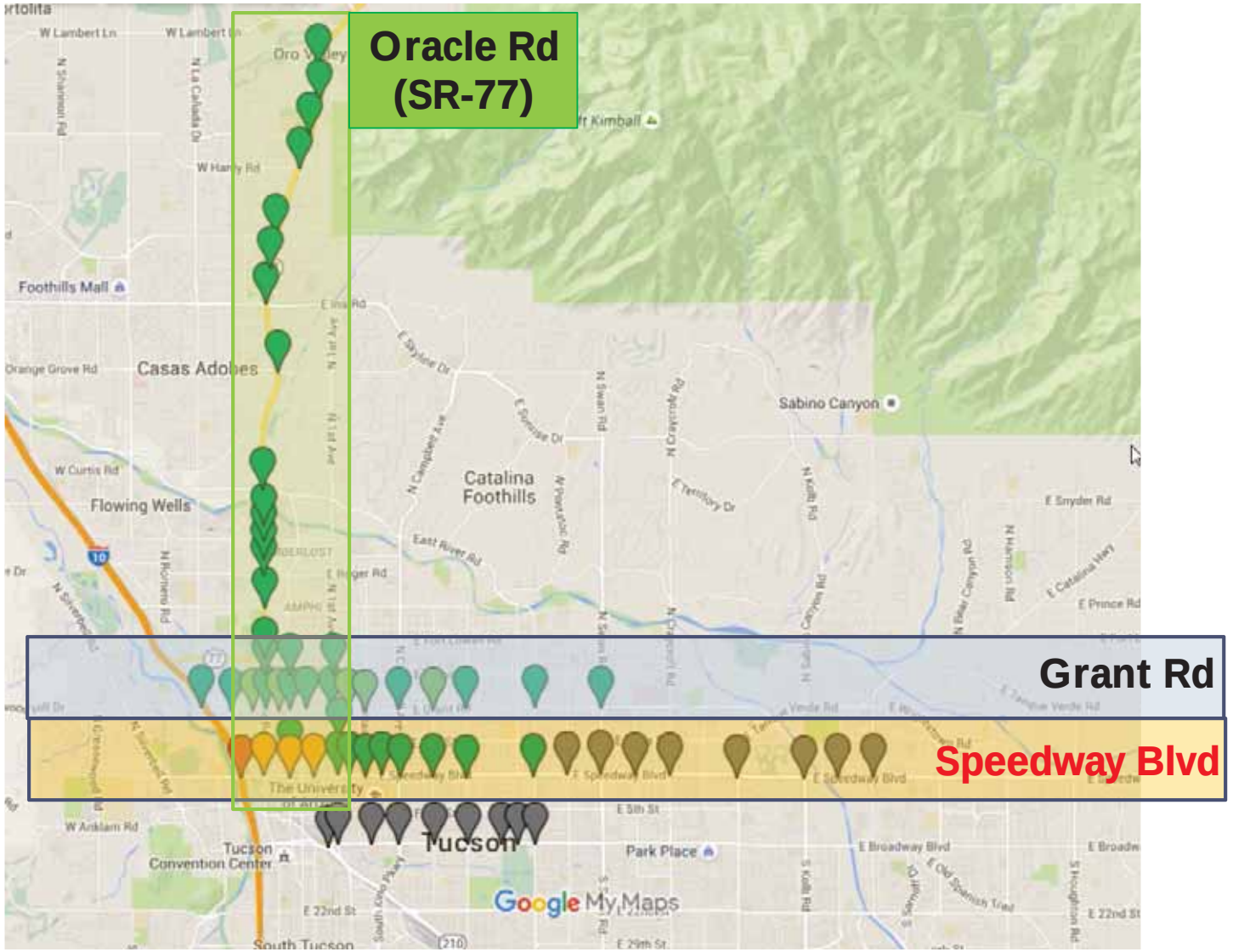
Bluetooth

Acknowledgments: Paul Casertano, Mike Hicks, Bob Hunt, Simon Ramos, Jorge Riveros, French Chris, Paul Burton, and many many people.

Bluetooth Sensor Locations

(as of Apr. 25, 2016)



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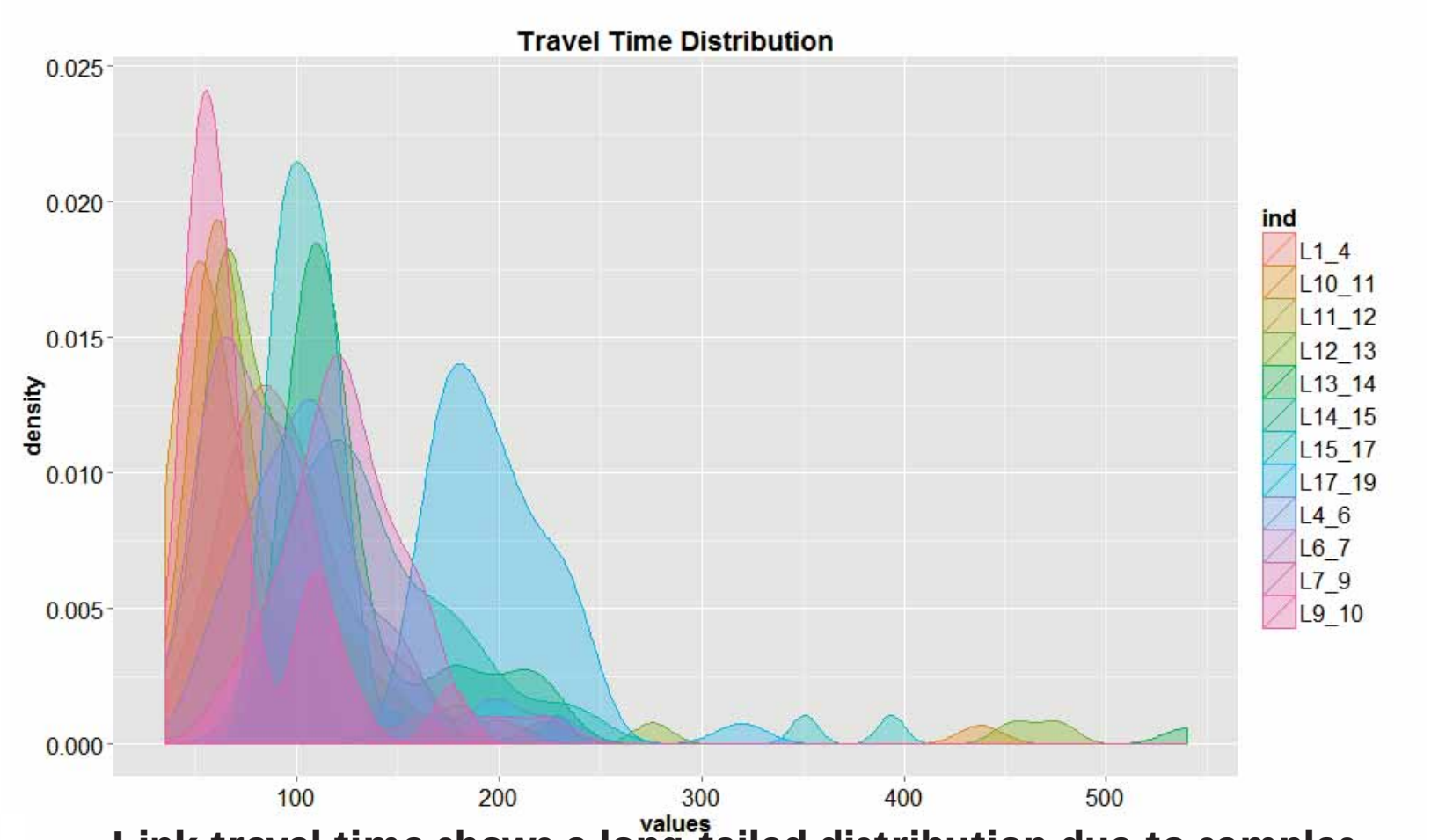
Low-Cost Bluetooth Module

- Idea originated from **Dr. Larry Head**

Bluetooth Adapter

Distribution of Link Travel Time



Link travel time shows a long-tailed distribution due to samples from low-speed subjects (i.e., pedestrian, cyclist)

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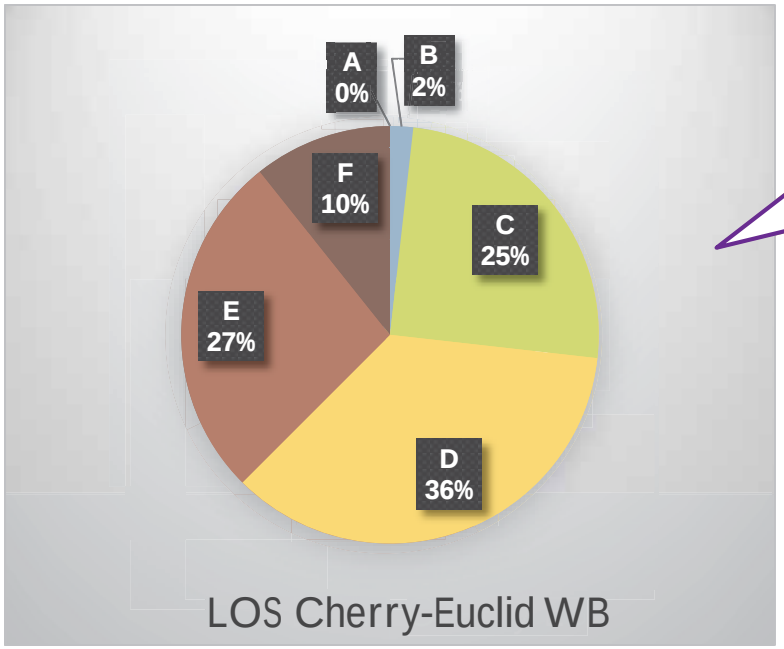
Application of Bluetooth Data for Arterial Performance Measurement



- Vehicles experience *LOS **E*** and ***F*** for about ***5 hours*** each weekday

LOS E Characteristics :

- *Unstable flow*
- *Significant delay*
- *Probably due to poor progression, high volume, and inappropriate signal timing*

* Analysis Period Includes 14h (6:00 AM to 8:00 PM, Jun. 10-11, 2014)
* Criteria : HCM 2010

Source: HCM 2010

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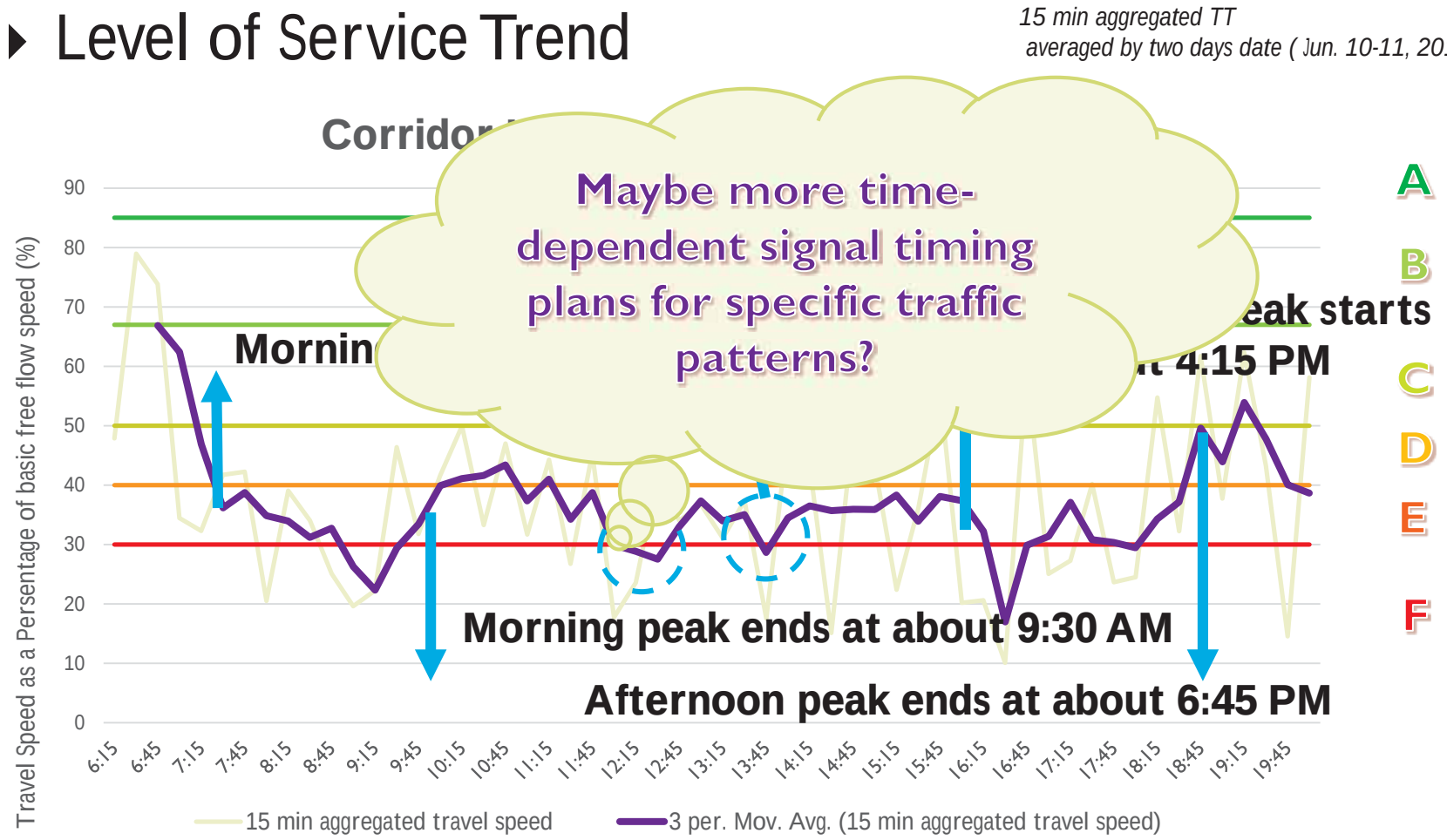
Application of Bluetooth Data for Arterial Performance Measurement

- Level of Service Trend



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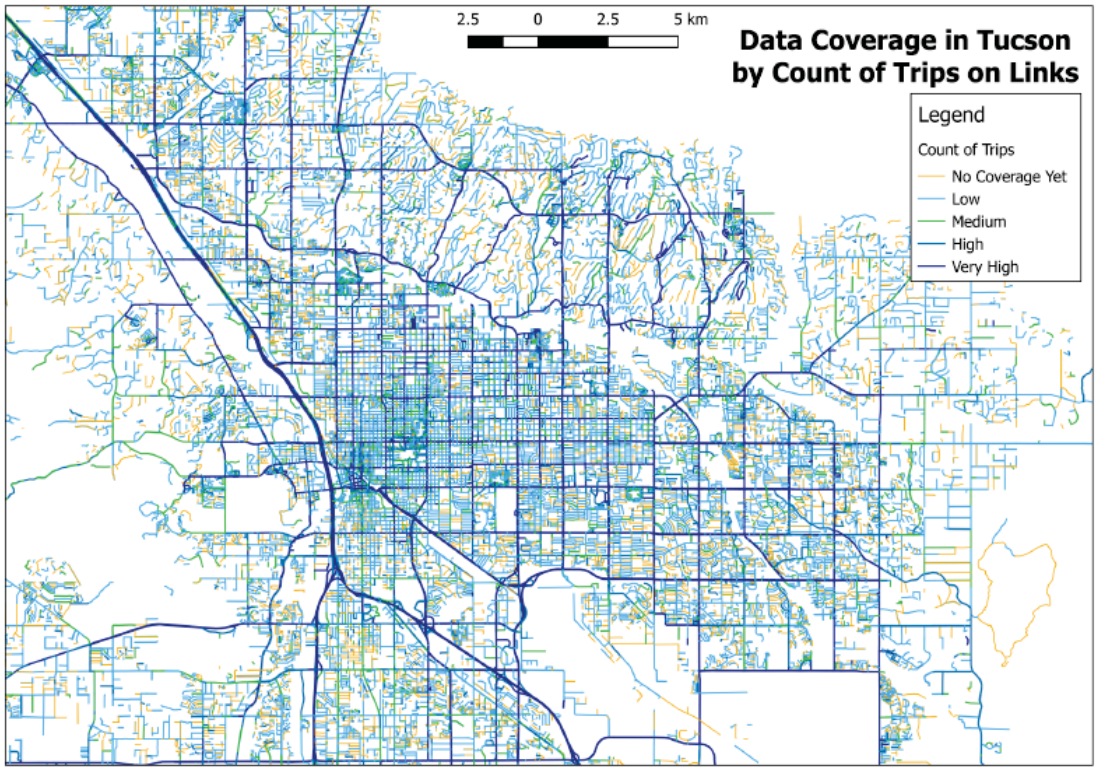
Probe Vehicle Data

Acknowledgements:

Metropia Probe Data

- Trips finished in Tucson: over 34,000
- GPS points collected in Tucson: over 32 million



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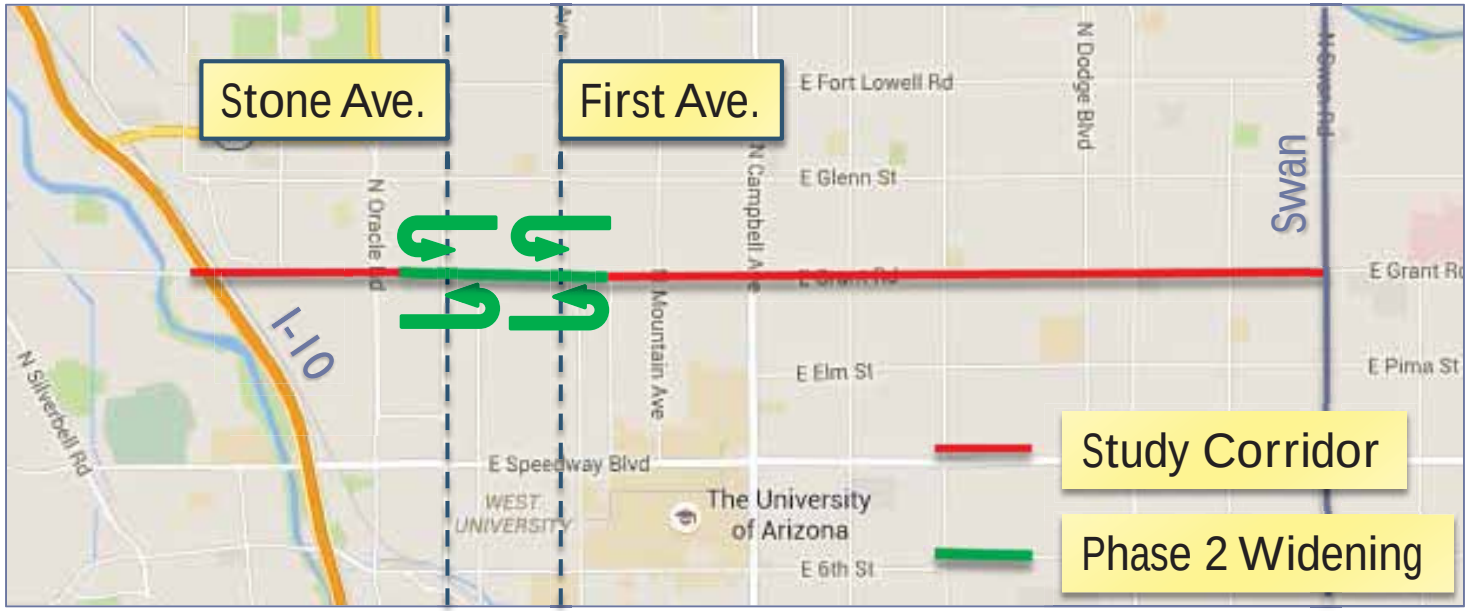
2015

metropia

Grant Road Improvement Project

- Widen Grant Road from 5 to 6 lanes between Stone Ave and Park Ave
- New indirect left turn (ILT) intersections at Stone Ave and First Ave



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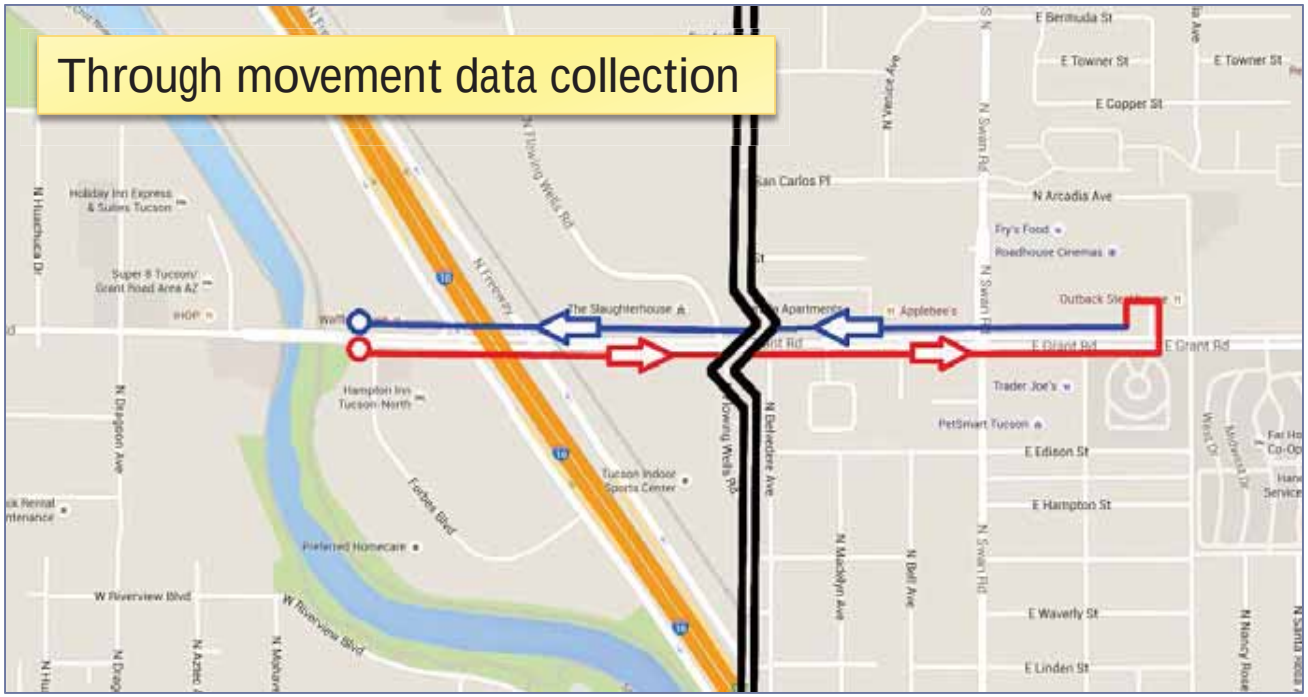
Probe Vehicle Data Collection

- Nearly 30 students volunteered to drive
  - Used the Metropia app
  - Provided <u>through</u> and <u>turning</u> movement trajectories
  - Used trajectories to estimate travel times



Probe Vehicle Data Collection

Student Routes at Grant Rd and Stone Ave

Student Routes at Grant Rd and First Ave

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UA Probe

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YouTube link here

Visualizing Probe Vehicle Trajectories

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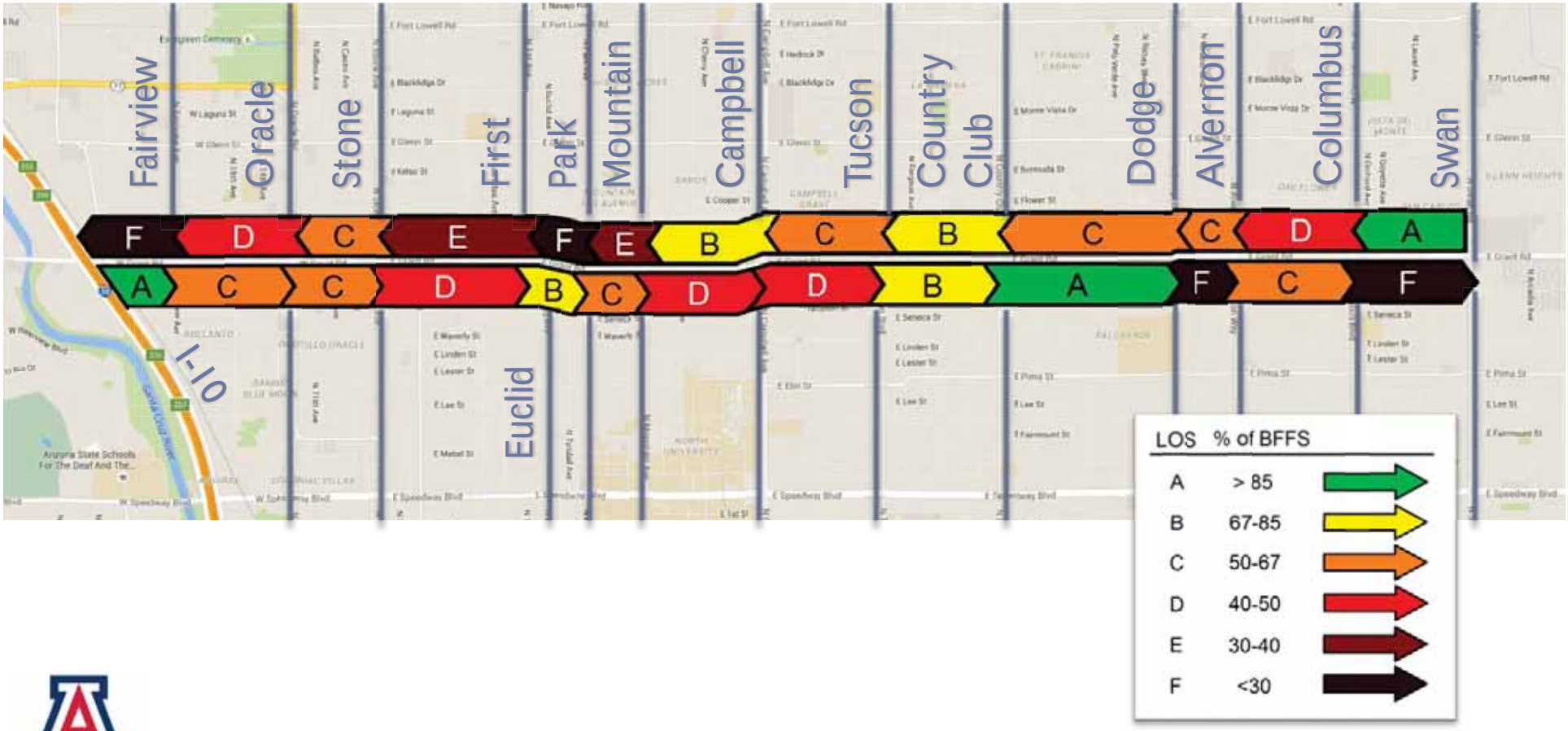
Data tech support: metropia Driving a better city

Probe Vehicle-Based LOS

11/17/15 4:00-6:00 PM



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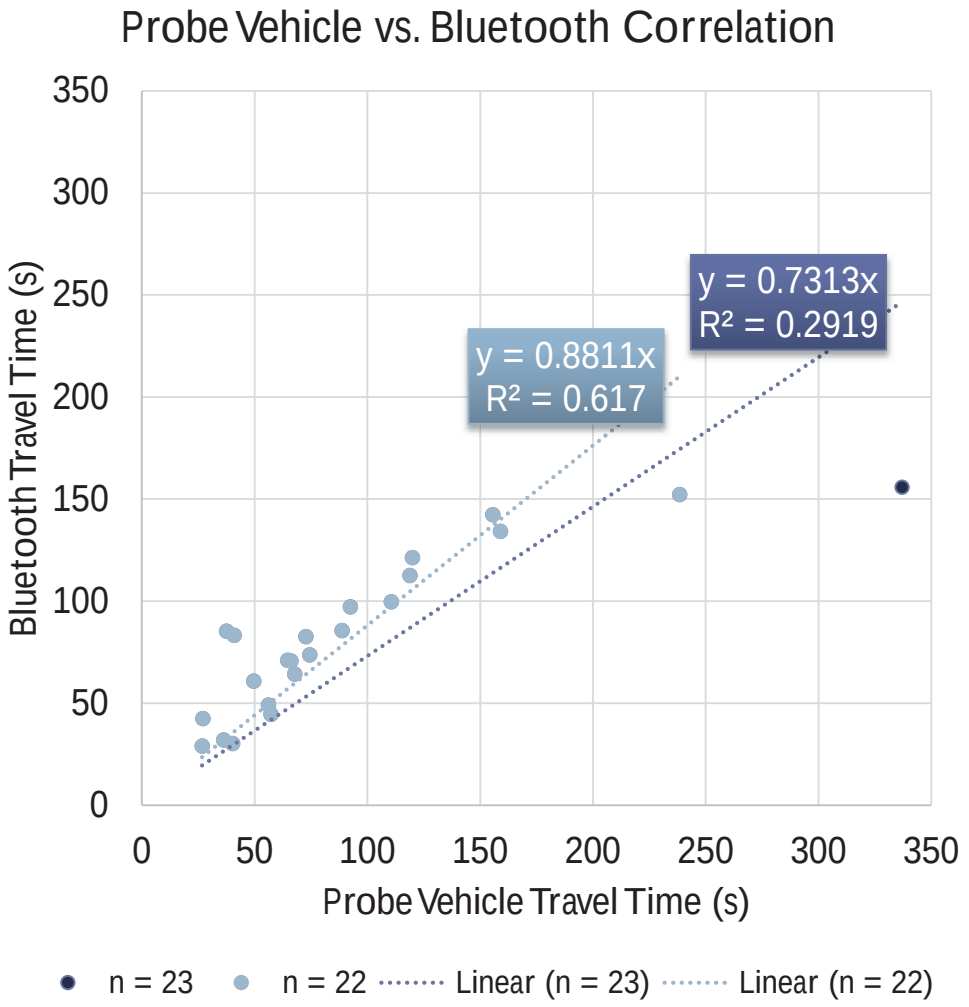
Data source: UA

Travel Time Comparison

Bluetooth vs. Probe Vehicle

- Directional average travel time for two-hour peak periods
- Outlier due to work zone lane closure



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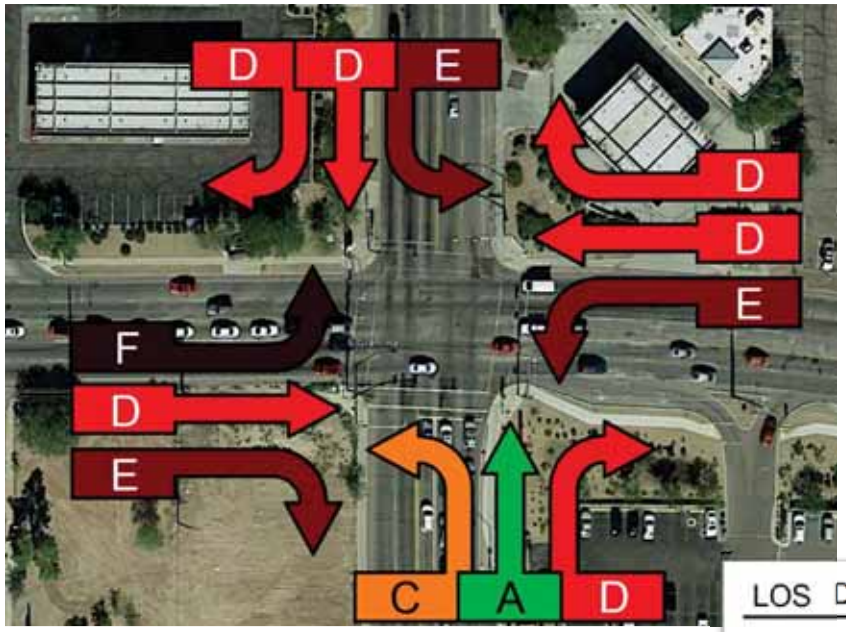
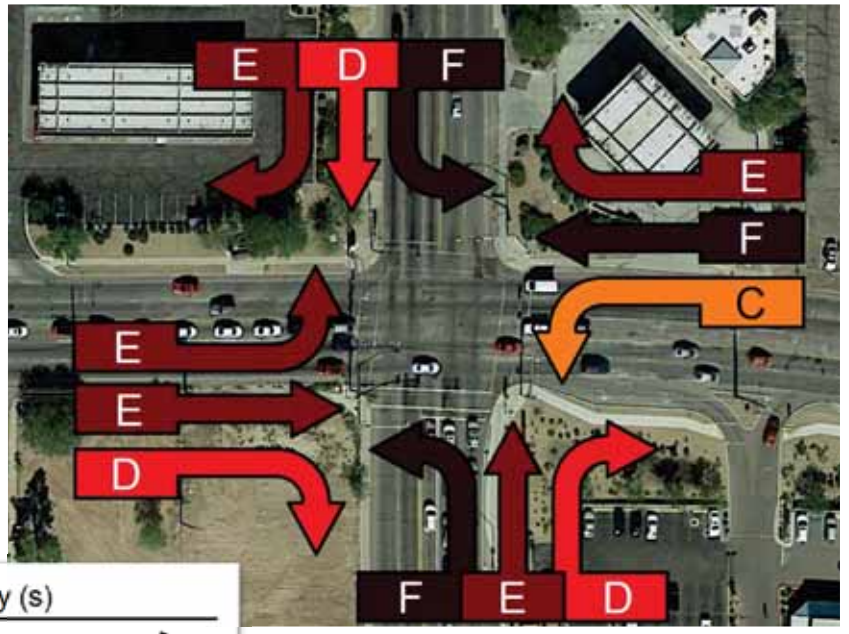
Grant / First Probe Vehicle-Based LOS

12/10/15 7:30-9:30 AM



12/10/15 4:00-6:00 PM



LOS	Delay (s)
A	< 10
B	10-20
C	20-35
D	35-55
E	55-80
F	> 80

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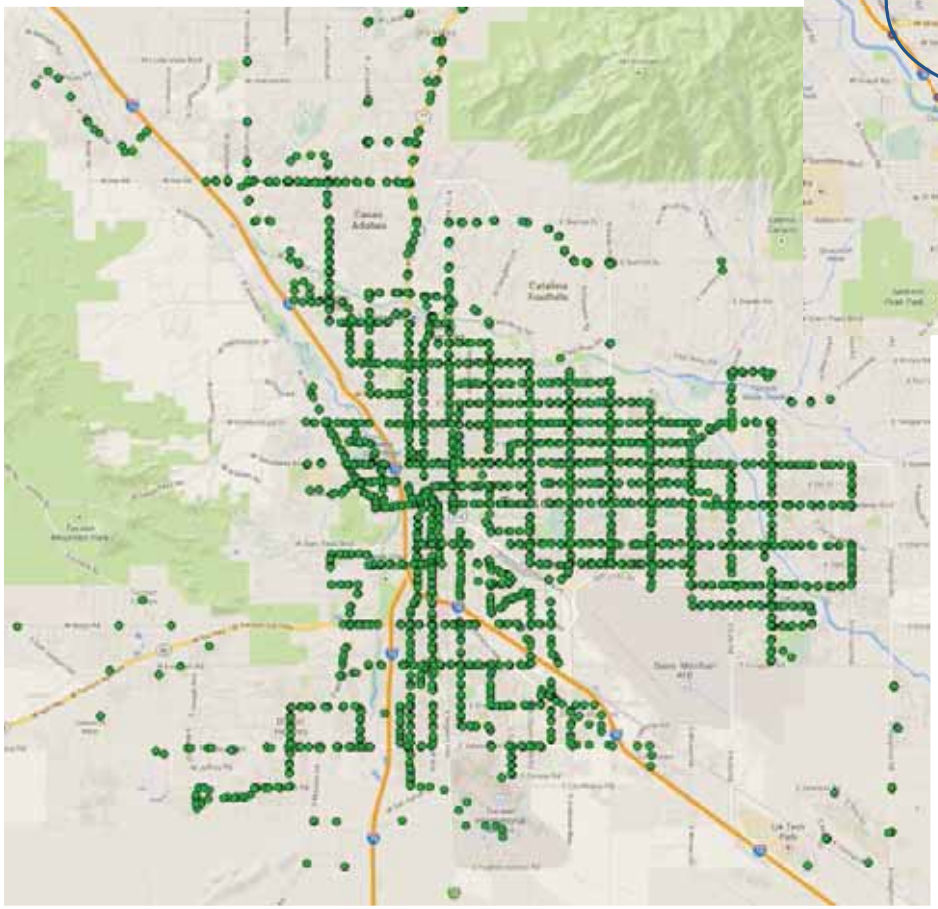
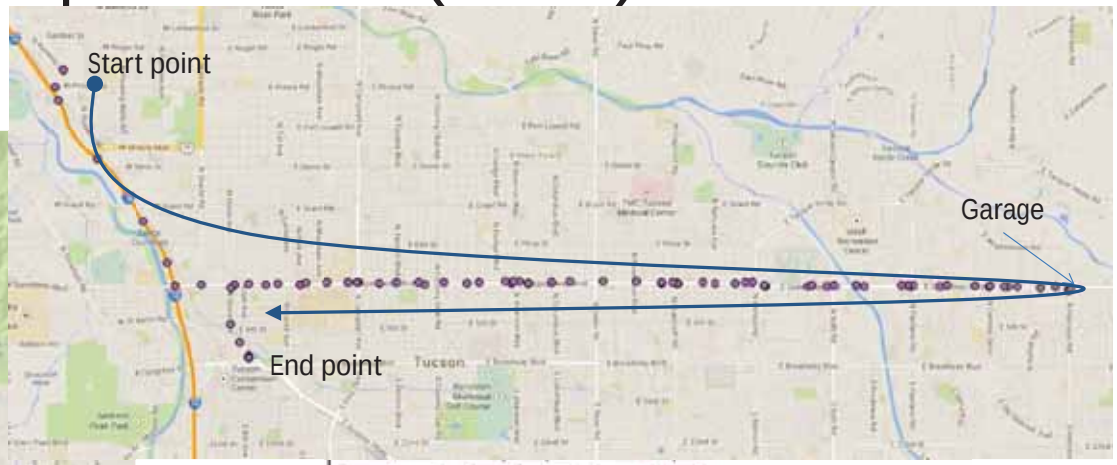
Data source: UA

Other Probe Vehicle Data in Tucson?

Transit Data

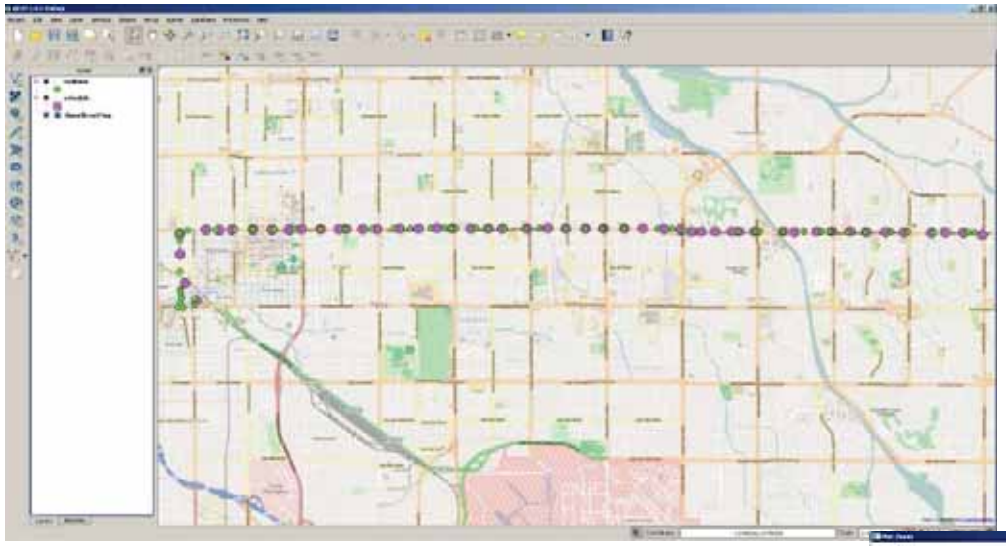
- General Transit Feed Specification (GTFS)
- GTFS-realtime



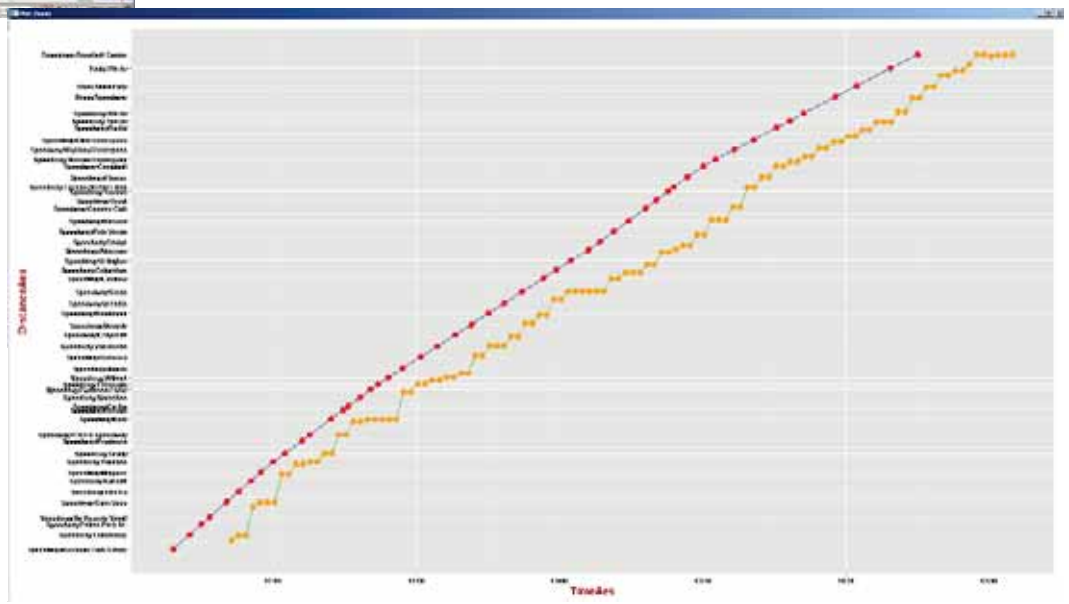


http://suntran.com/tmwebwatch/

Transit Scheduling



Parse GTFS-realtime data

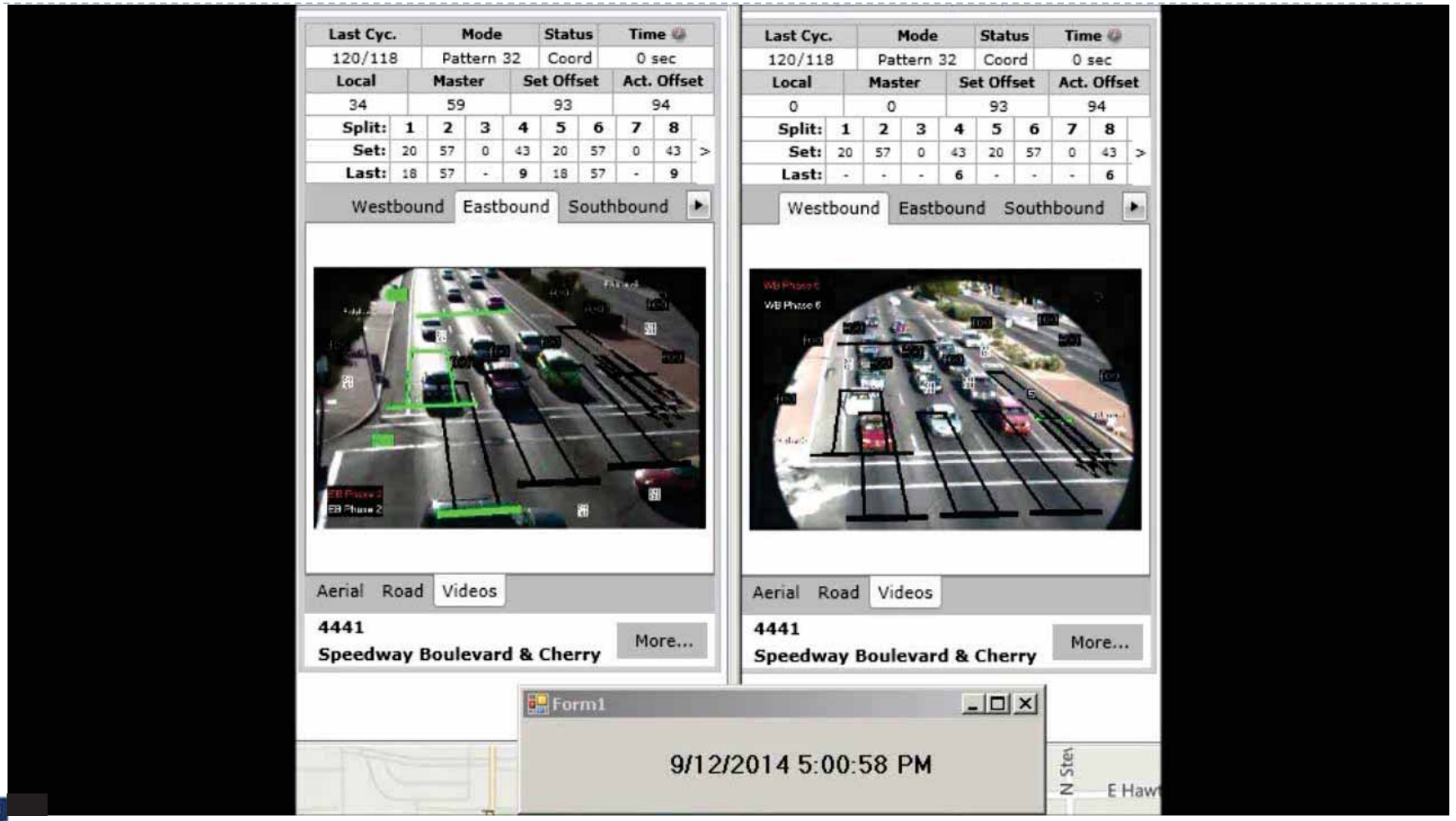


Calculate delays at bus stops
(Arterial delay estimation)

Video-based Sensors

Acknowledgment: Simon Ramos

Demo Video



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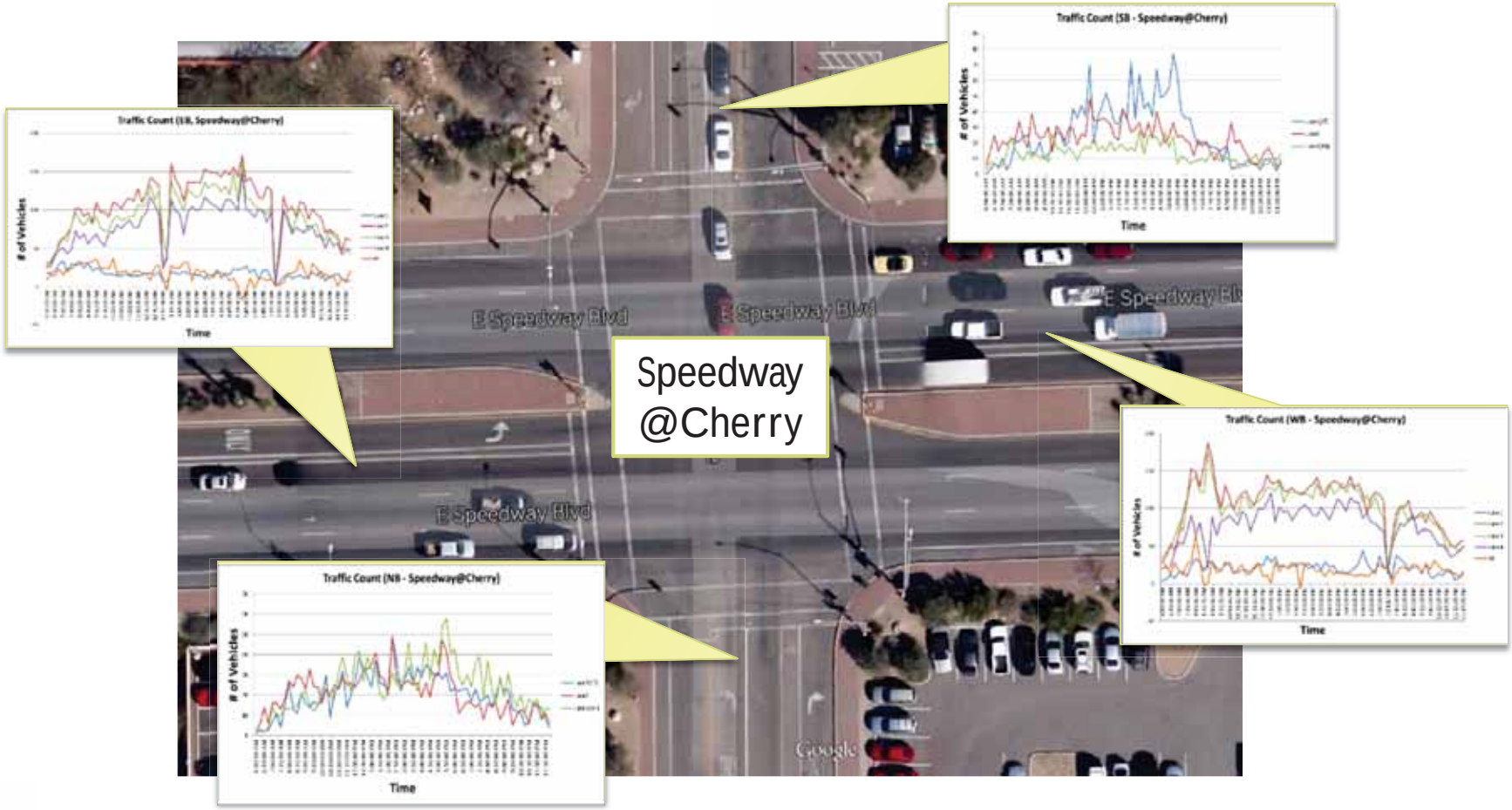
24/7 Traffic Count Evaluation



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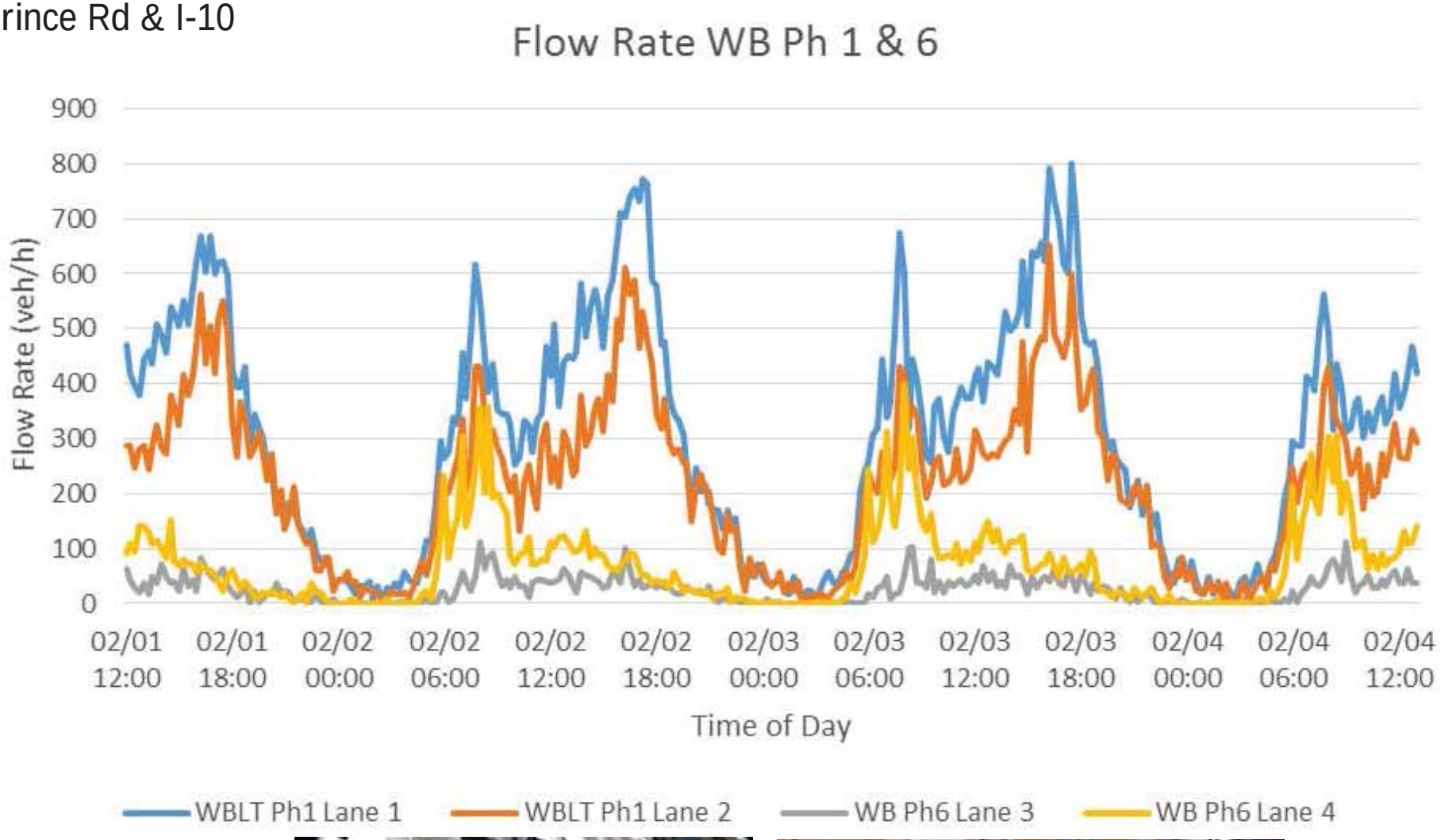
Prince Rd & I-10



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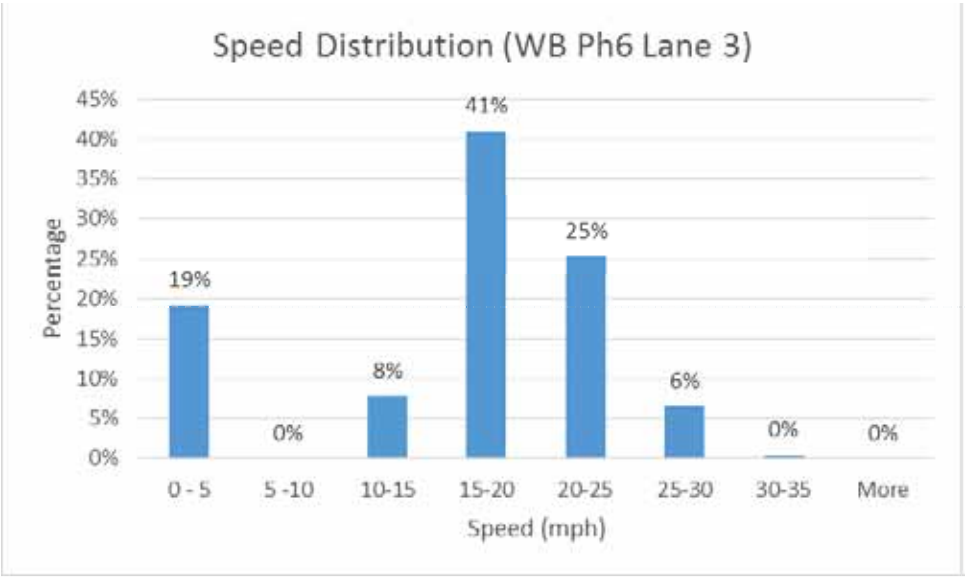

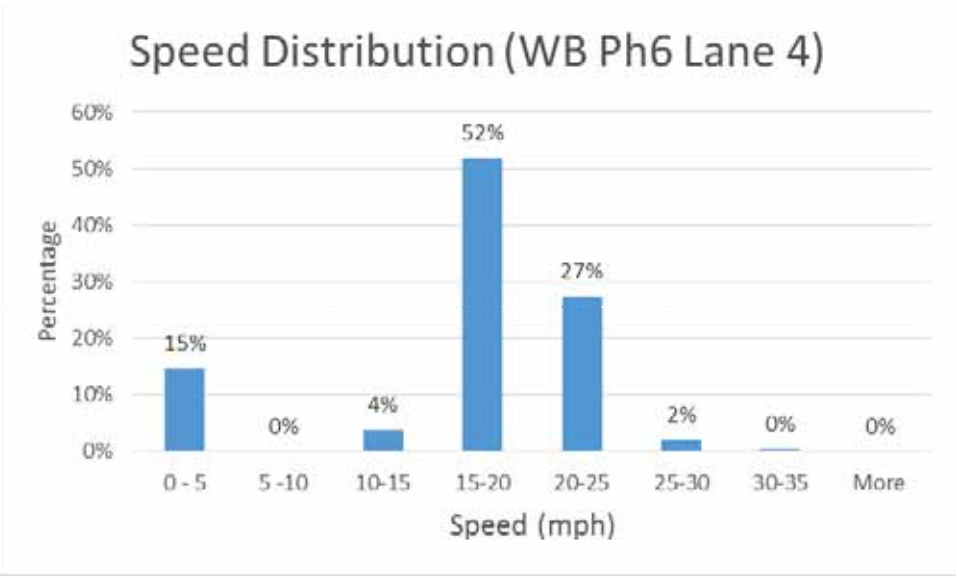

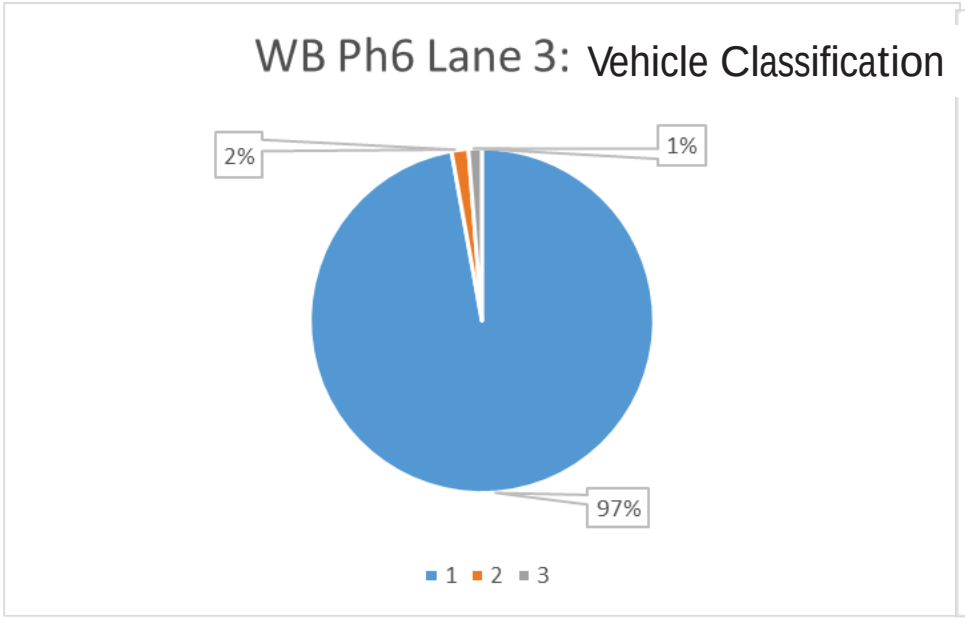

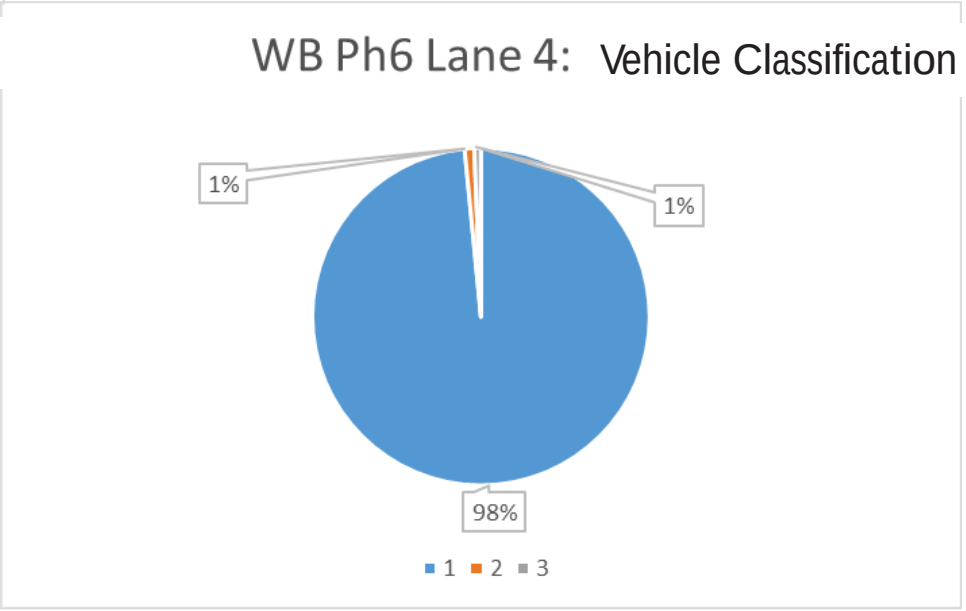

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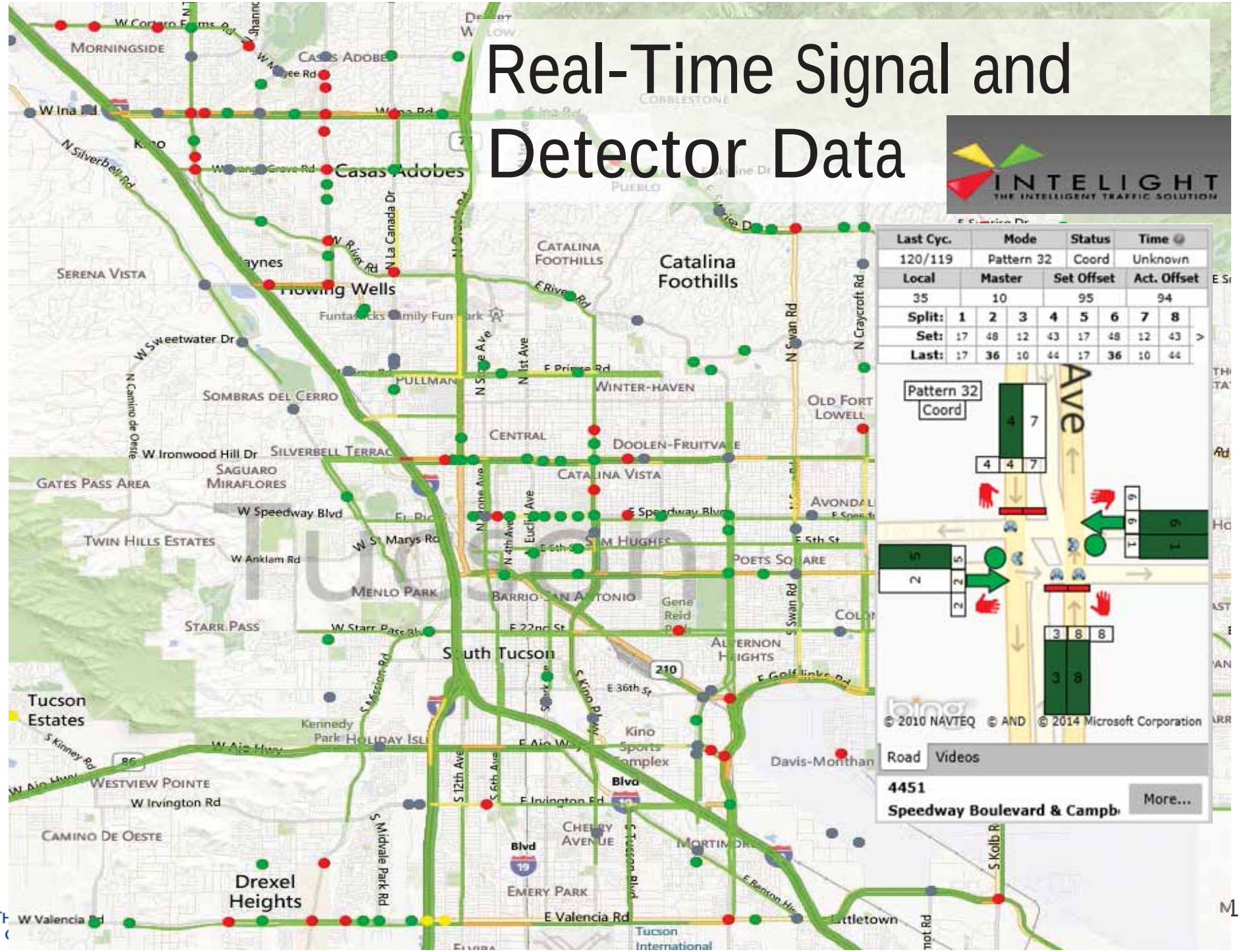
Real-Time Signal Timing Data

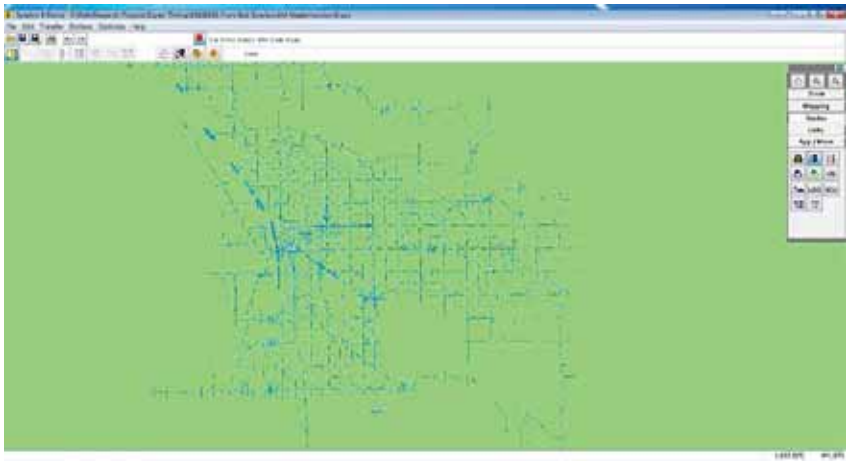
Acknowledgments: Mike Hicks, Bob Hunt, Simon Ramos

Real-Time Signal and Detector Data



Actual vs. Programed Signal Timing

Synchro
(Deterministic Model)



vs.

Maxview
(Real-time Signal System)

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Synchro
(Deterministic Model)

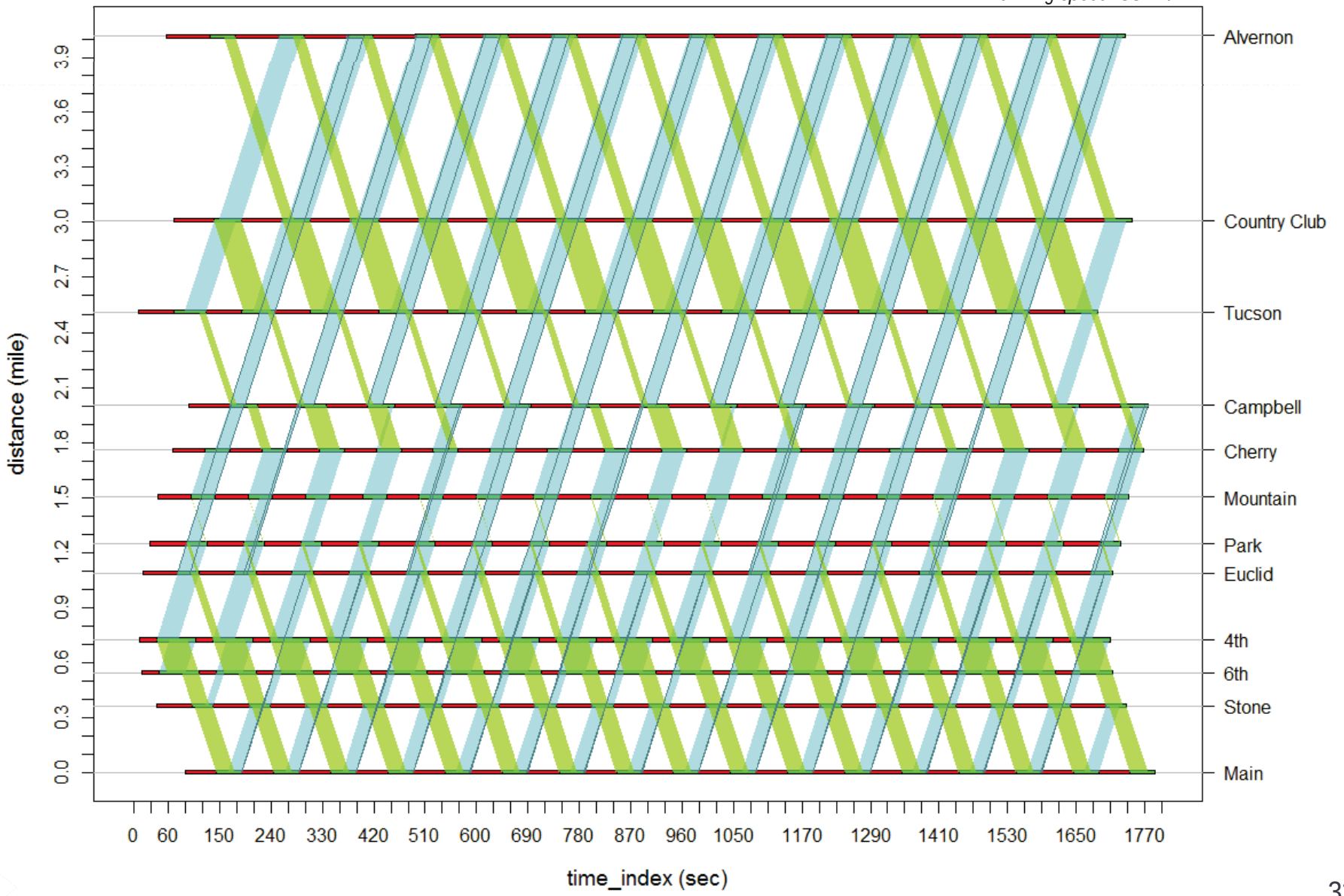
Common cycle length (8:00 AM -3:00 PM)

- *Alvernon – Campbell : 120s*
- *Cherry – Main :100s*

Design Bandwidth

4/22/2015 13:30:00 to 4/22/2015 14:00:00

Running speed: 35 mi/h



Maxview

(Real-time Signal System)

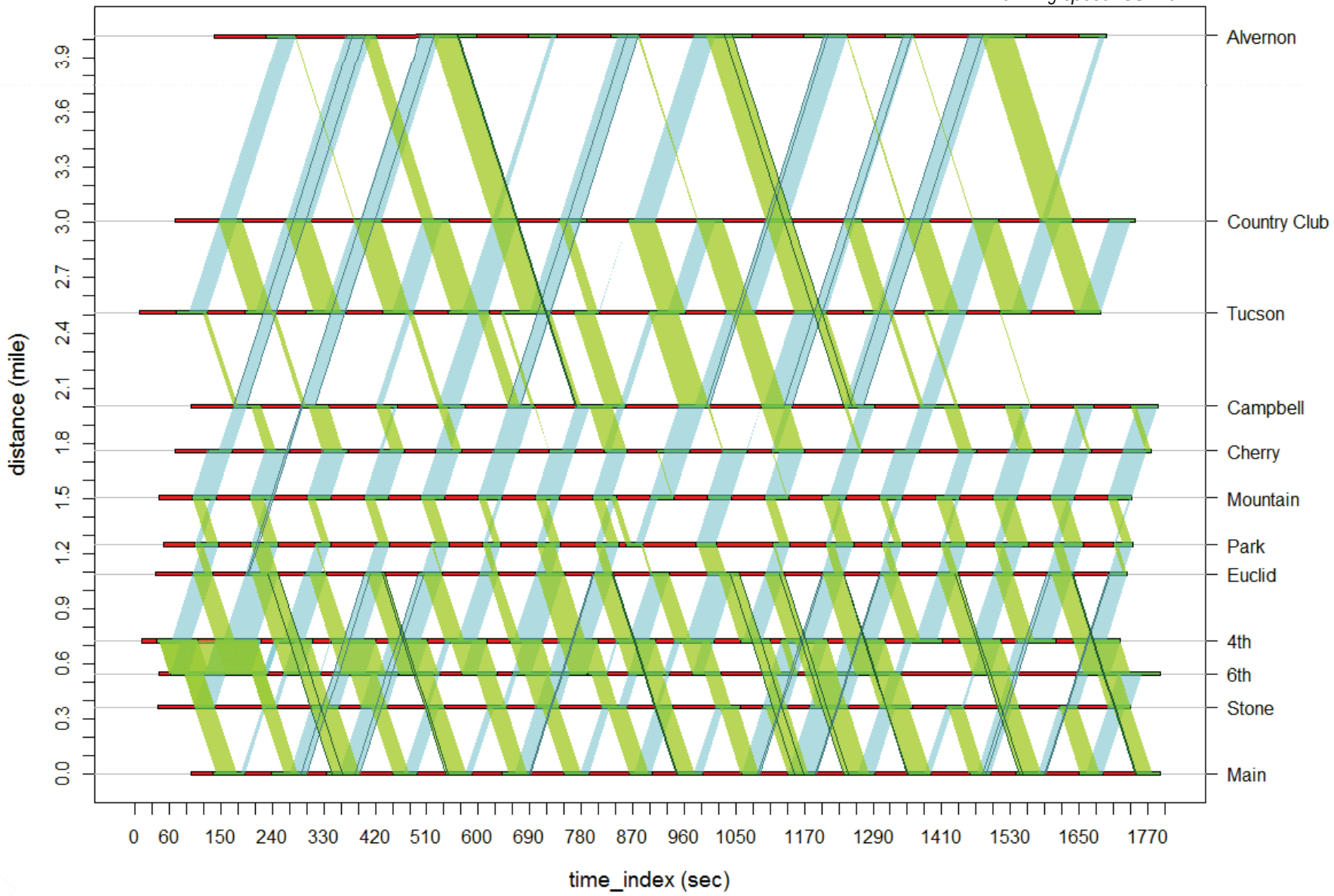
Common cycle length (8:00 AM -3:00 PM)

- *Alvernon – Campbell : 120s*
- *Cherry – Main :100s*

Real Bandwidth

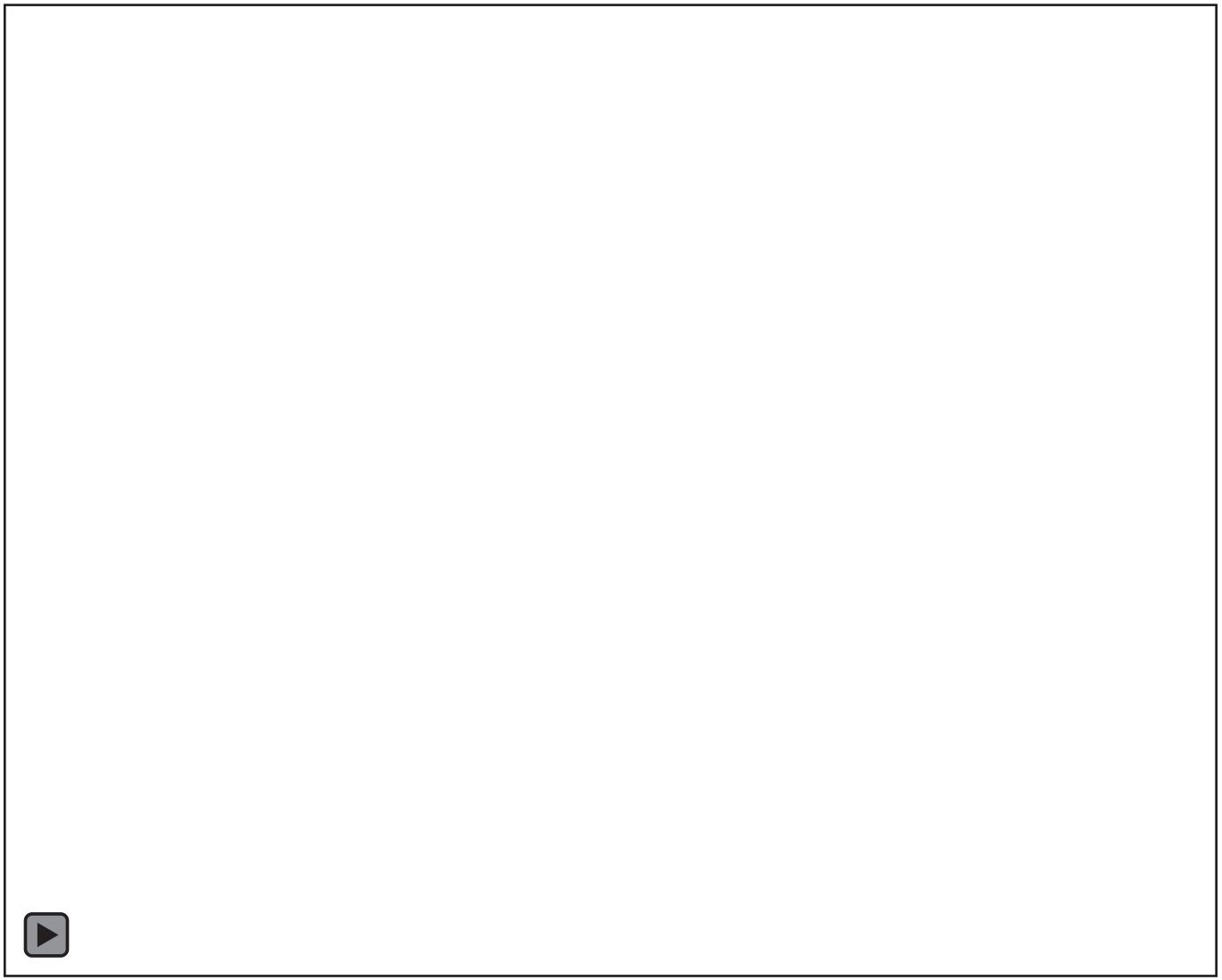
4/22/2015 13:30:00 to 4/22/2015 14:00:00

Running speed: 35 mi/h



Traffic Signal Diagnosis Tool

(Beta 1.01)



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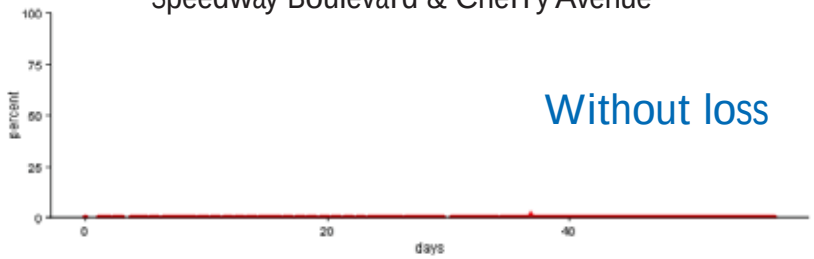
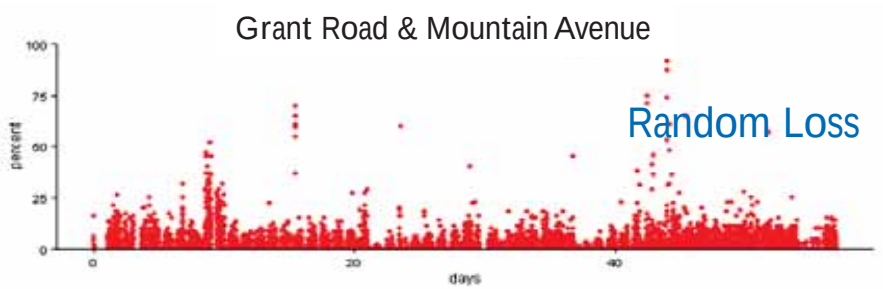
Communication Quality

Speedway Boulevard & Cherry Avenue



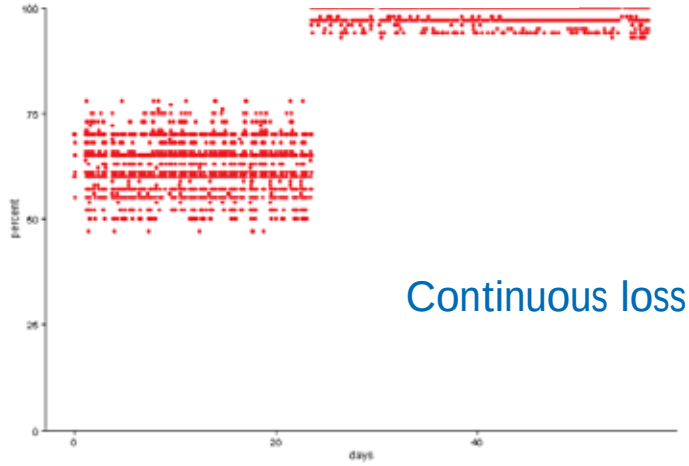
Without loss

Grant Road & Mountain Avenue



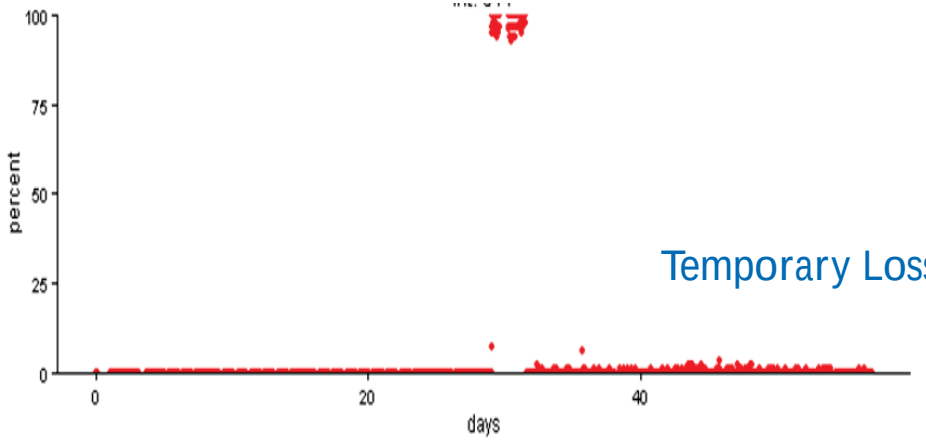
Random Loss

Grant Road & Craycroft Road



Continuous loss

Speedway Boulevard & Main Avenue



Temporary Loss

Using communication event-based data from Maxview

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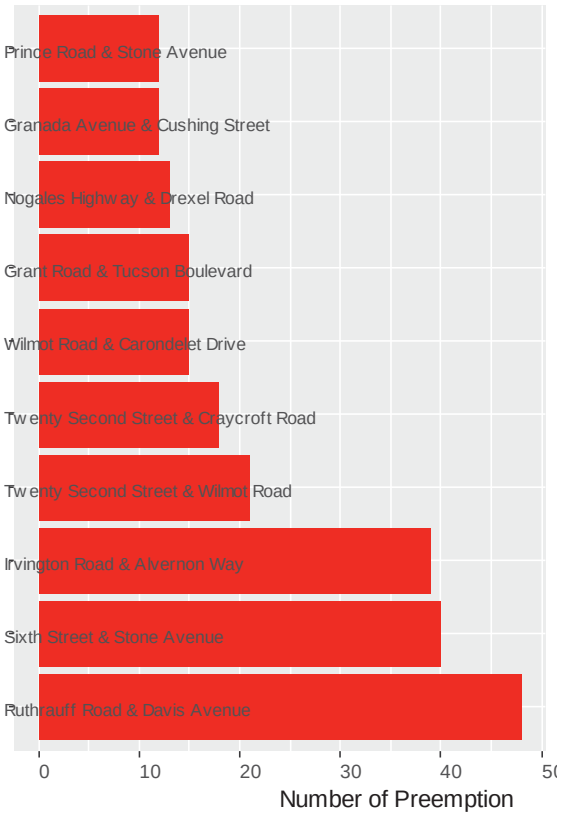
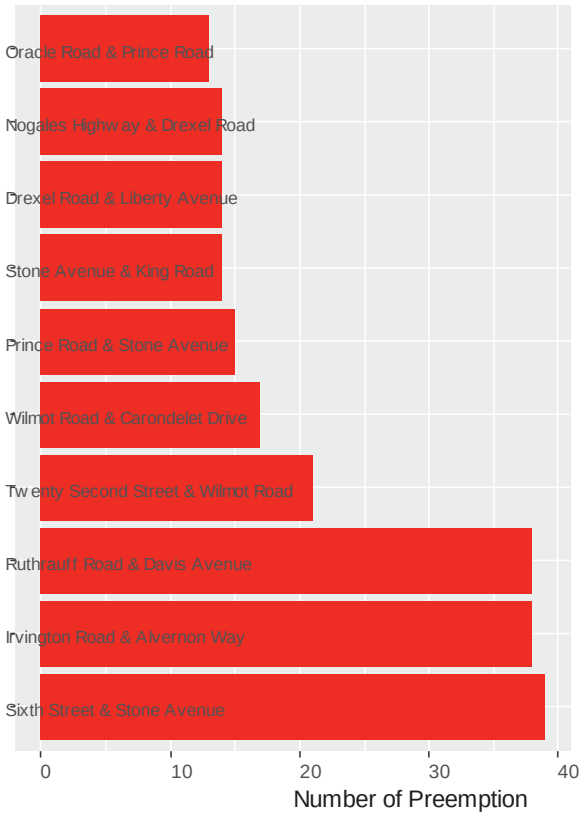
Rank Number of Preemptions

Top 10



Monday, September 14, 2015

Top 10



Tuesday, September 15, 2015

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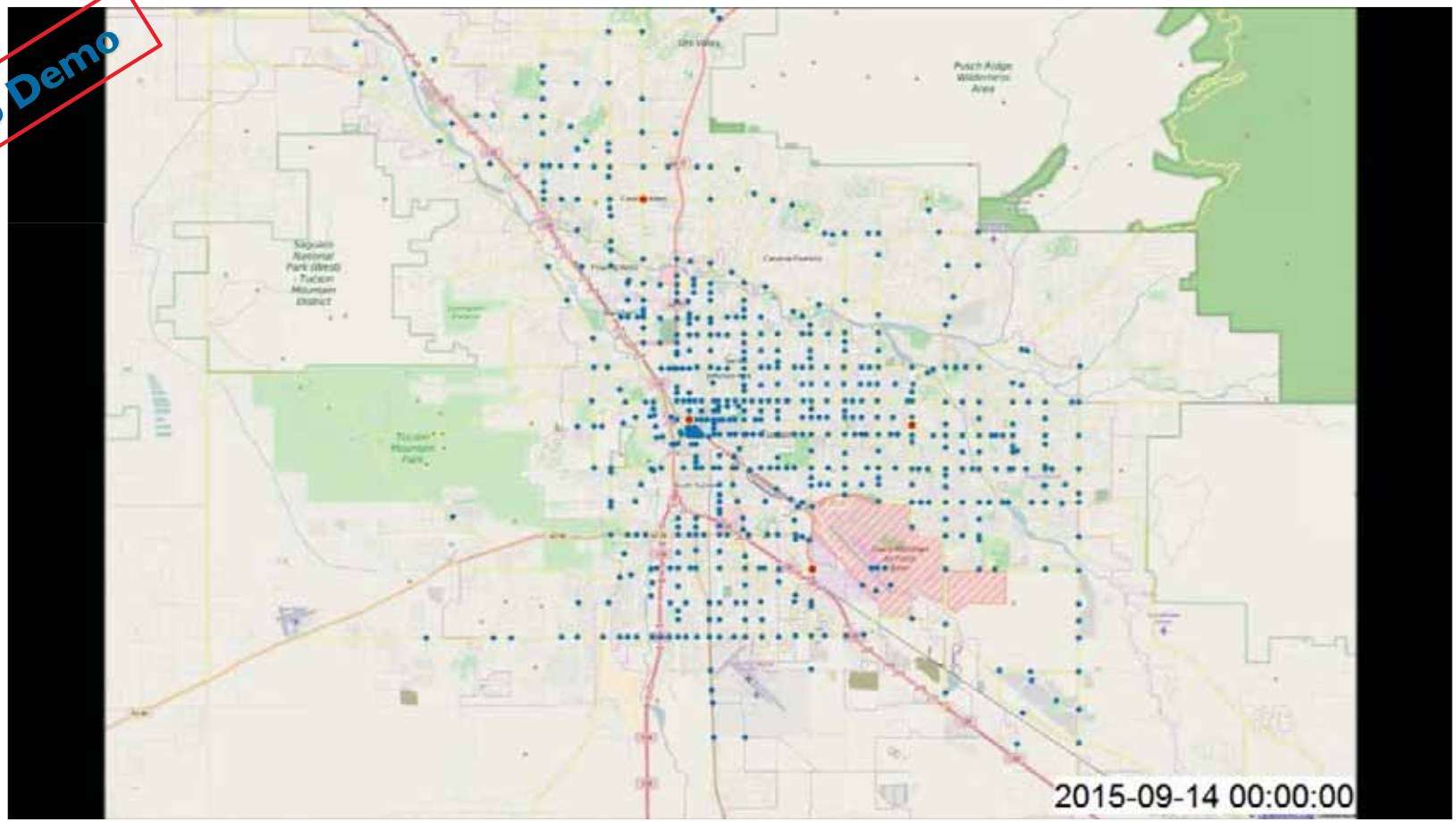
Preemption Replay

Video Demo



https://youtu.be/gk9-I7T6SSI

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Real-Time Signal Timing Data

+

Video-based Sensors

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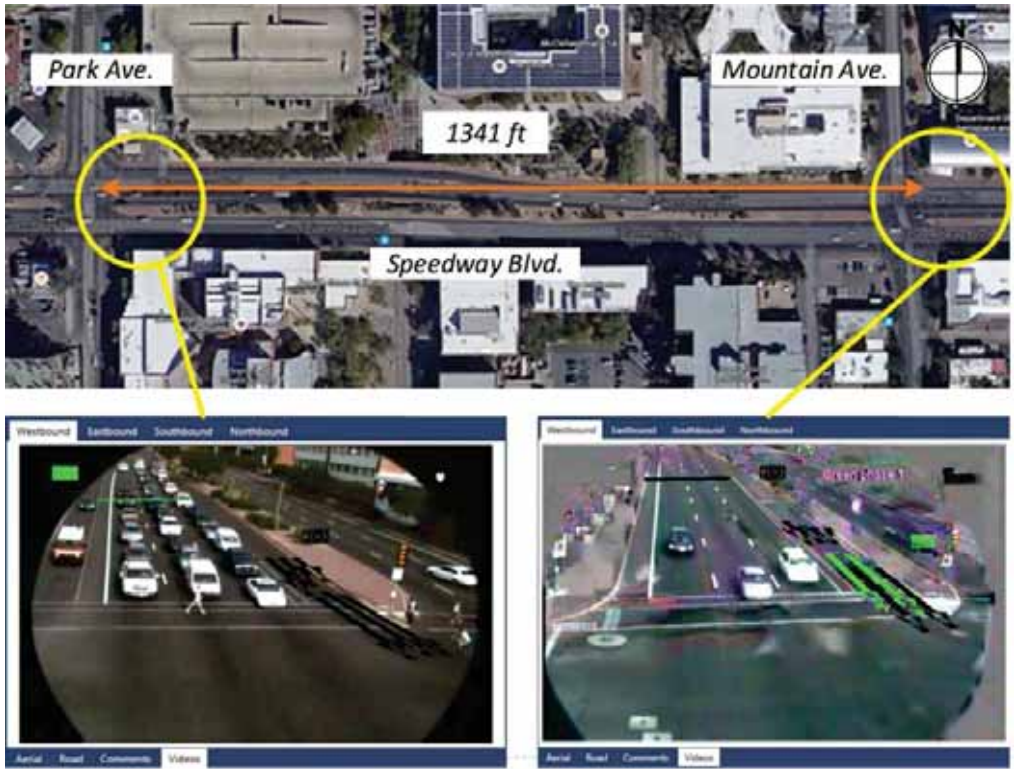
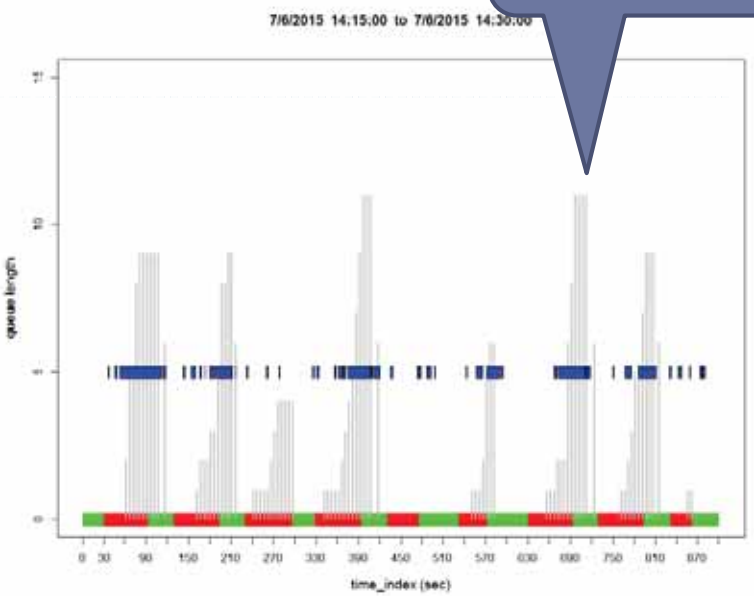
Real-Time Queue Length Estimation

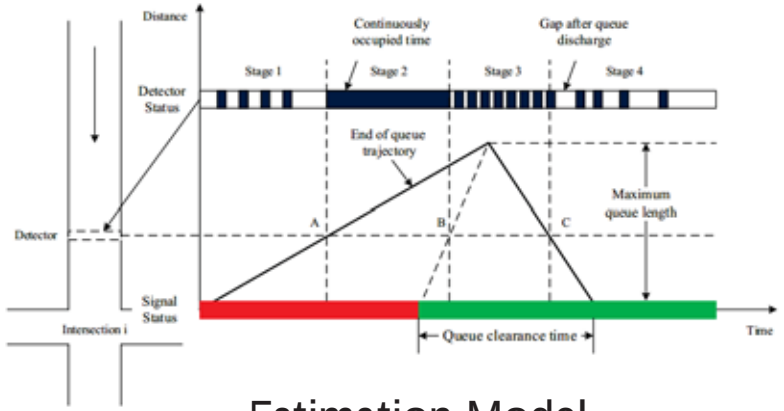
Ground Truth



Location and detector configurations of the selected intersections



Field observation



Estimation Model

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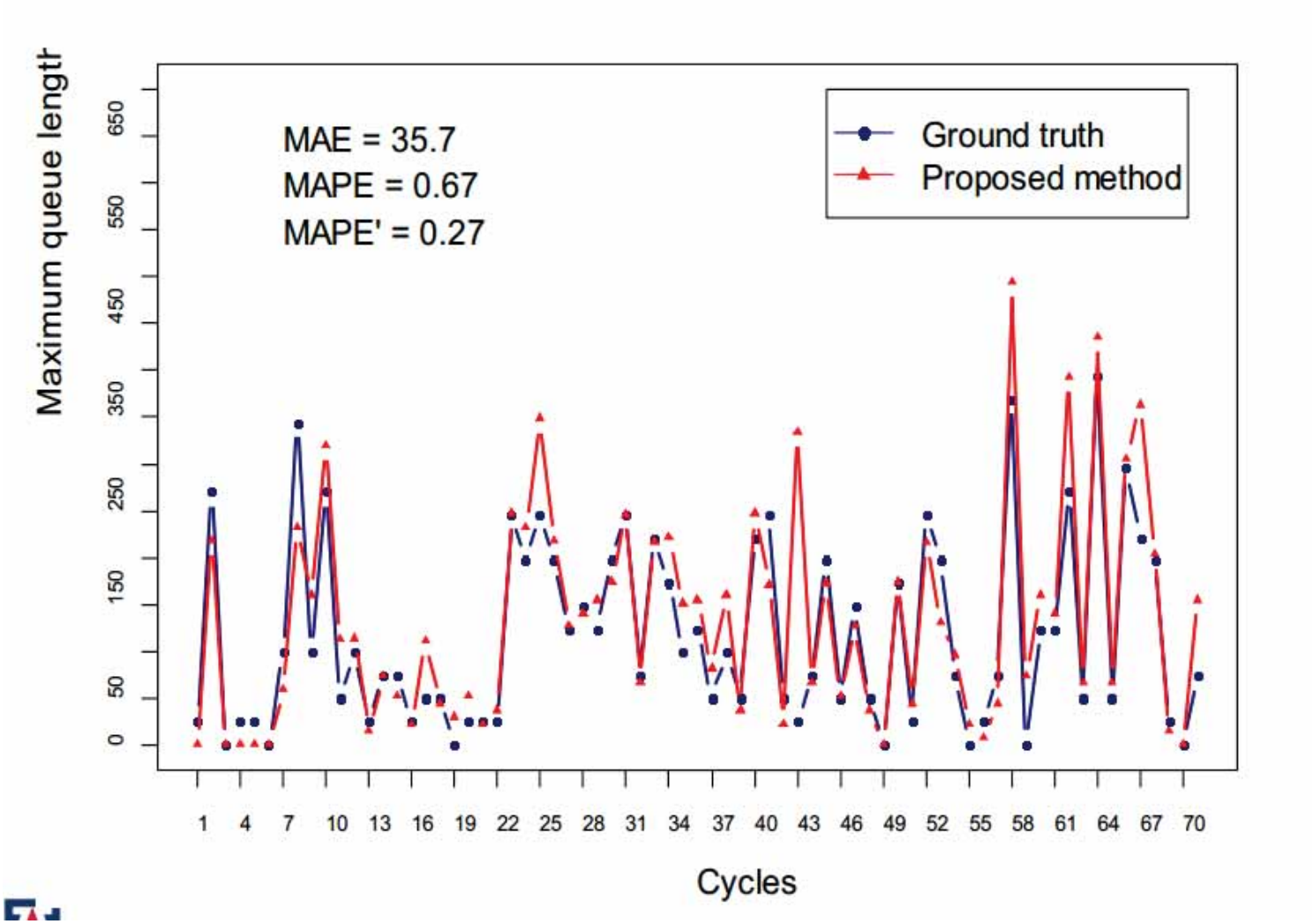
Using detector and phase event-based data from Maxview

Real-Time Queue Length Estimation



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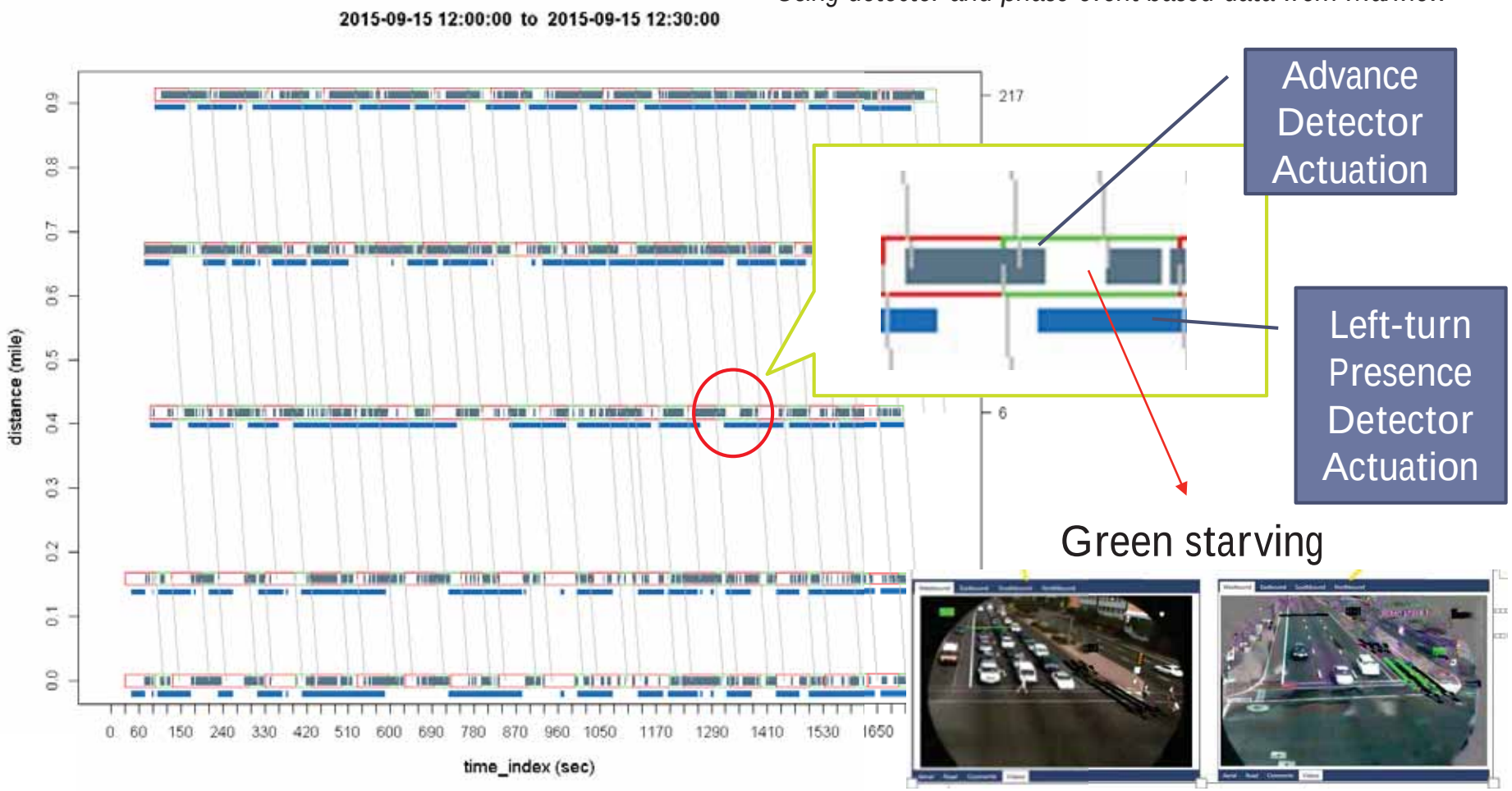
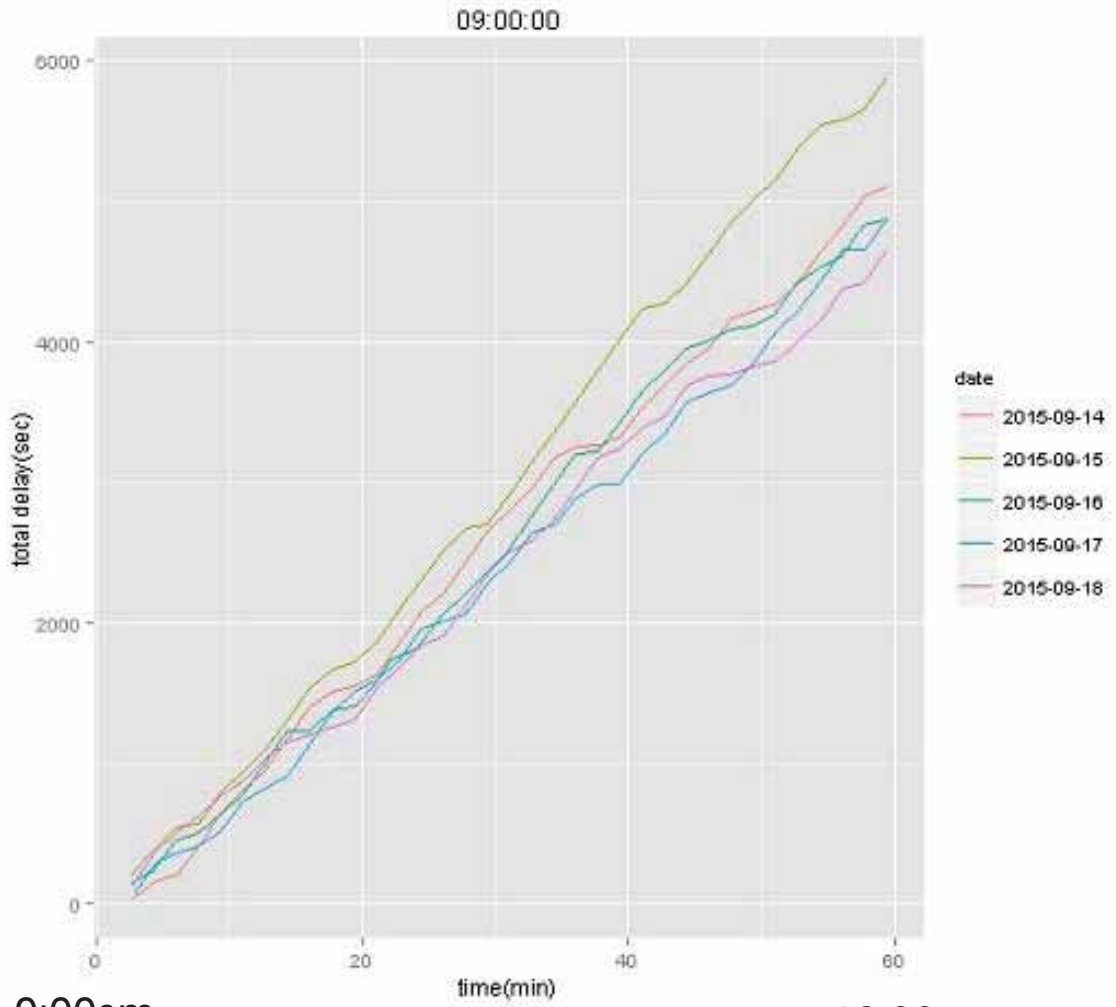
Bandwidth Utilization

Using detector and phase event-based data from Maxview



Real-time signal timing and detector status for WBT on Speedway

Real-Time Delay Estimation



Speedway & Cherry WBT total delay estimation

9:00am 9:30am 10:00am

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Real-Time Signal Timing Data

+

Video-based Sensors

+

Bluetooth Readers

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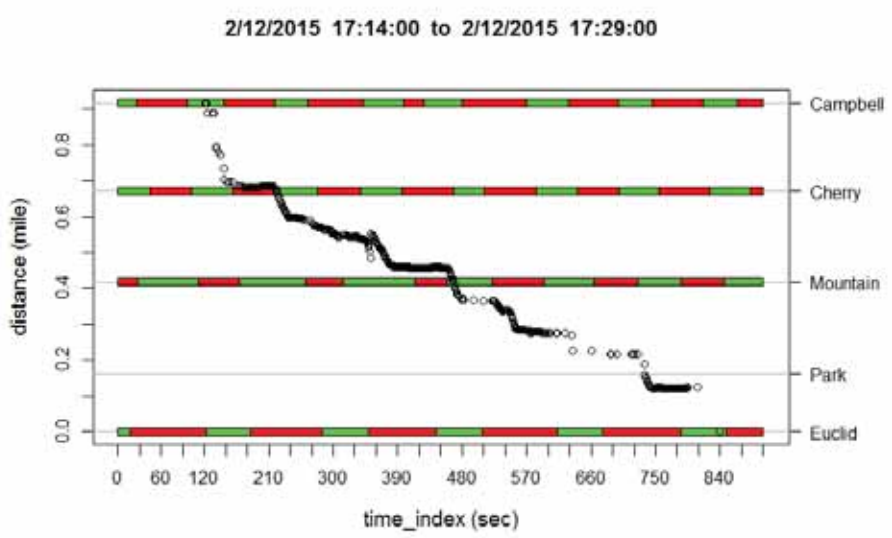
Before-After Case Study

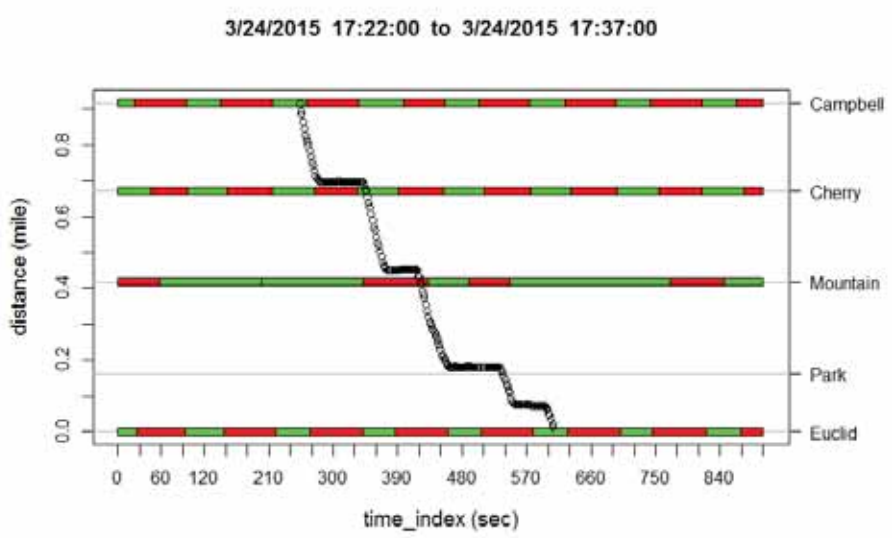
Westbound** (Campbell-Euclid)* ***17:00:00 – 17:30:00

Before



Travel Time: ***719 s*** *Speed:* ***4.6 mi/h*** *Stops:* ***7***

After



Travel Time: ***354 s*** *Speed:* ***9.3 mi/h*** *Stops:* ***4***

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Data Source: *Maview Real-Time Data and GPS Trajectory Data*

Benefit Analysis (conservative estimation)

***Westbound** (Cherry-Euclid)* ***16:30:00 – 17:30:00** (peak hour)*

Assumptions:

- *Time value = **$10** per hour*
- *Vehicle occupancy = **1.2** person per vehicle*

Segment traffic throughput:

- *Average through volume = **1457 veh/h***

❖ ***Cost per hour** = volume * vehicle occupancy * time value * travel time improvement*

✓ *One Peak-Hour Cost Saving:*

$ 1224

✓ *Monthly Cost Saving (20 weekdays):*

$ 24480

✓ *Annual Cost Saving (251 work days in 2015):*

$ 307,224

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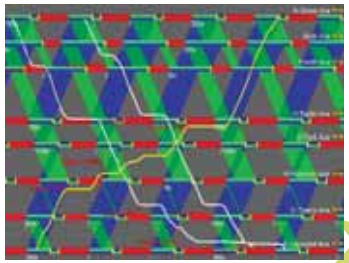
Volume data source: *Autoscope at Cherry/Speedway*

What's Next?

Integrated Approach for Signal Re-timing



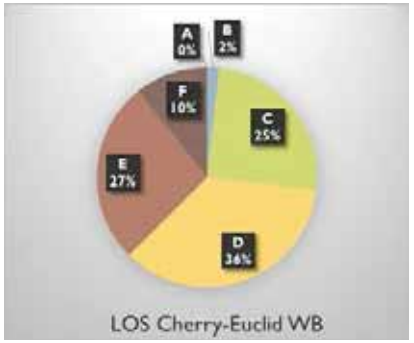
Existing Timing Plan

Data Collection

Bluetooth

GPS (Probe Vehicle)

Event-Based Detector Data



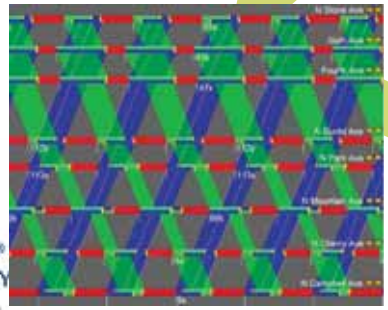
Feedback Process for Signal Retiming

Performance Measurement

Travel Time

Delay

Signal Optimization using TranSync



Traffic Pattern Change Over Time

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What's Really Next?

Adding Data

- Connected Vehicle Test Bed by Dr. Larry Head

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Happening in NATMEC

- **Sunday, May 1** 5:30 p.m.–7:30 p.m
- **Exhibit Opening and Reception,** *Regency Ballroom*
  - **Evaluating Signal Performance Using High-Resolution Event-Based Data**
    - Chengchuan An, Yao-Jan Wu, Amin Ariannezhad, University of Arizona

- **Monday, May 2** 10:30 a.m.–noon
- **Traffic Database Design and Architecture (Working with and Reporting of Traffic Data),** *Hibiscus A*
  - **Automatic Freeway Performance Reporting Using an Open Source Platform**
    - Shu Yang, Yao-Jan Wu, University of Arizona

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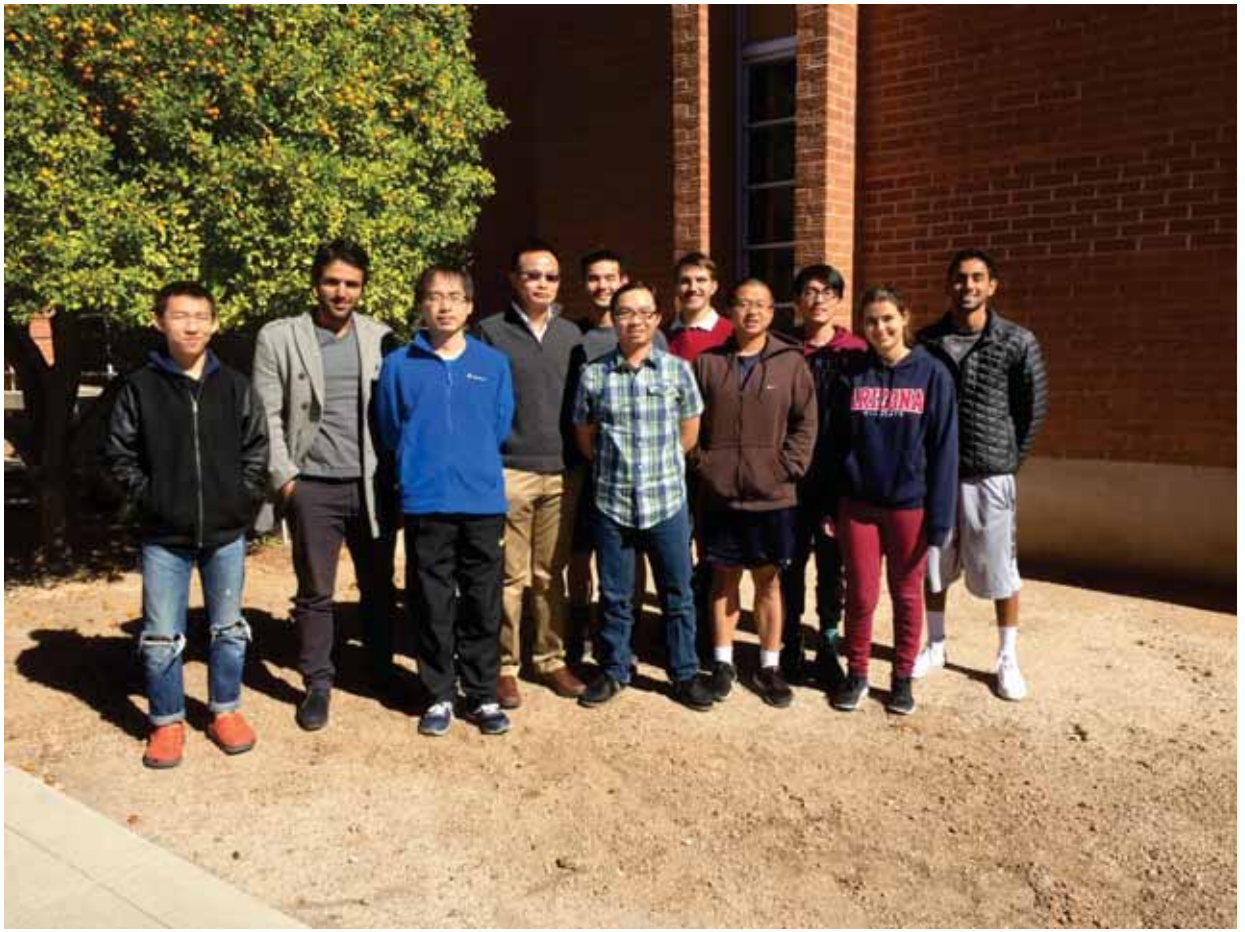
Acknowledgements

Jiangsu (Zhitong)
Intelligent Transportation System Co, Ltd.

Acknowledgements

- My students



Thank you! Questions?

Yao's Contact

Office: (520) 621-6570

Email: yaojan@email.arizona.edu

More info on my website: https://sites.google.com/site/yaojan/

or simply Google "Yao-Jan Wu"

Arterial Data and Performance Workshop

NATMEC - 2016

May 01 2016

1:30-4:30

Work Shop Order

1:15 – 2:45 Collecting Arterial Performance Data

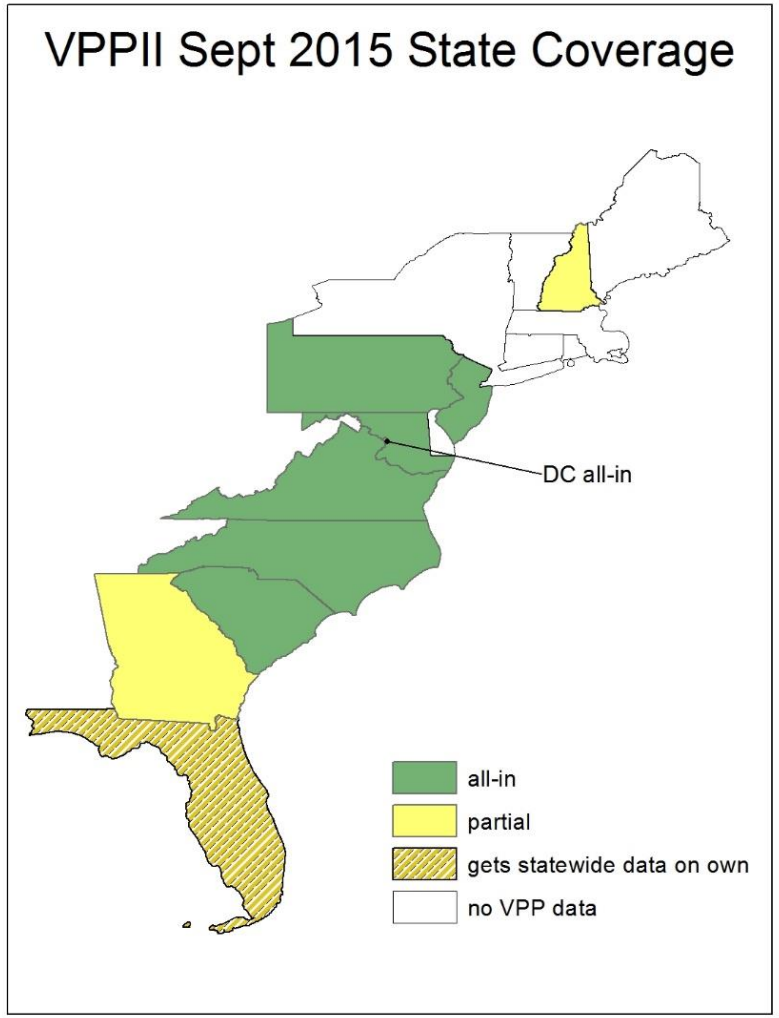
- Outsource Probe Data & Perf Measures Framework - Young
- Multi-source Data within a corridor – Yao-Jan Wu
- Putting High Resolution Data to Work – Darcy Bullock

3:00 – 4:30 Use and Application of Arterial Performance

- Longitudinal Corridor Optimization and Assessment – Chris Day
- Need for Multi-level Performance Measures – Shawn Turner
- CROWD PARTICIPATION – Recommended practices and future direction

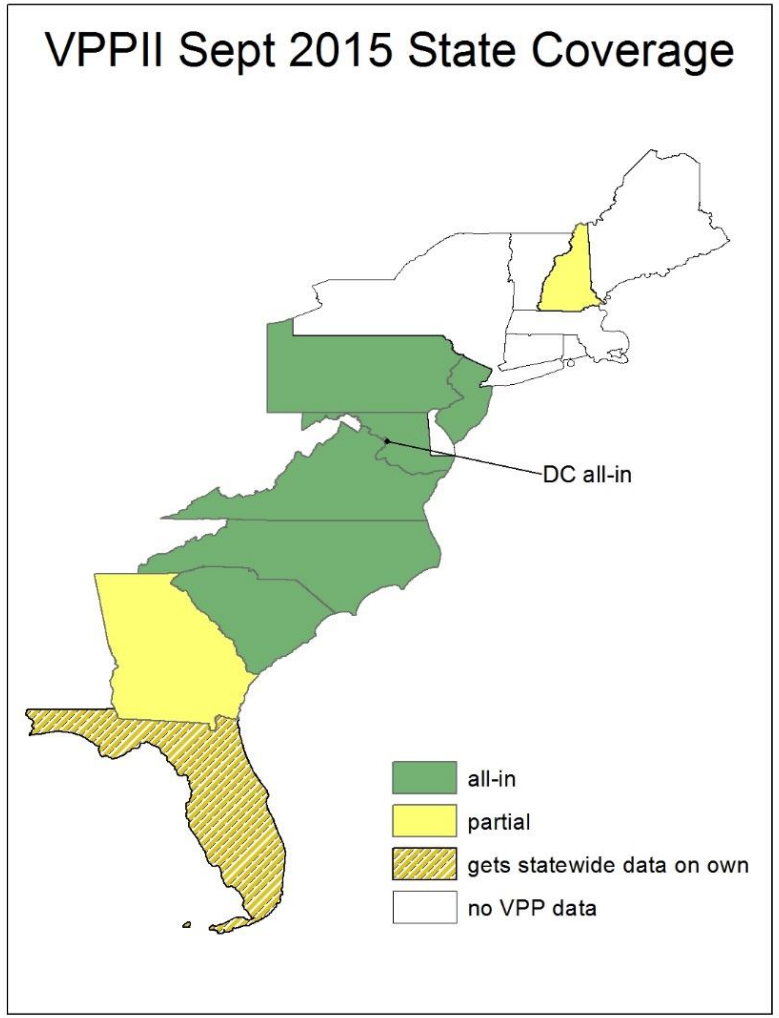
Outsourced Probe Data & APM Framework

- **Vehicle Probe Data Quality Update**
- **Future Direction of VPP Validation**
- **Proposed Top Level Performance Measures**
- **Observability in Overlay and CFDs**



Outsourced Probe Data & APM Framework

- **Vehicle Probe Data Quality Update**
- Future Direction of VPP Validation
- Proposed Top Level Performance Measures
- Observability in Overlay and CFDs



Arterial Probe Data Recommendations (Jan 2015)

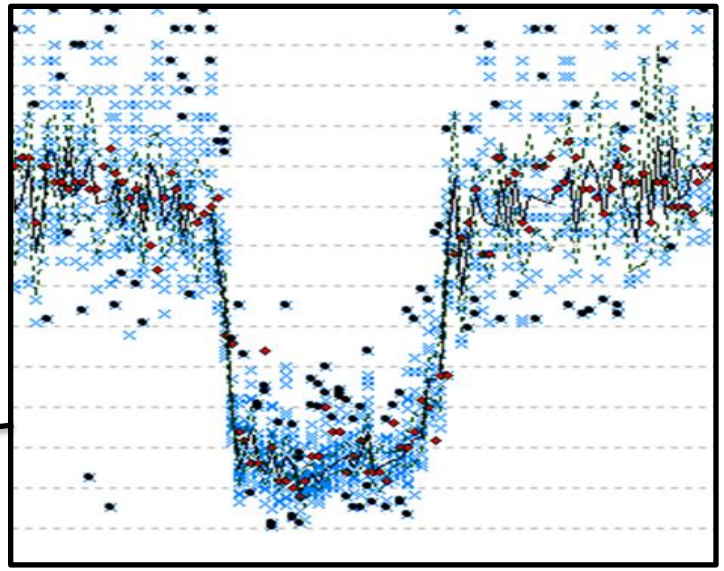
✓ RECOMMENDED	🔑 SHOULD BE TESTED	✖ NOT RECOMMENDED
● <= 1 signal per mile ● AADT > 40,000 vpd (2-way) ● Limited curb cuts Principal Arterials Likely to be accurate…	● 1 to 2 signals per mile ● AADT 20K to 40K vpd (2-way) ● Moderate number of curb cuts Minor Arterials Possibly accurate, test …	● >= 2 signals per mile ● AADT < 20K (2-way) - low volume ● Substantial number of curb cuts Major Collectors Unlikely to be accurate…

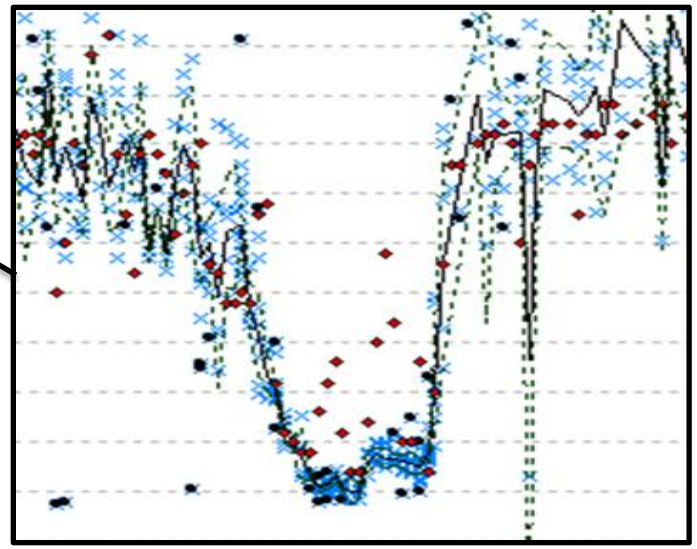
- **Data quality most correlated to signal density**
- **Consistently over-reports speed during congestion**
  - As probe data improves, delay will increase
- Other issues / challenges:
  - Challenged by queuing, multi-cycle failures
  - Follows faster mode in bi-modal traffic
  - Insensitive to signal timing changes
- Improvement anticipated …

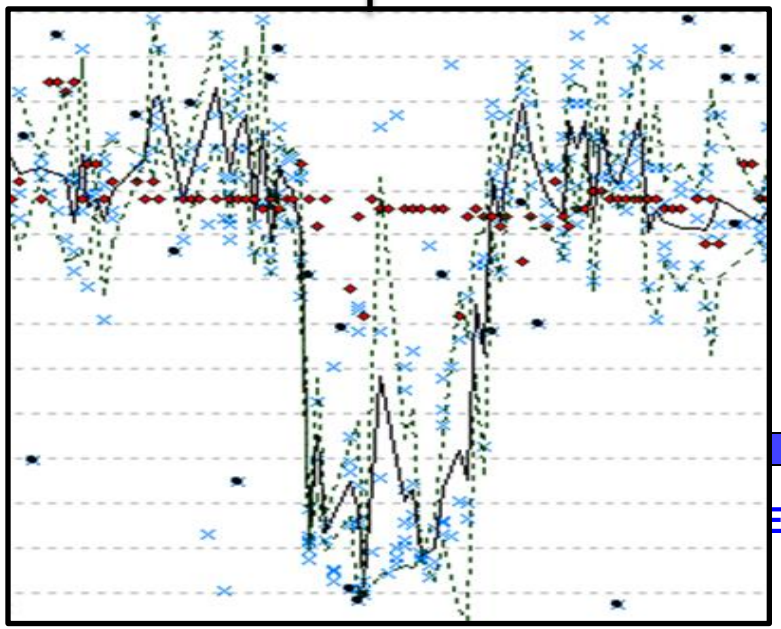
Full Report posted to the
I-95 Corridor Coalition Website

Slowdown Analysis

- Slowdowns identified
  - Major : >15 mph in speed, > 1 hour
  - Minor : > 10 mph in speed, > 30 minutes
- For each slowdown rate as:
  - Fully Captured
  - Partially Captured
  - Failed to Capture

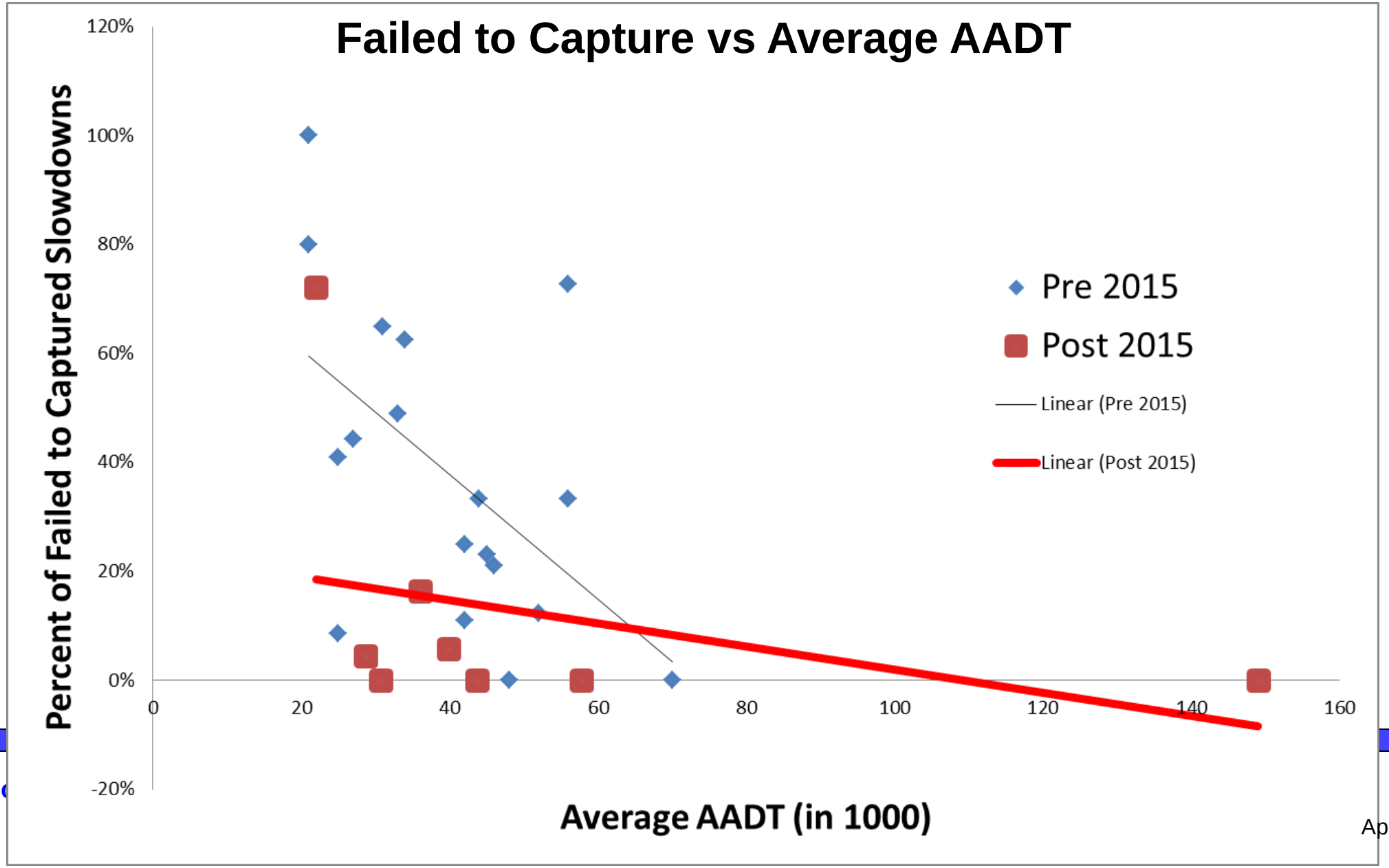




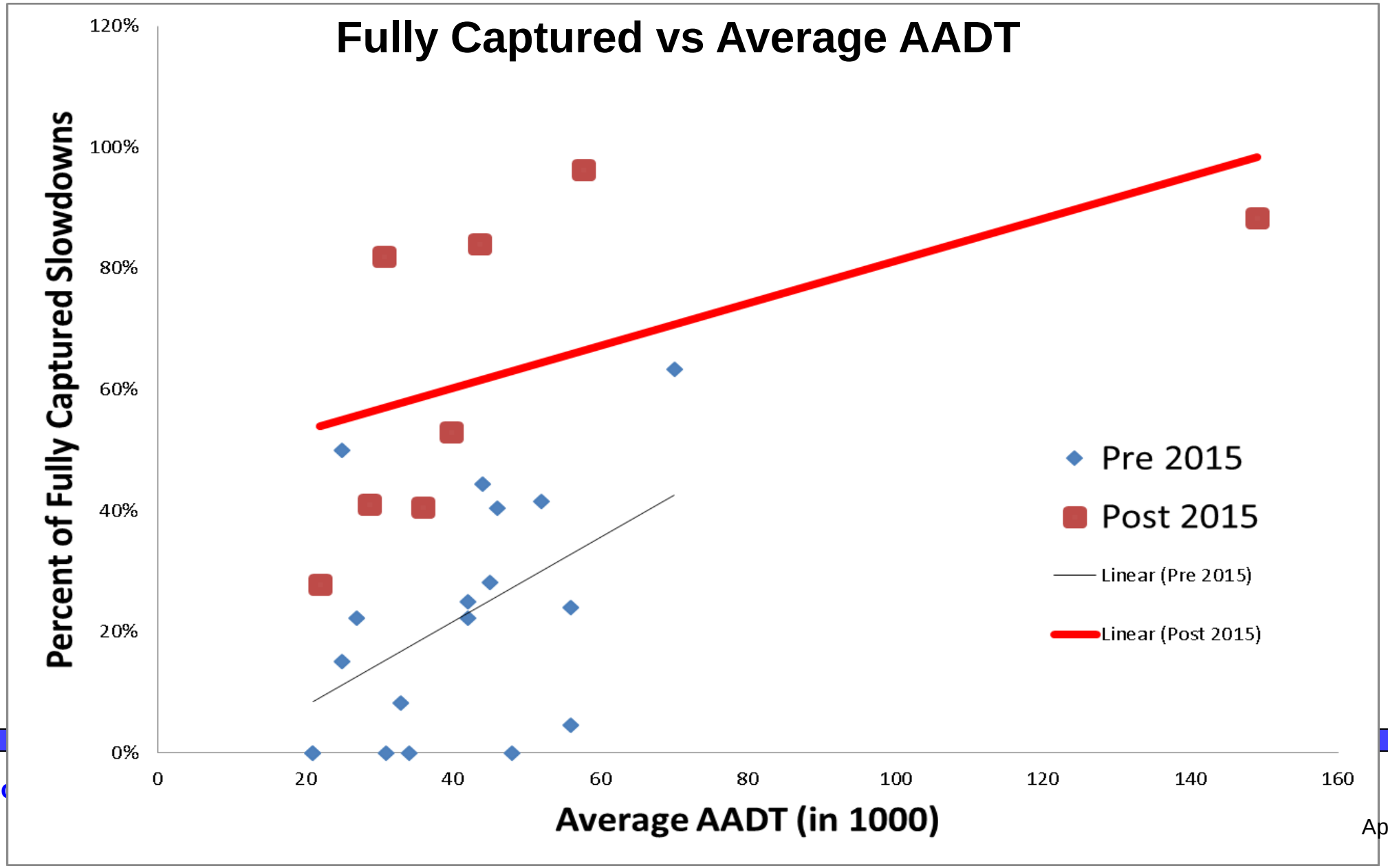


	Total	Fully	Partially	Failed
Major	45	11	25	9
Minor	33	11	13	9

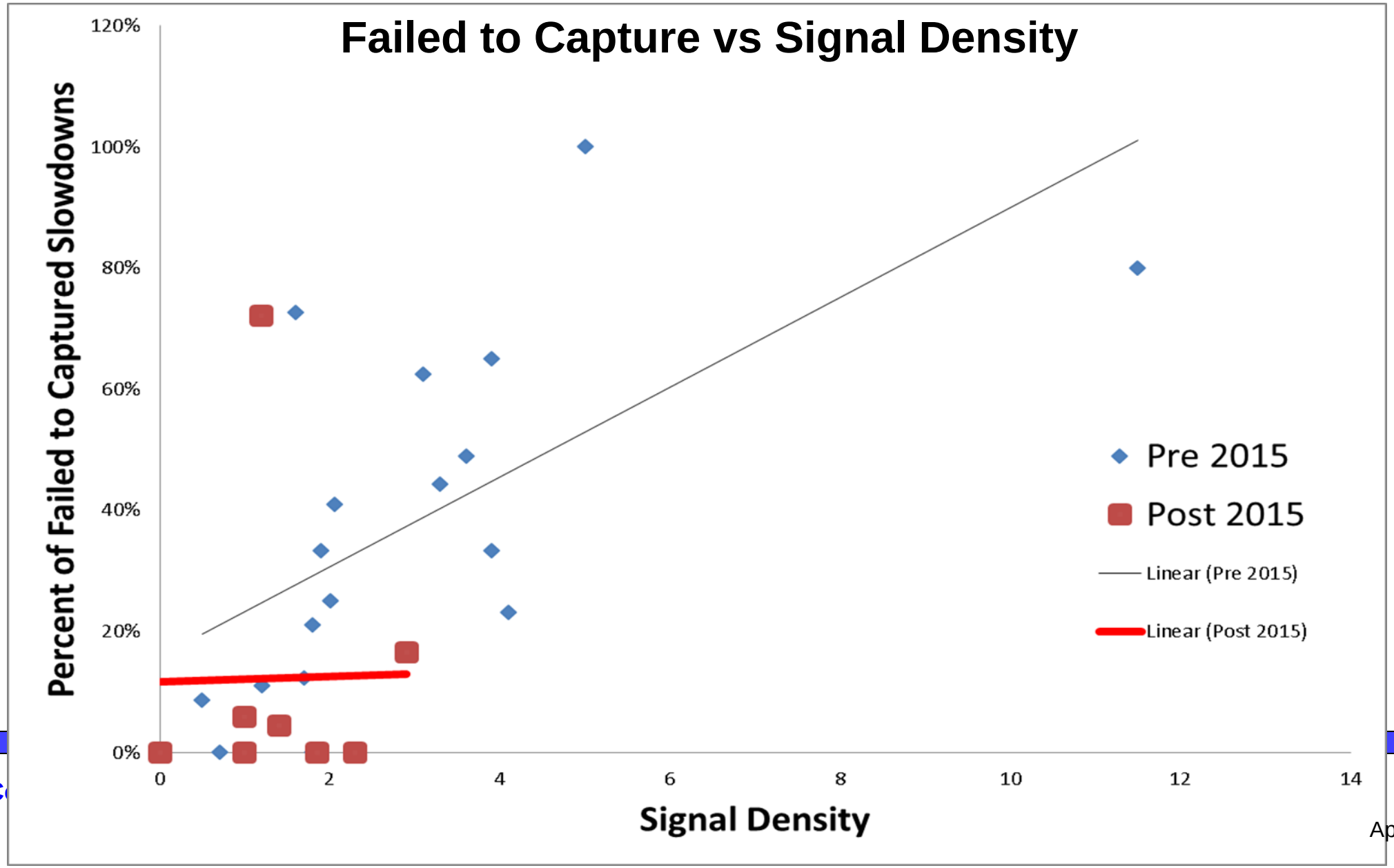
Results since 2015 (1/4)



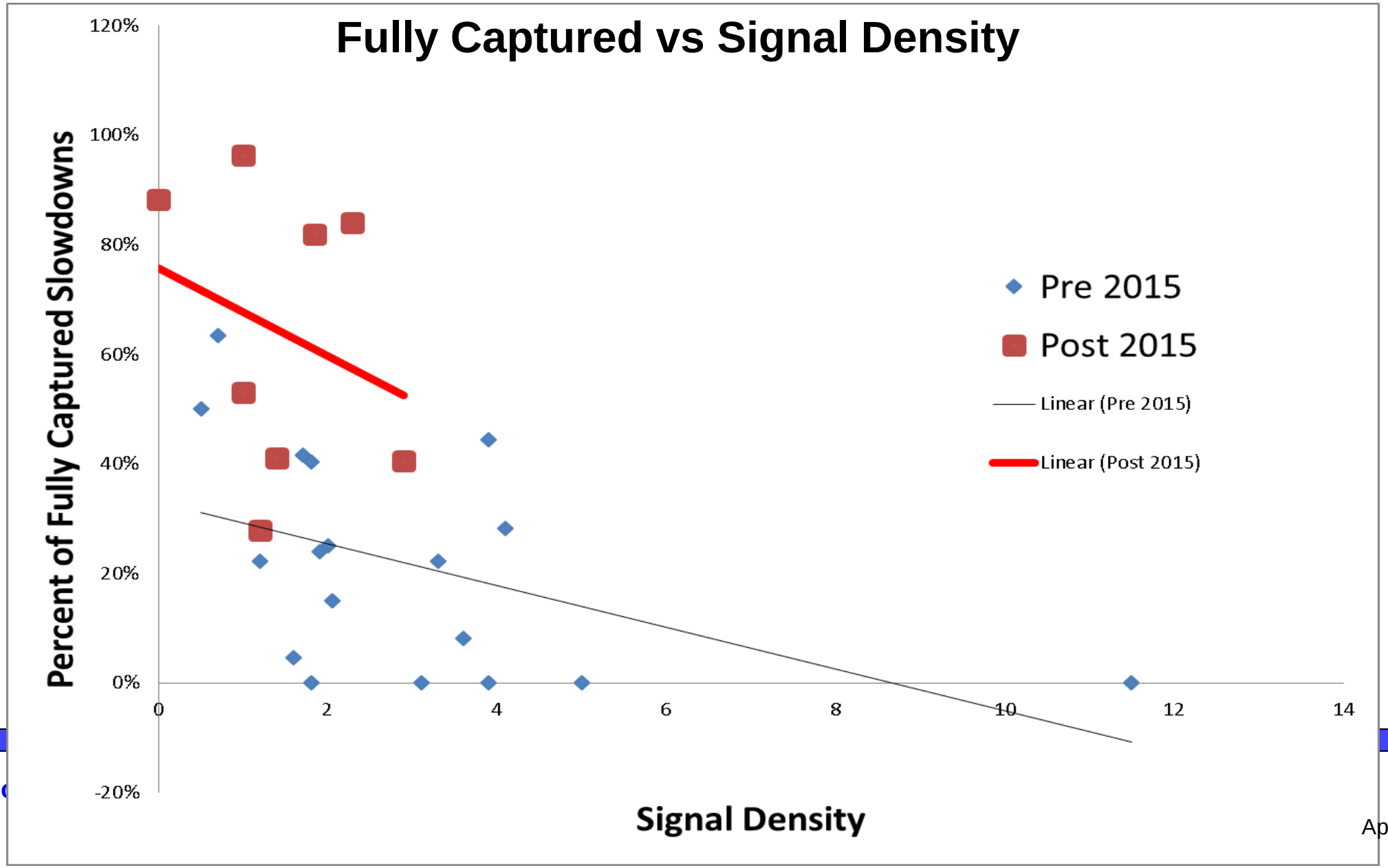
Results since 2015 (3/4)



Results since 2015 (2/4)



Results since 2015 (4/4)

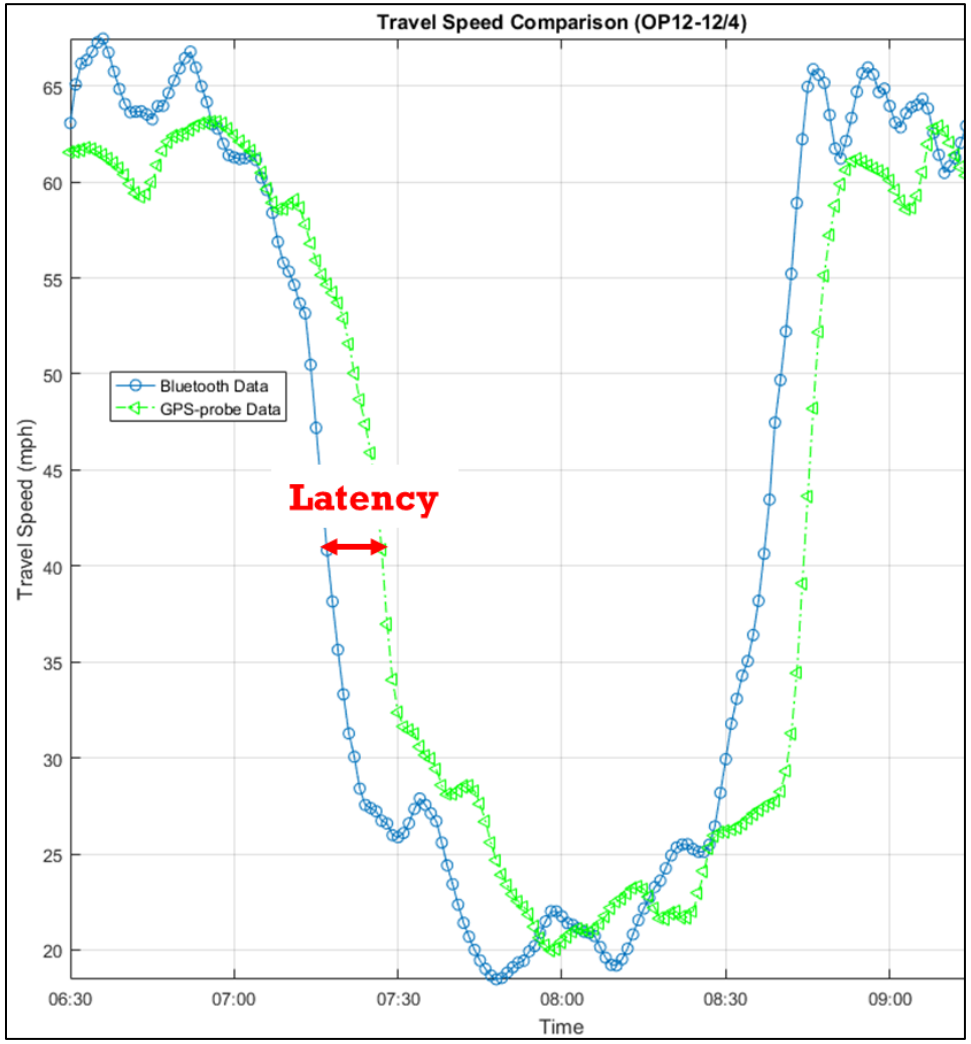


Vehicle Probe Arterial Data Quality

- Statistically significant movement since 2015
- Anticipate updated report later in 2016
  - Contacts Masoud Hamedi and Elham Sharifi
- ‘Slowdown Analysis’ to become part of standard VPP reporting

Outsourced Probe Data & APM Framework

- Vehicle Probe Data Quality Update
- **Future Direction of VPP Validation**
- Proposed Top Level Performance Measures
- Observability in Overlay and CFDs



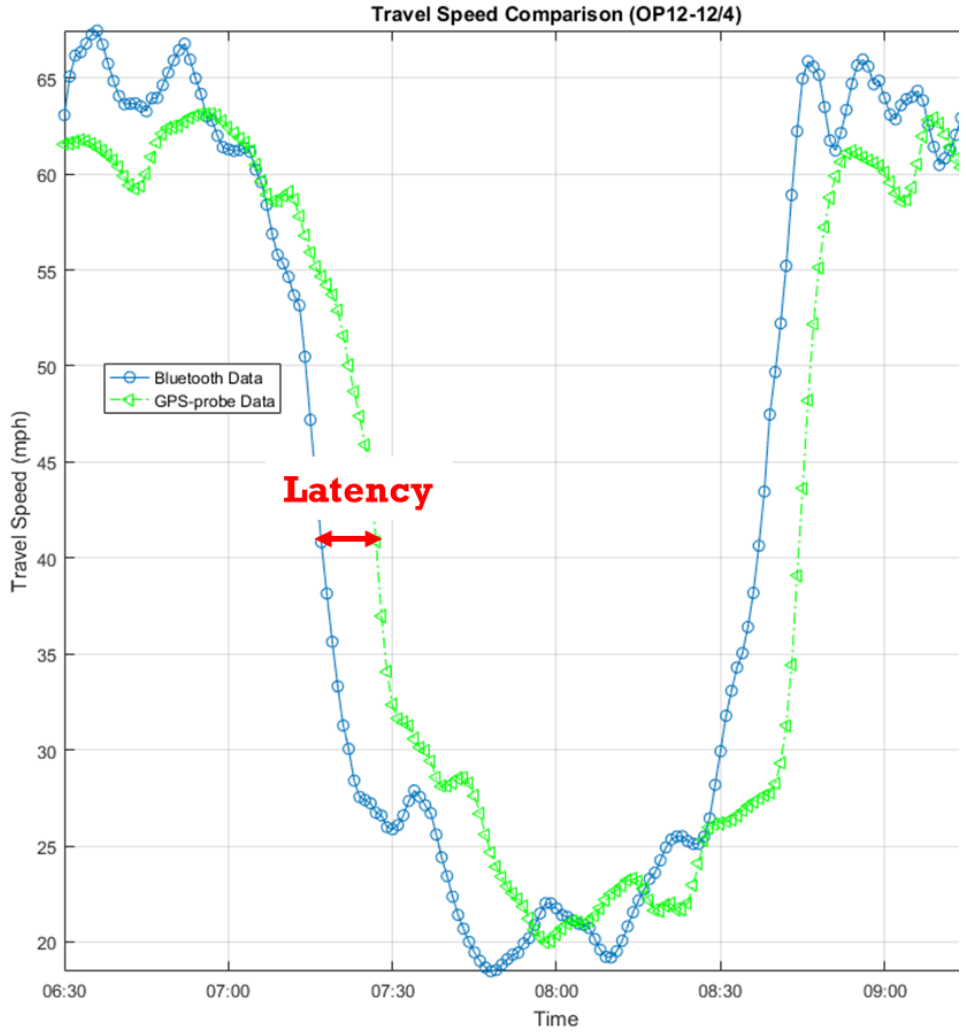
VPPII Data Validation

- Three data vendors, HERE, INRIX and TomTom
- Data Collection:
  - Validation balanced, but emphasized arterials
  - Approximately monthly
  - Moving toward Bluetooth + WiFi
- Individual validation reports are produced for each state & each vendor
- Assessing additional quality metrics

SEQUAL 2016

VPPII Data Validation

- Additional performance measures are monitored including:
  - **Data availability:** to check for time lapses in the data
  - **Real-time share:** indicating the proportion of real-time data according to the criteria set by each vendor
  - **Latency:** the time offset between the time that a change in traffic pattern occurs, and the time that it is reported by probe data.
    - The current latency measurement method is only applicable to freeways

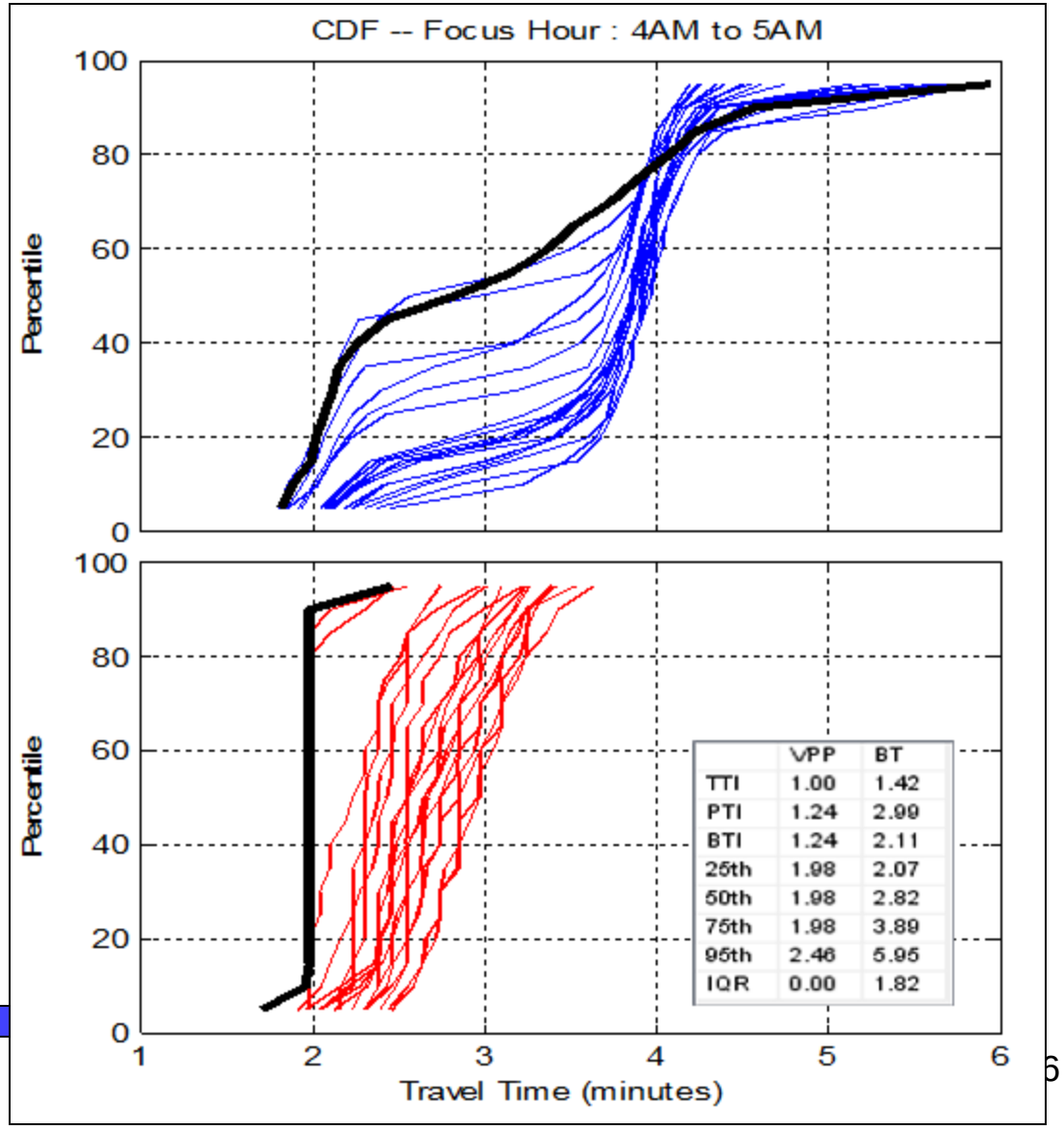


Other VPP and Probe Initiatives

- **Real-time Volume and Turning Movement from Probe Data**
  - UMD CATT / NREL / INRIX / HERE / TomTom
  - Calibration Network from I95 Coalition members count stations
  - Serves as ‘Base Stations’ to estimate network wide volumes
- **Probe Trip Data (“Bread Crumb Trail”)**
  - Maryland statewide data set being assessed
- **TMC White Paper –** 2016, webinar May 11
- **Proposed Transportation Energy Analytics Dashboard**
  - Augment existing VPP visualization with Energy/GHG

Outsourced Probe Data & APM Framework

- Vehicle Probe Data Quality Update
- Future Direction of VPP Validation
- **Proposed Top Level Performance Measures**
- Observability in Overlay and CFDs



Roadmap for Arterial Management Systems

- Arterials perform fundamentally different than Freeways
- THEN, continuous monitoring/measurement was infeasible
  - Performance had to be modeled or periodically sampled.
- NOW, technology-enabled continuous, ubiquitous performance assessment
  - Vehicle probe, Re-identification, High-Resolution Controller data
- DATA perspective, we are NOW (2016) with arterials, where we were in 2008/9 with freeways
- Significant opportunity – significant challenge
  - Common language, lexicon, tools, performance measures
  - Bridge culture divide between traffic, planning and operations
  - Legacy thinking and approaches

Technologies Enabling Arterial Management Systems

Re-identification

- Direct samples vehicle travel time (5% - 20% BT & WiFi)
- Works best at corridor level
- Independent of Signal System
- Provides top-level user experience information

High-Res Signal Data

- Logs ***all*** actuation and phasing information
- Works at intersection level
- Integrated with Signal System
- Provides detailed intersection analysis and data for optimizing signal system

Both enabled by consumer wireless communication and big data processing.
Available Now – Multiple Vendors - Cost Effective

Not one or the other… but both!

Emerging Arterial Performance Measures

- **Travel Time & Travel Time Reliability – based on sampled travel time sources**
  - Enabled by re-identification data
  - Fundamentally linked to statistical distribution of travel time
- **Quality of progression - Percent Arrivals on Green**
  - Supported by Purdue Coordination Diagram tools
- **Split Failures (frequency of occurrences)**
  - Reflects capacity constraints
  - Related to GOR / ROR

Arterial Performance Measures

THEN	NOW
Both fundamentally based on delay	

- TEMPORAL:
  - Sampled yearly – ‘typical day in May’
  - Weekday peak peroid
- DATA: Travel time runs, and counts
  - Manually collected
- Intersection & corridor
- MEASURES:
  - HCMLOS based on Delay
  - User complaints
- Annual Performance Measures

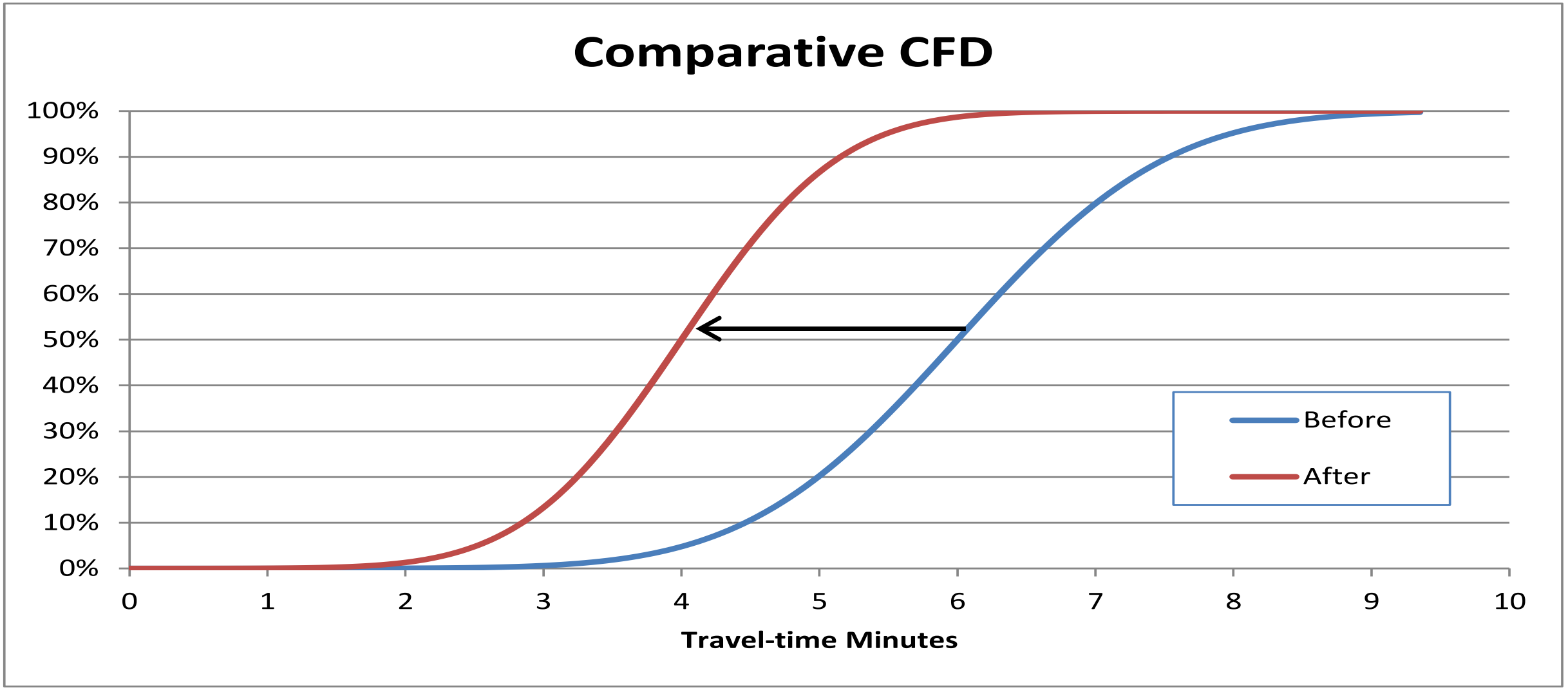
- TEMPORAL
  - Continuous – ubiquitous coverage
  - All Days, every signal cycle
- DATA: Probe, Re-ID, & HRCD
  - Automated
  - Integrated with Signal System
- Intersection, corridor, & network
- MEASURES: Emerging
  - Travel Time & Reliability
  - Corridor Progression Quality
  - Capacity Utilization
- Supports maintenance, operations, and annual performance measures

Moving to Real-time Dynamic Feedback!

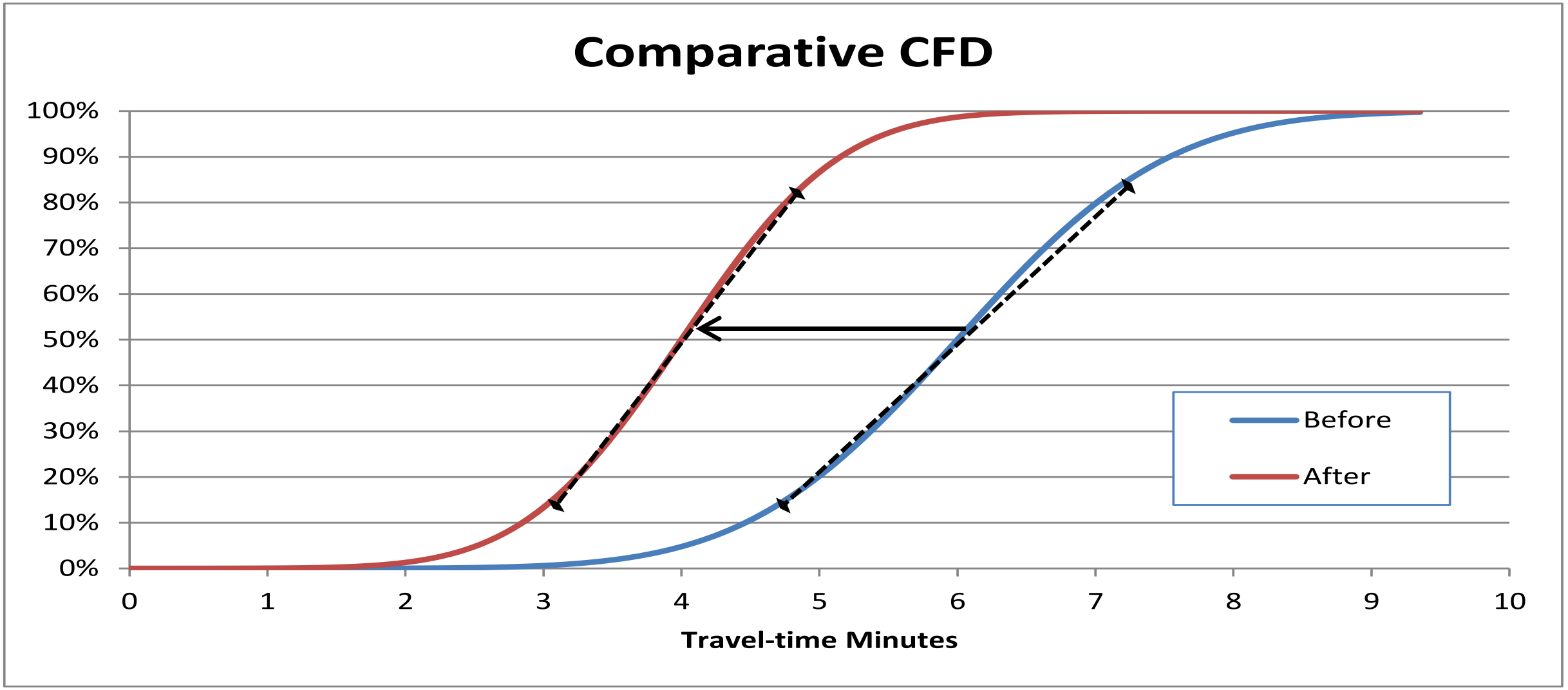
Travel Time and Travel Time Reliability

- Based on directly sampled travel time measurements
- Directly reflects concerns of the traveling public
  - Efficient and predictable travel
- Measures can be applicable to other modes of travel
  - Freeway, transit, air, etc.

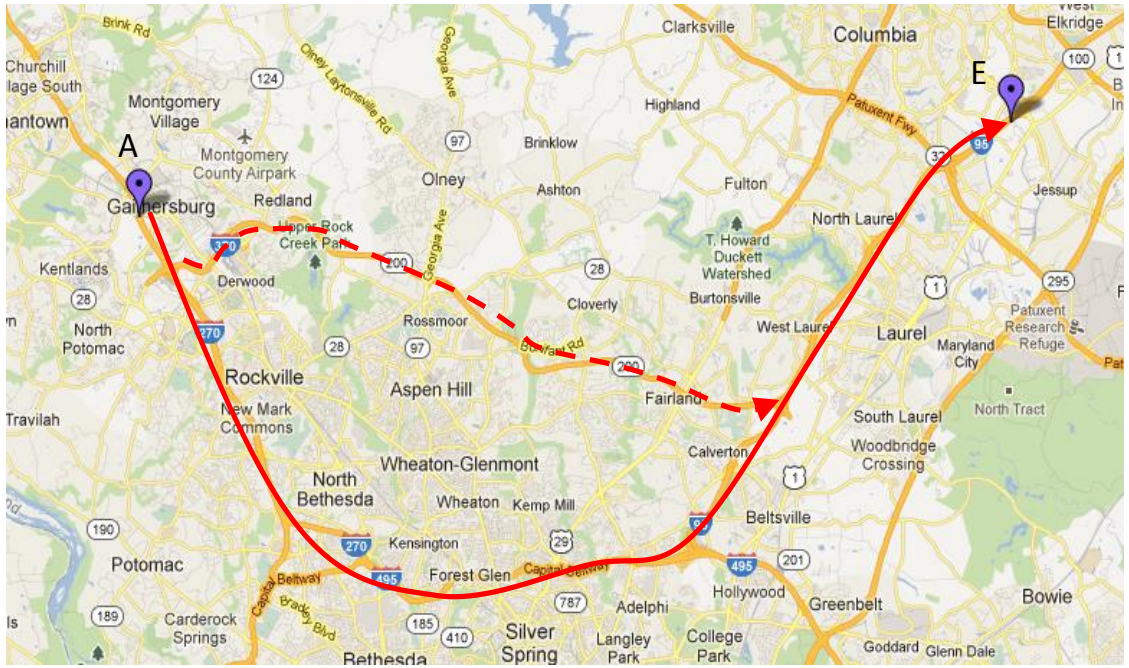
Travel Time

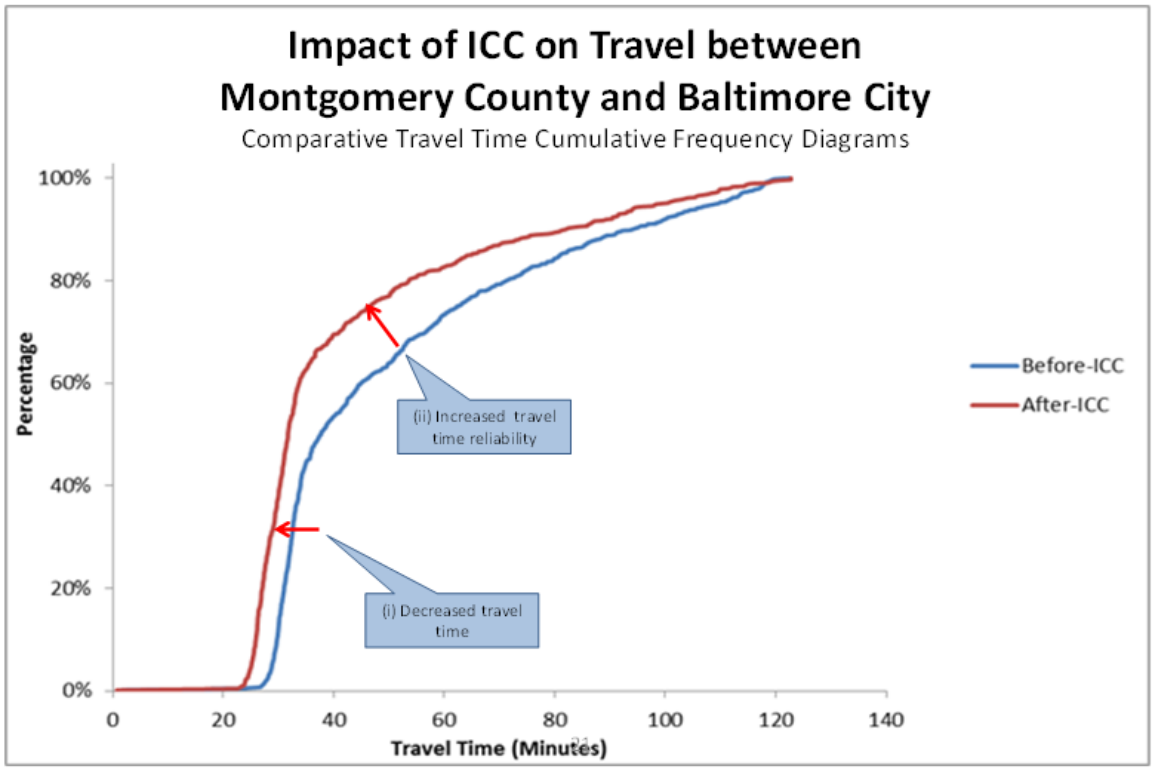

Comparative CFD
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
6
7
8
9
10
Travel-time Minutes
Before
After

Travel Time Reliability

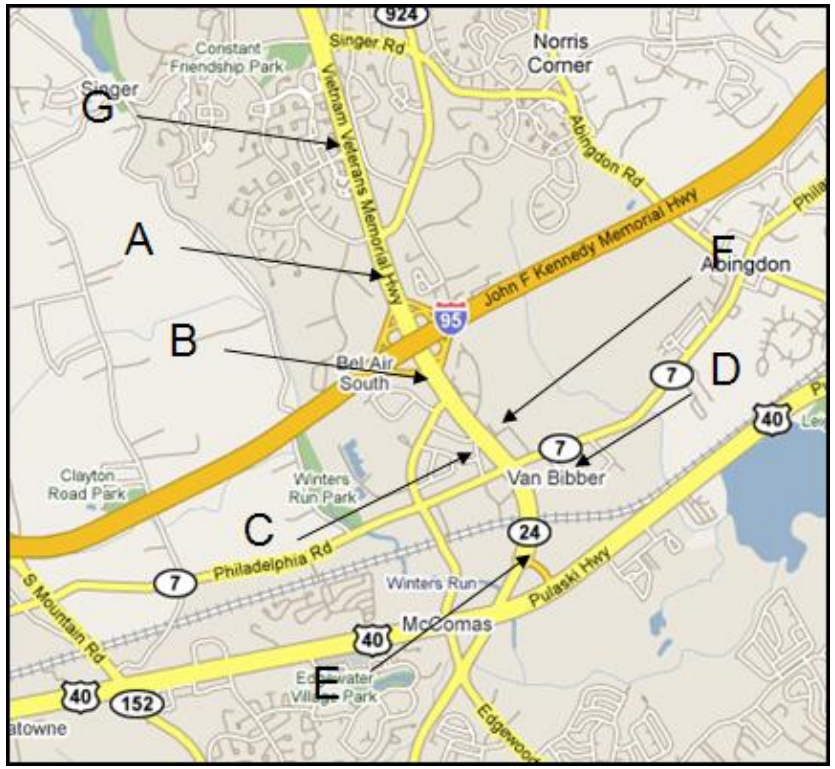


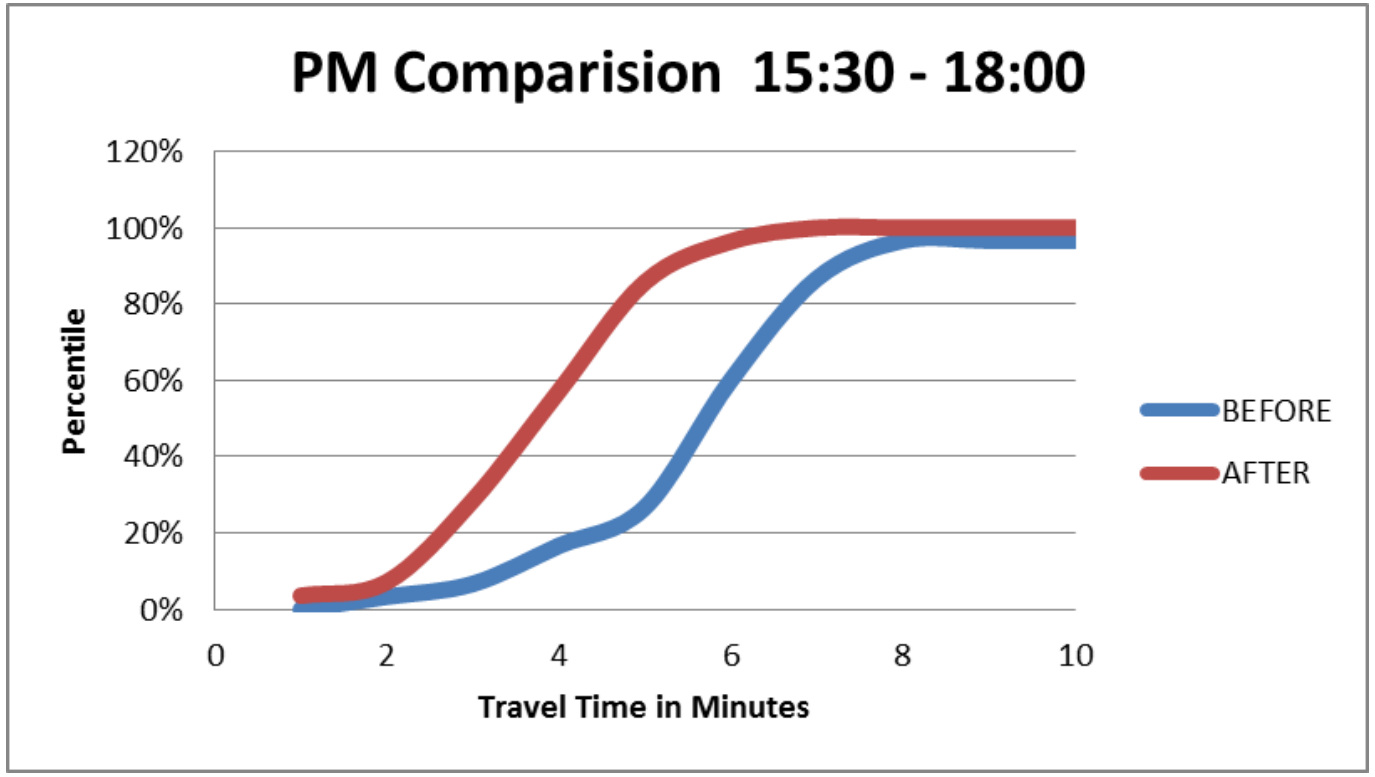
Travel time impact of the Inter-County Connect (ICC)(MD-200) in Maryland





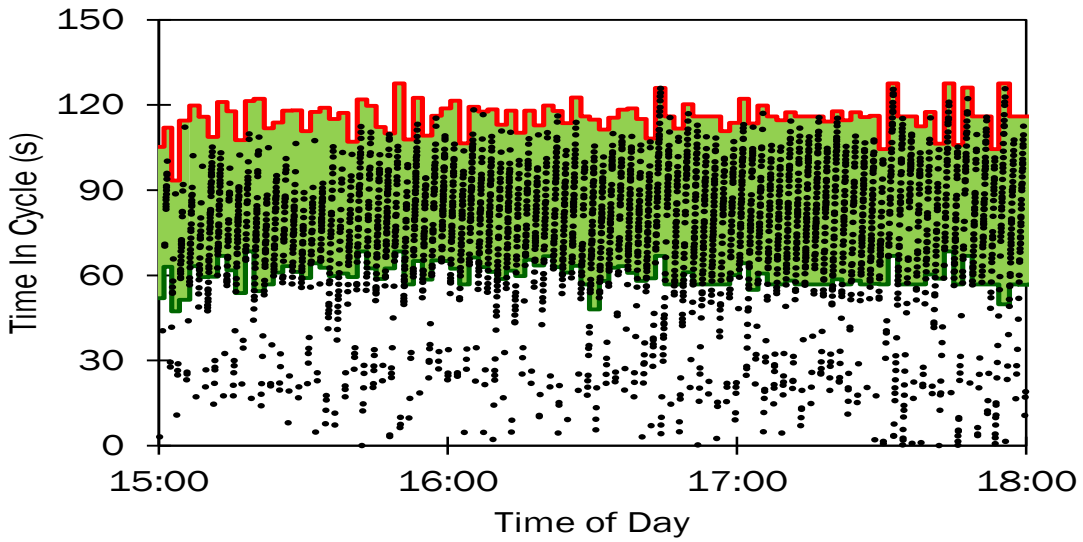
Before / After Maryland Route 24 Signal Timing Plan

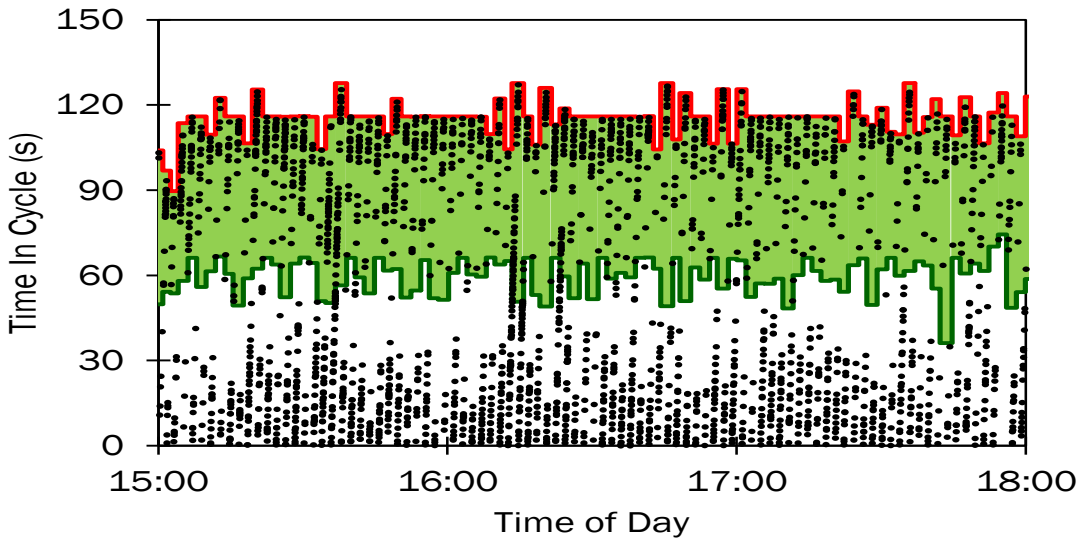




Sample Metric - PAGs

Purdue Coordination Diagram

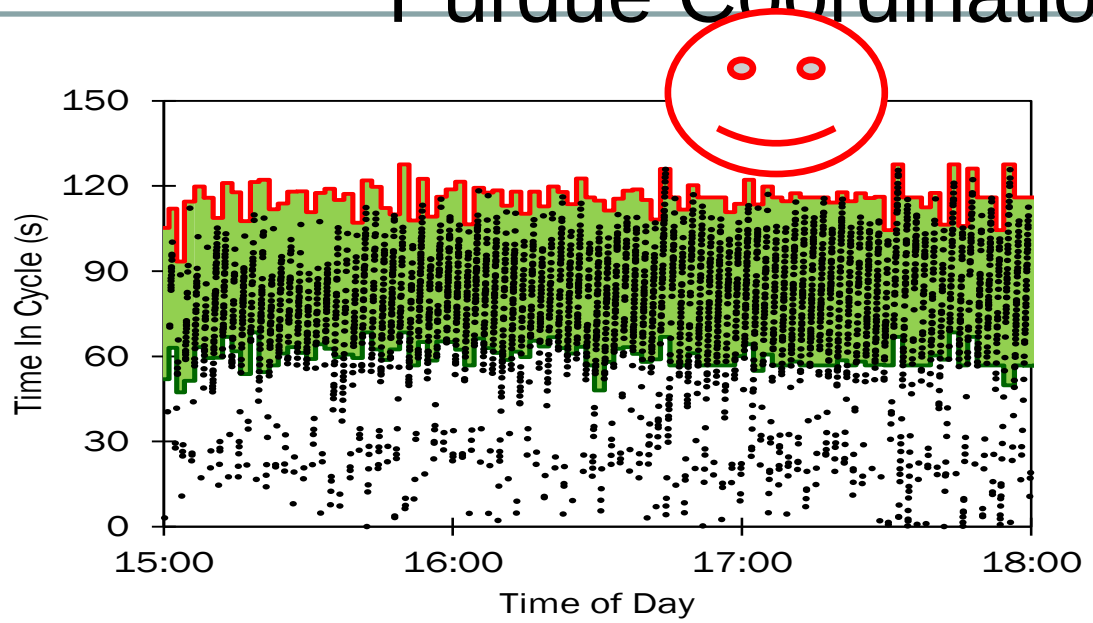


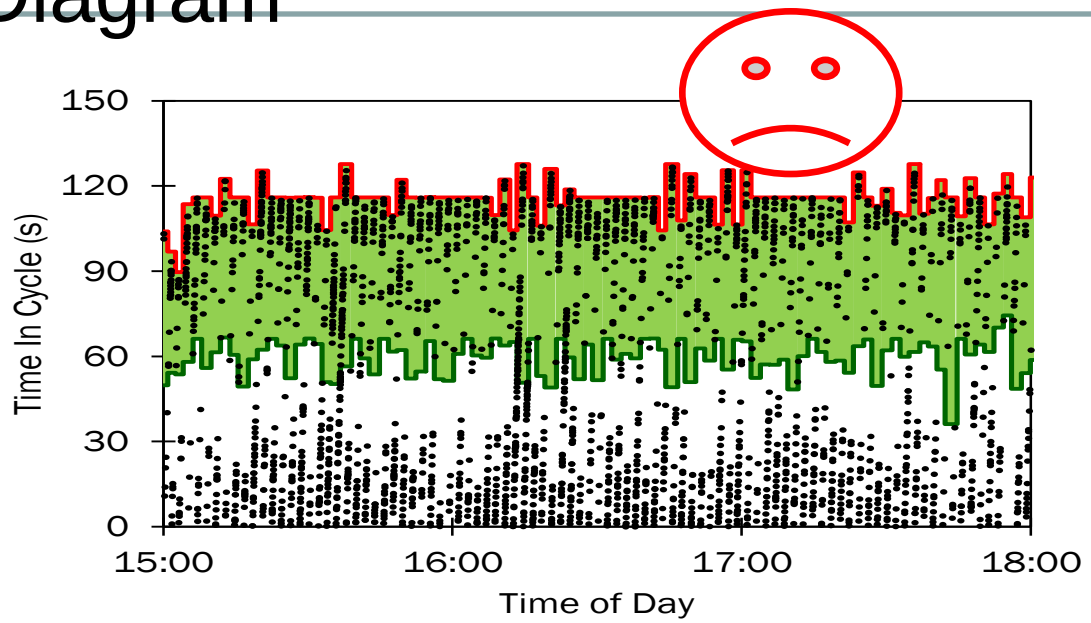


Purdue Univ.

Sample Metric - PAGs

Purdue Coordination Diagram





Purdue Univ.

Percent Arrivals on Green in the news!

Salt Lake City 53 °
Traffic

The Salt Lake Tribune
WWW.SLTRIB.COM MAY 21, 2015

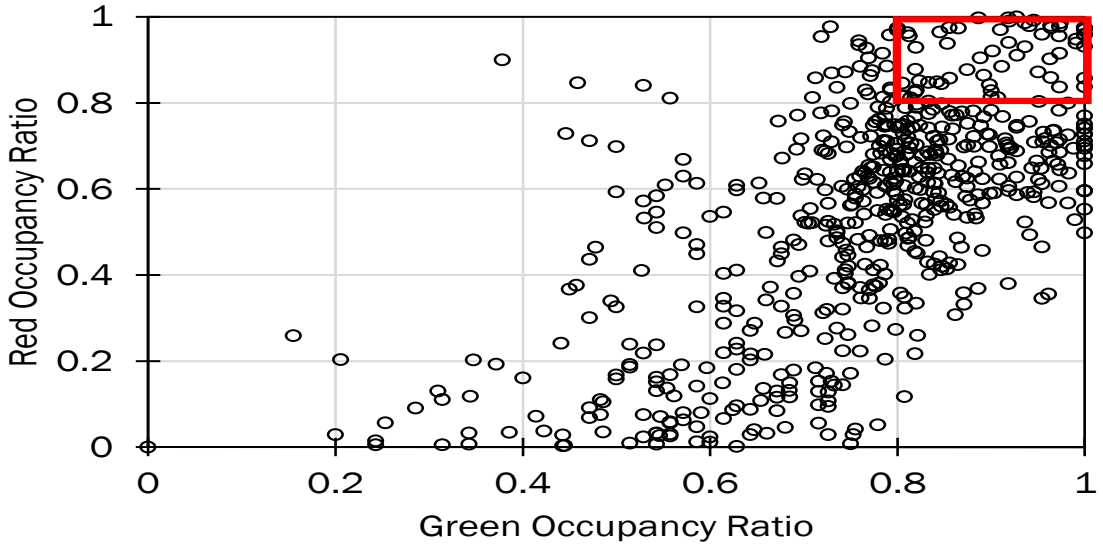
Odds of hitting a red light in Utah? Just 1-in-4

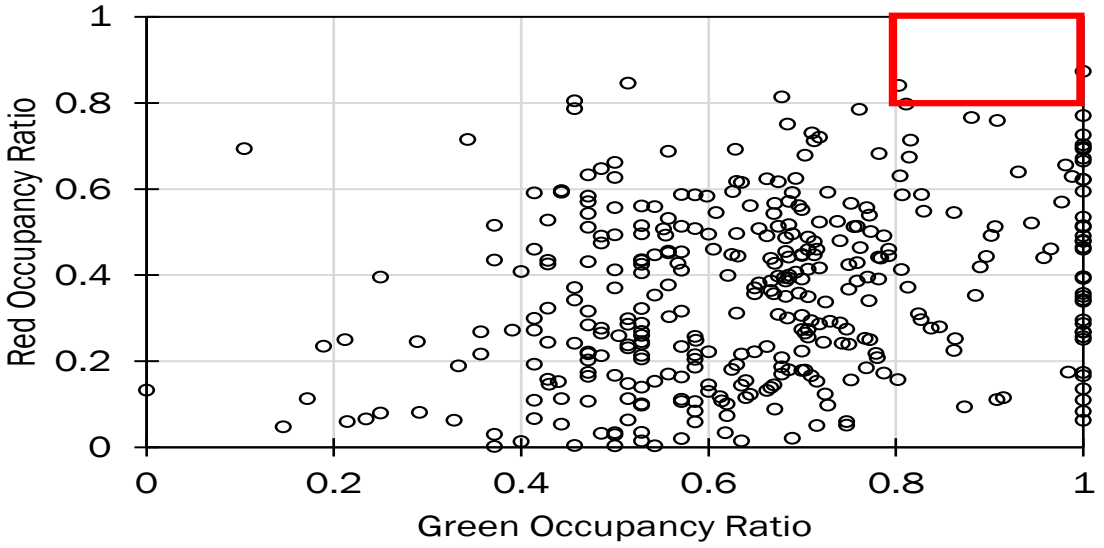
By Lee Davidson The Salt Lake Tribune

Published December 23, 2013 10:04 pm

Sample Metric - Intersection

Movement Capacity Analysis (ROR – GOR)





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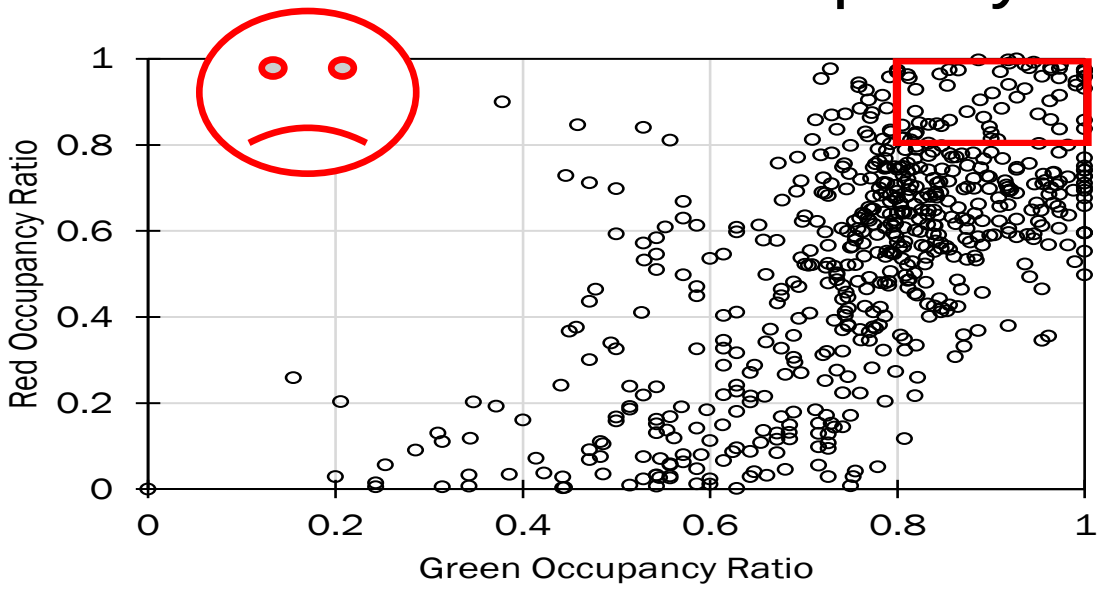
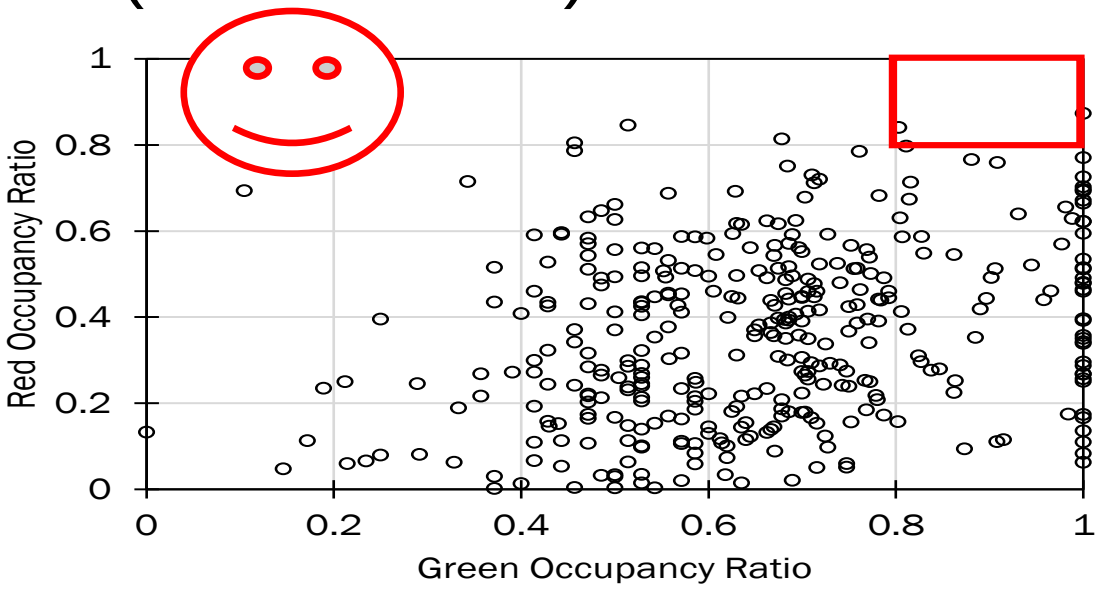
Sample Metric - Intersection

Movement Capacity Analysis (ROR – GOR)





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Frequency of Split Failures

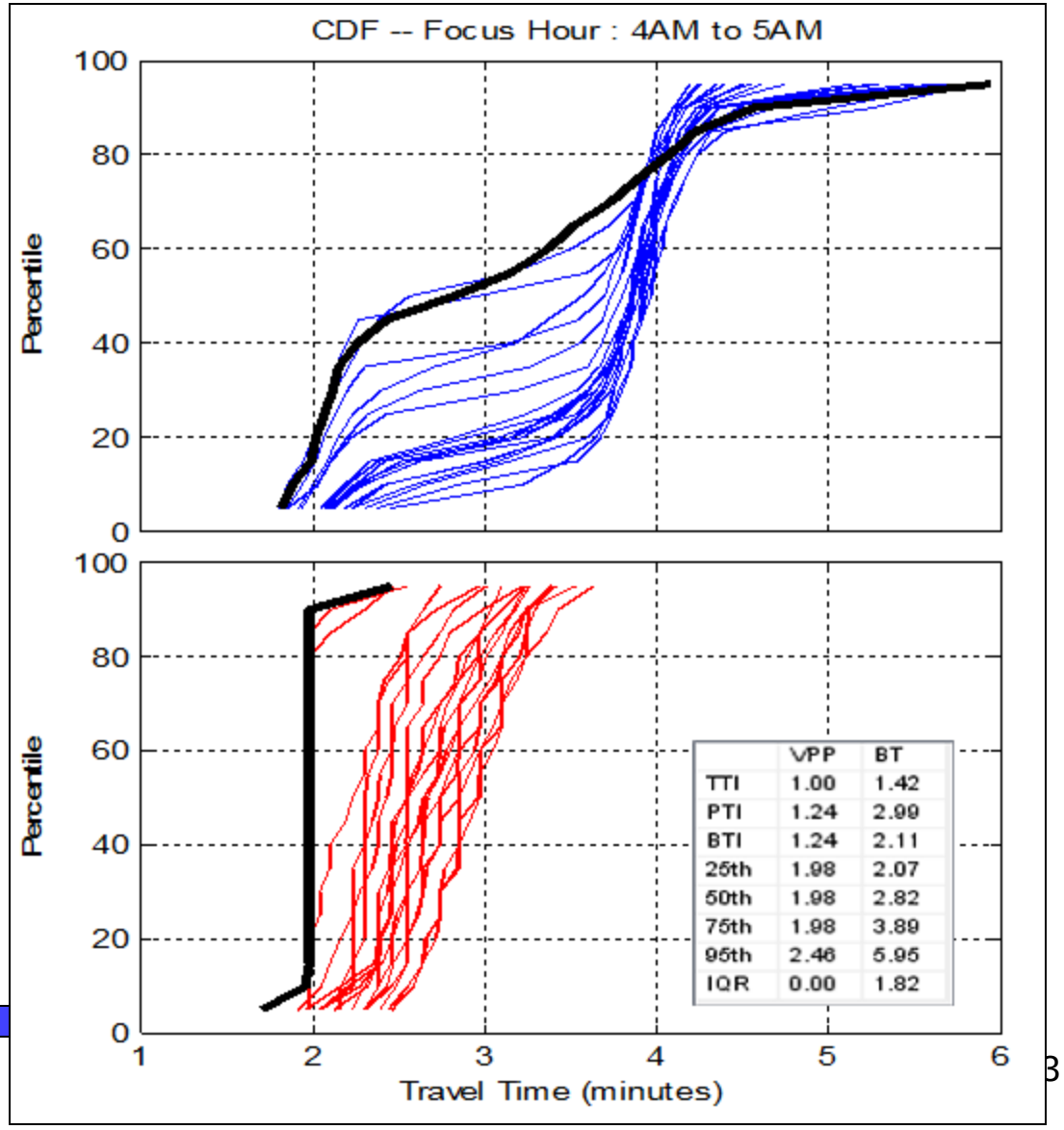
- Indicator of oversaturation
  - When demand overruns capacity
- Indicates when additional capacity or demand management is required
- Also known as the metric for ….
  - ‘Get off my back, nothing left to do’
  - ‘Time to share the pain’
  - ‘Give me another lane if you want this solved’

Products of SBIR Initiative

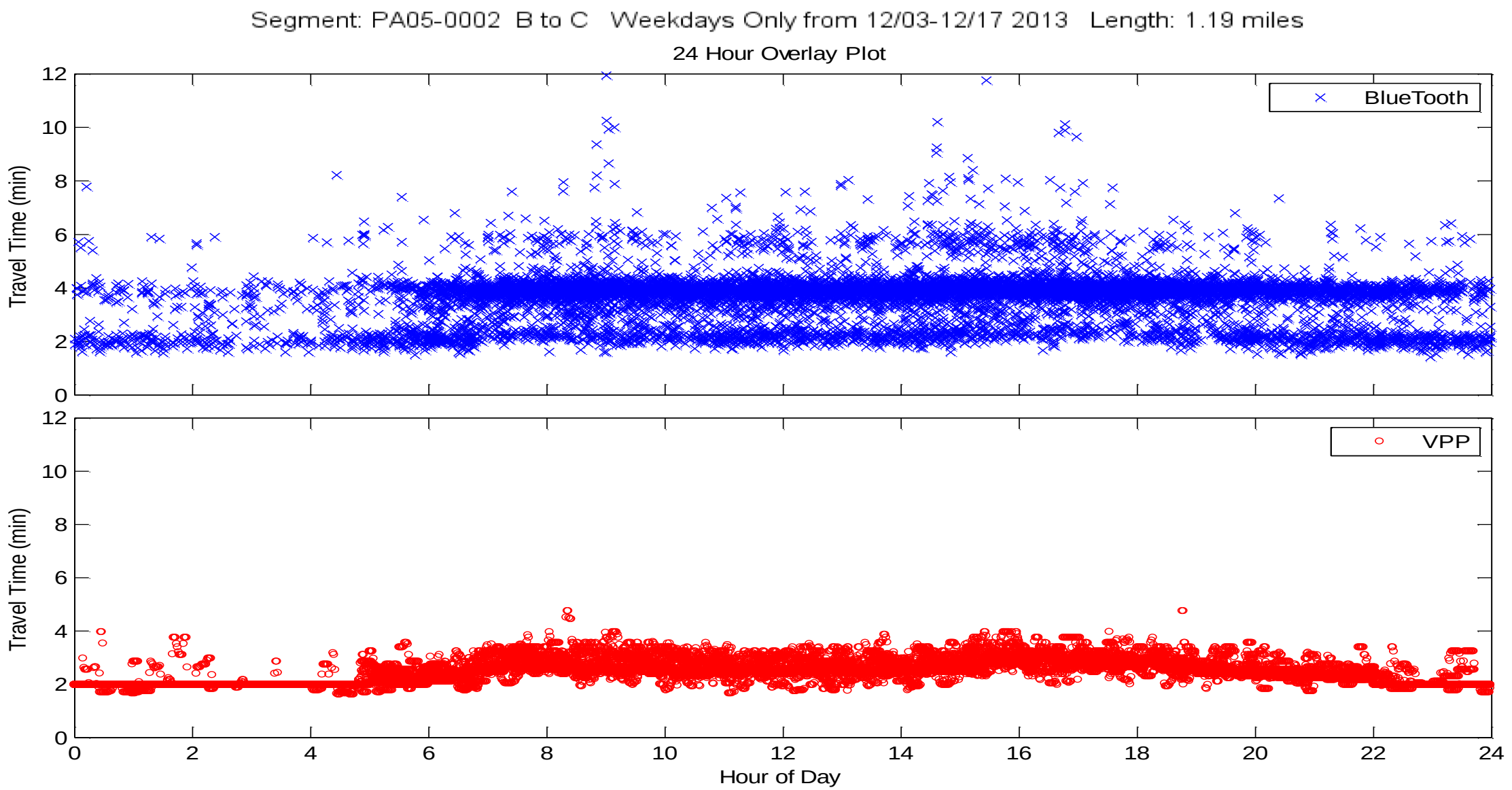
- Arterials Performance Measures Framework – Main
- Two Case Studies
- Technical Reports
  - Real-time Measures
  - Graphics Report
  - Network Performance Measures
  - Measuring how arterials are used
- Software Tools
  - Standard data format and reference implementations

Outsourced Probe Data & APM Framework

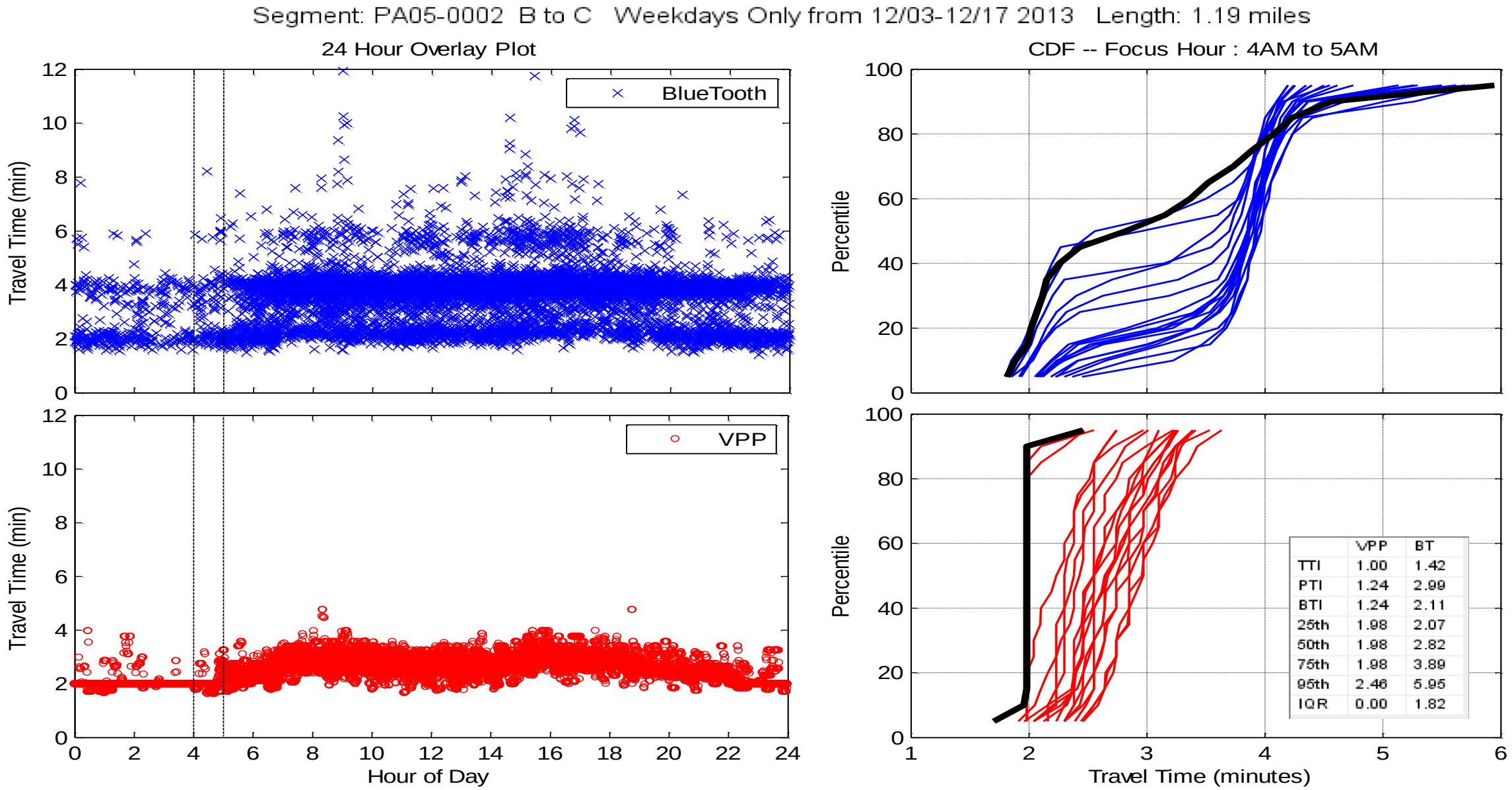
- Vehicle Probe Data Quality Update
- Future Direction of VPP Validation
- Proposed Top Level Performance Measures
- **Observing Travel Time and Travel Time Reliability in Overlay and CFDs**



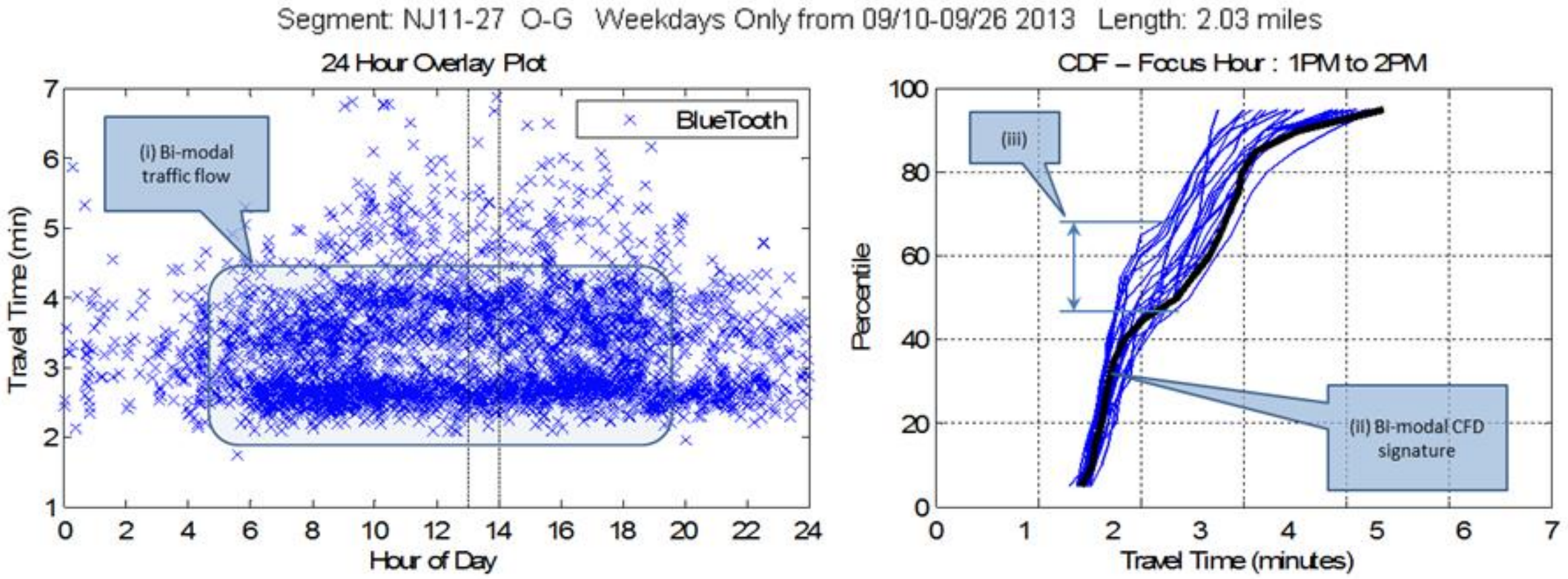
Re-Id Travel Time Data Fidelity



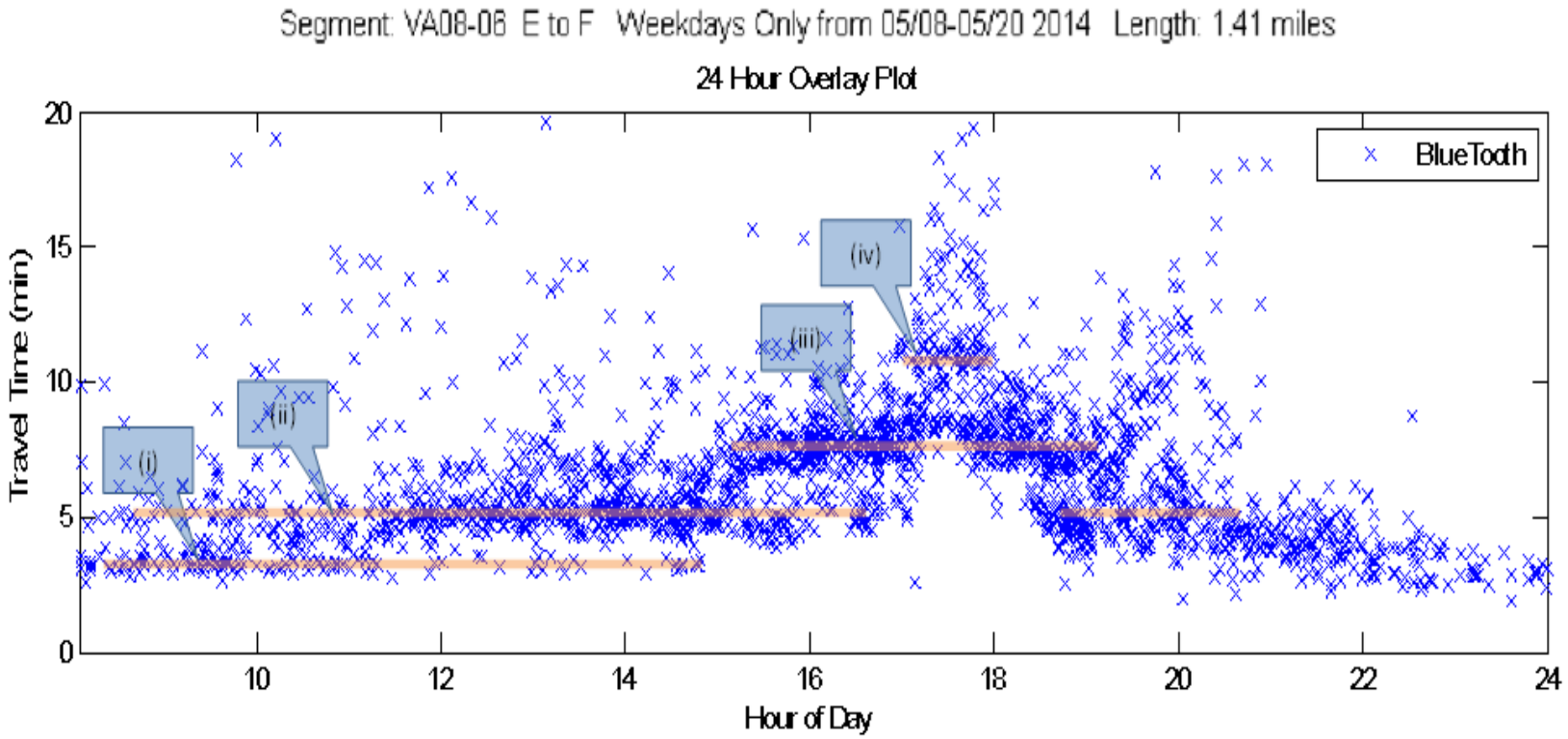
CFD Statistical Performance Measures

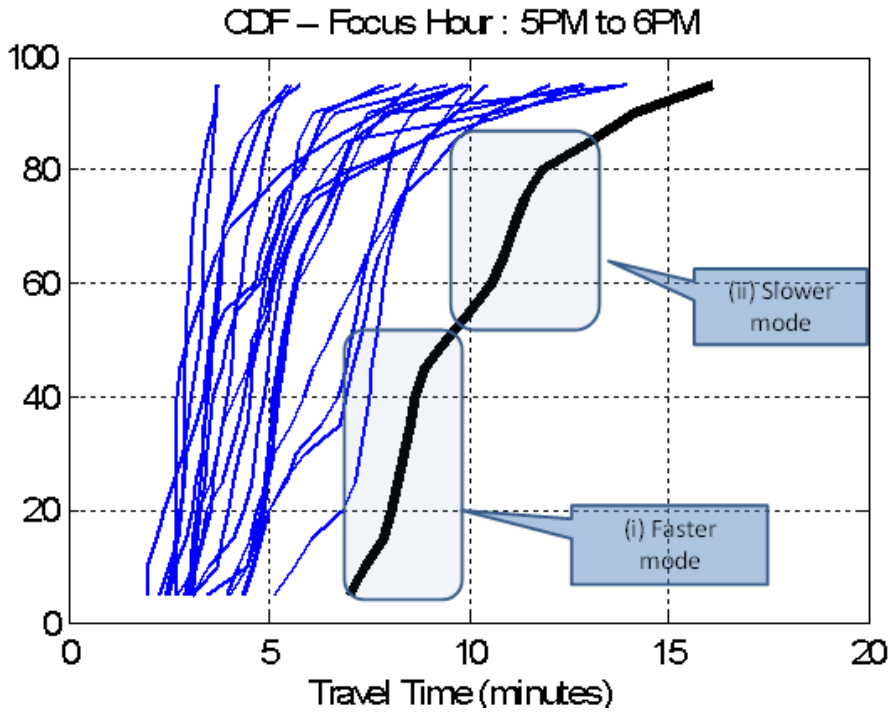


Bi-Modal CFD on US-130

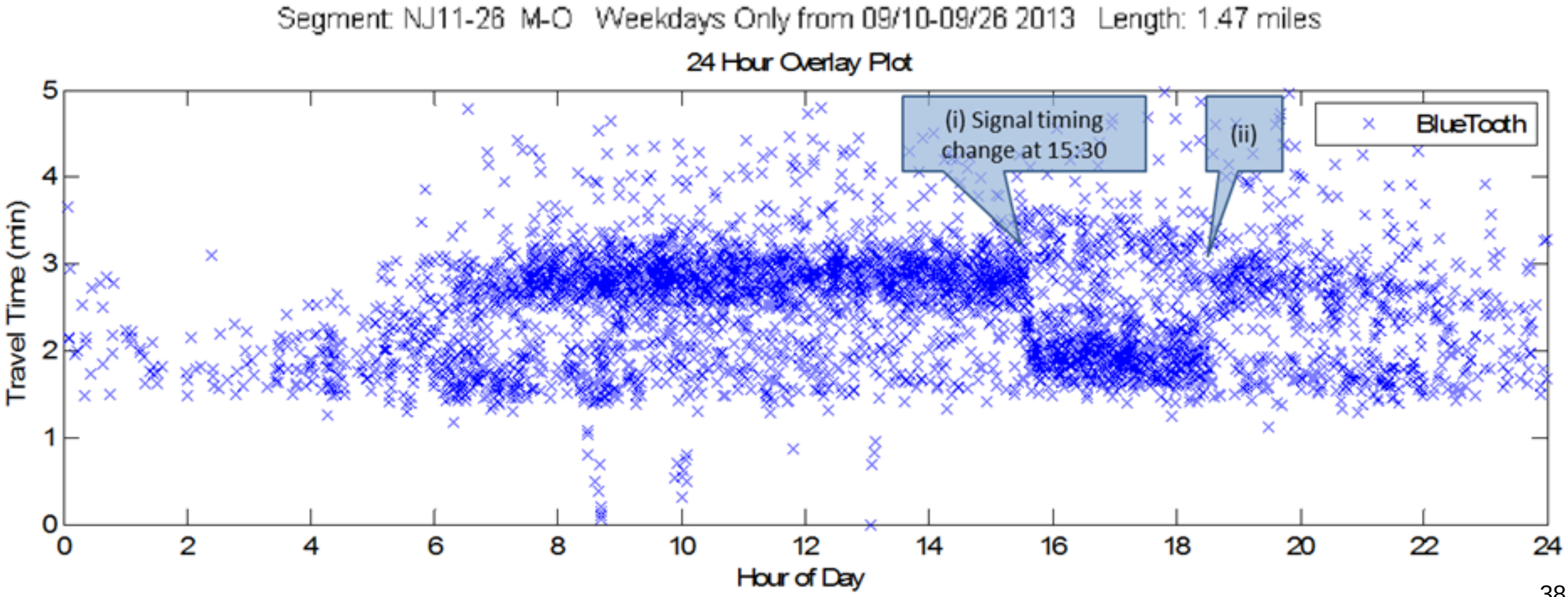


US-29 – Multi-Cycle Failure

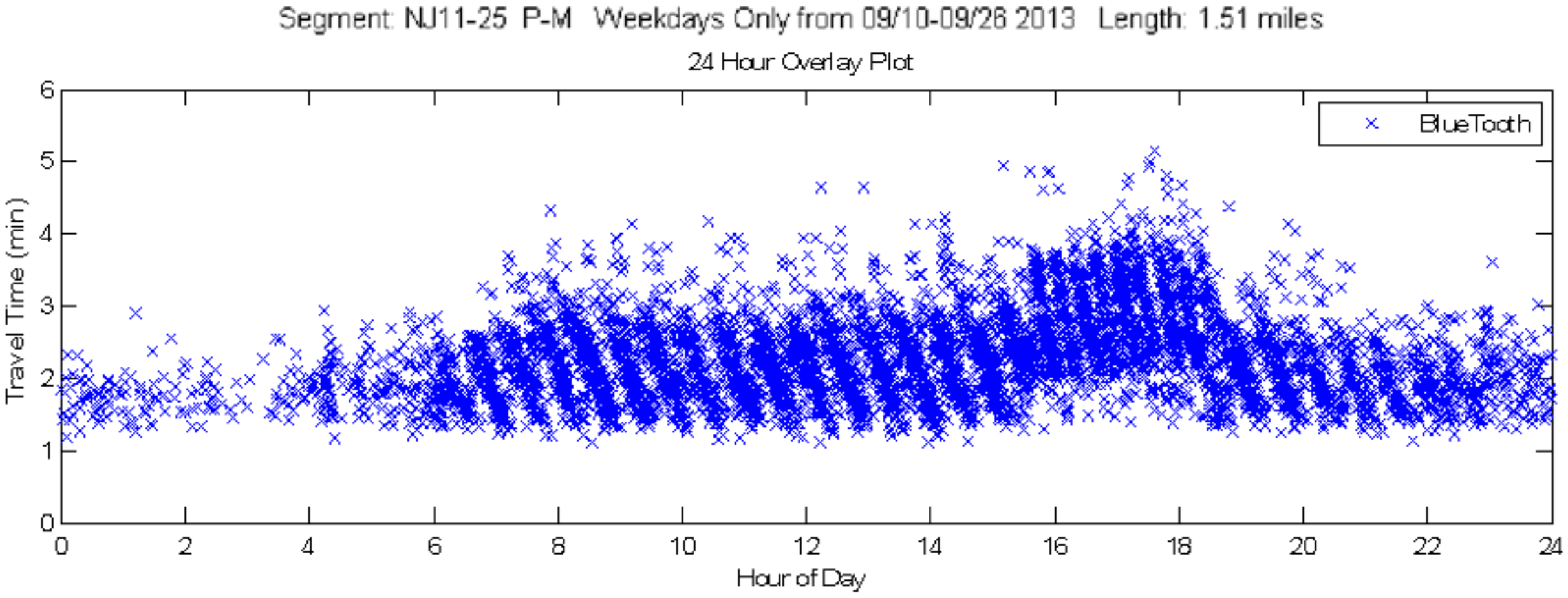




US-130 NB Signal Timing Change



US-130 NB Mismatched Cycle Lengths



Conclusions – Final Thoughts

- Vehicle Probe Data Validation
  - Arterial Data Accuracy is Improving
  - Anticipate updated report in 2016
  - Expand to data availability, real-time perf., latency
- Arterial Performance Measures Framework
  - Travel time and travel time reliability with re-id
  - Quality of progression and capacity analysis with HRCD
  - Next generation of Arterial Performance Management

Texas A&M Transportation Institute

Thoughts on Arterial Street Performance Management

Shawn Turner, P.E.

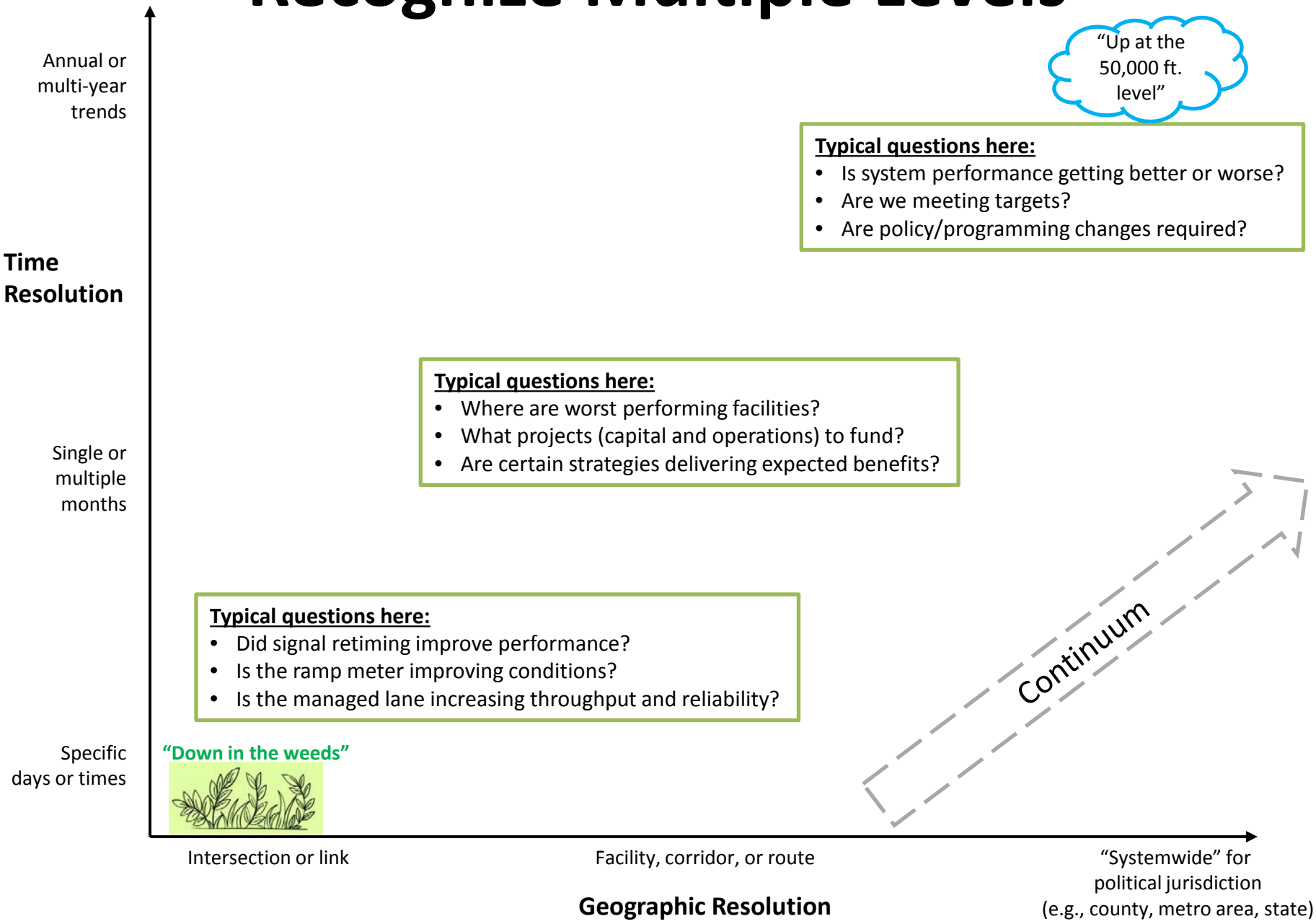
Texas A&M Transportation Institute (TTI)

NATMEC -- May 1, 2016 -- Miami, FL

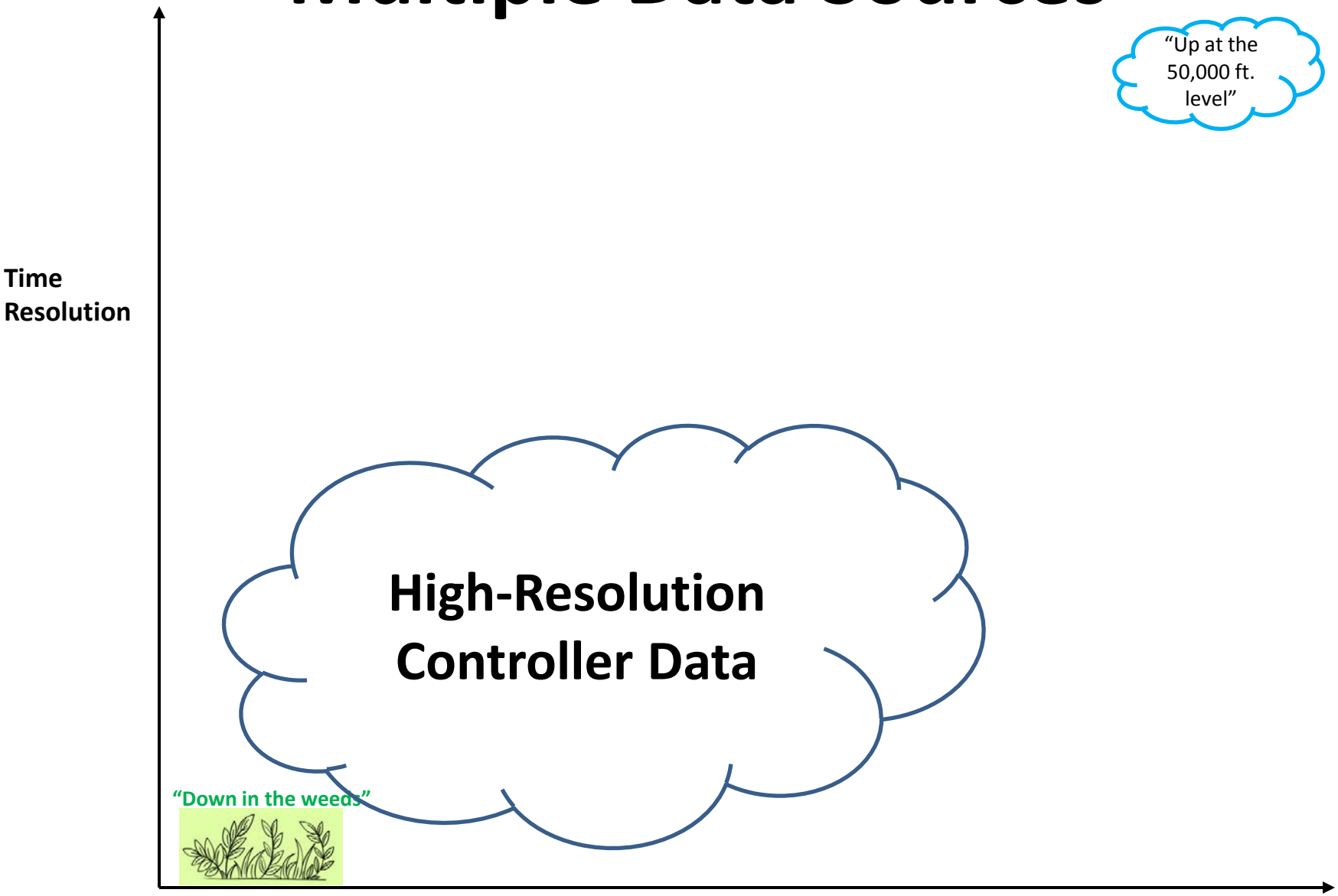
Outline

1. Emerging best practices
2. Arterial data accuracy
3. How do evolving methods affect year-to-year trend information?

Recognize Multiple Levels



Multiple Data Sources



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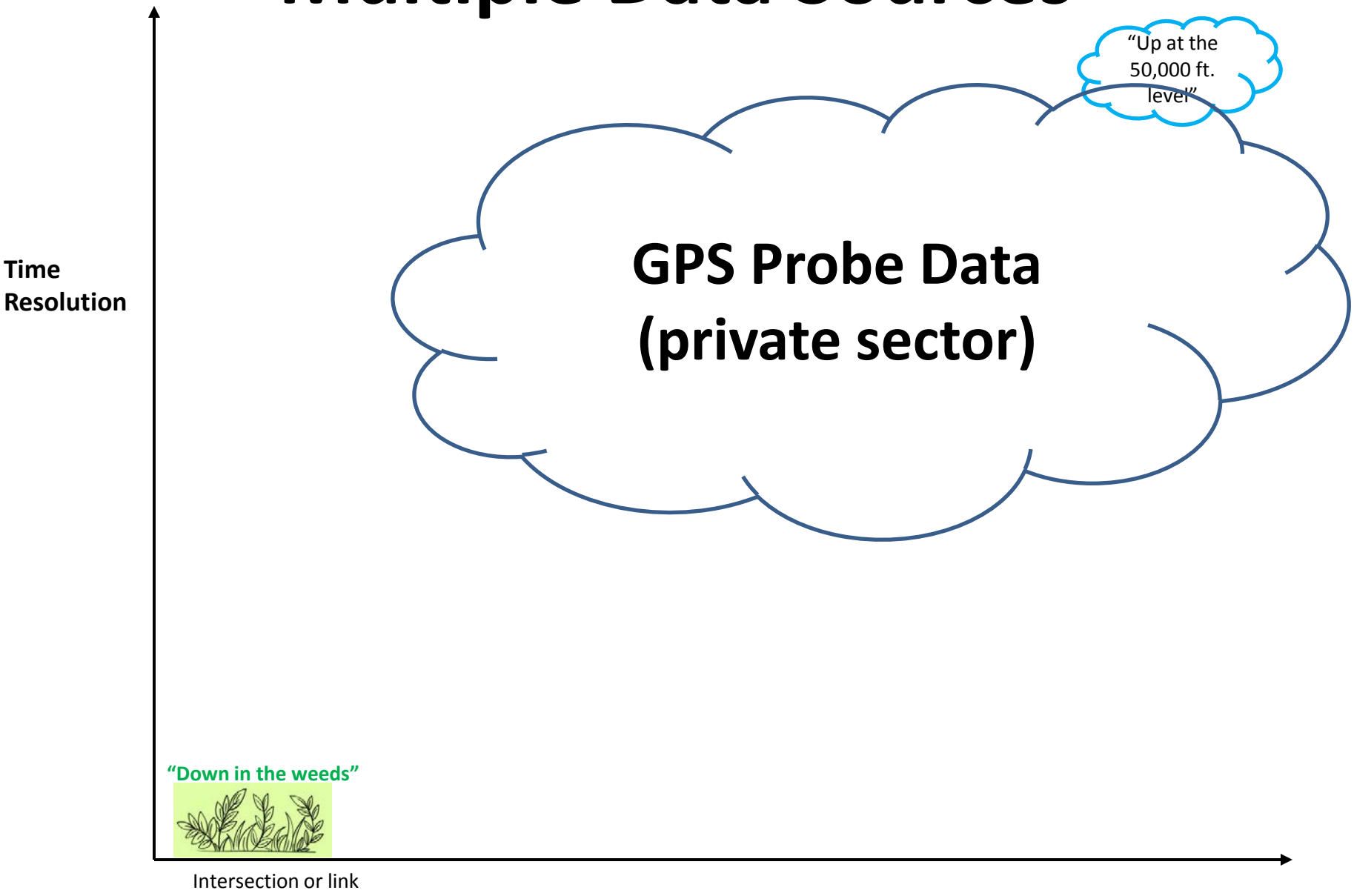

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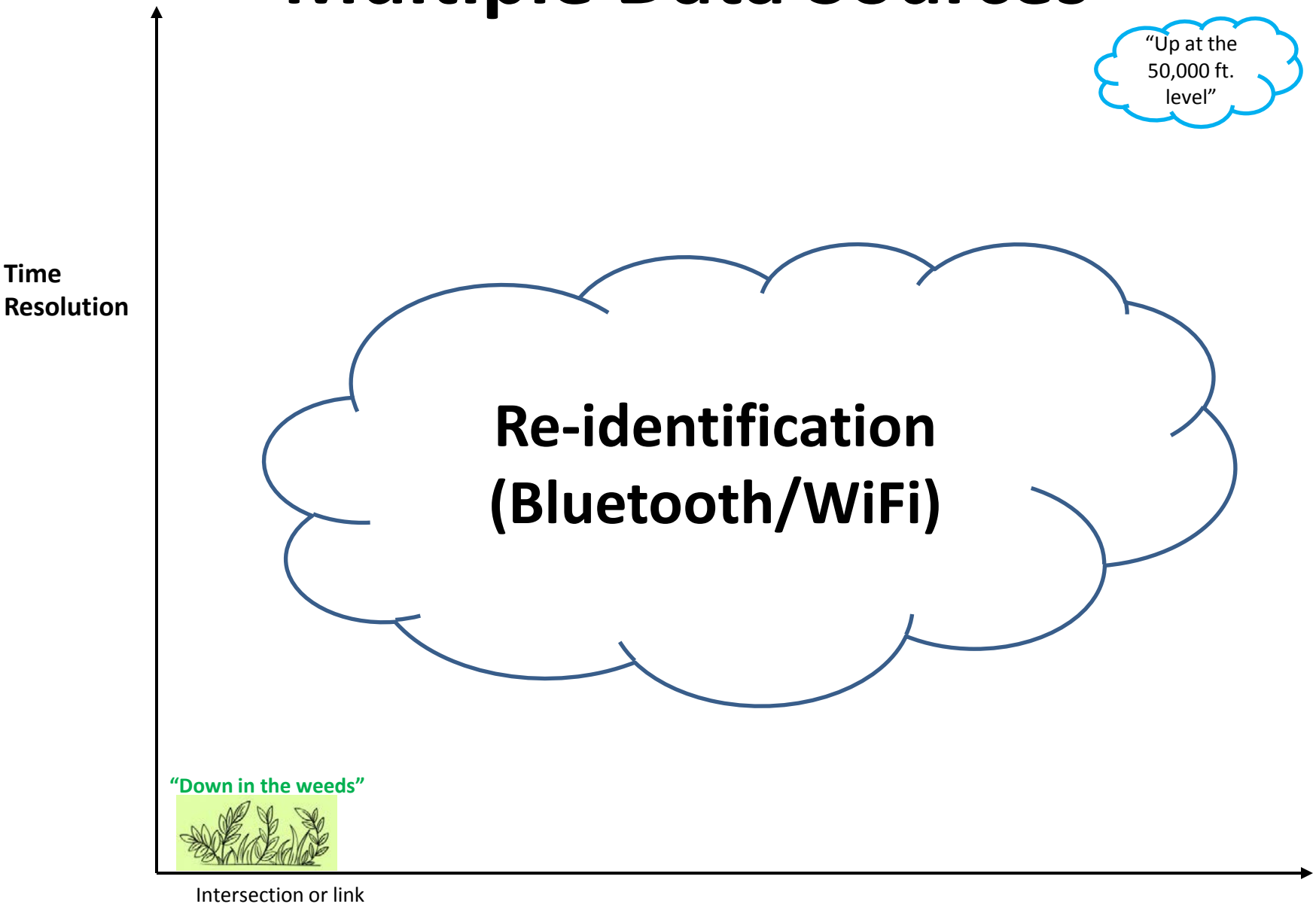

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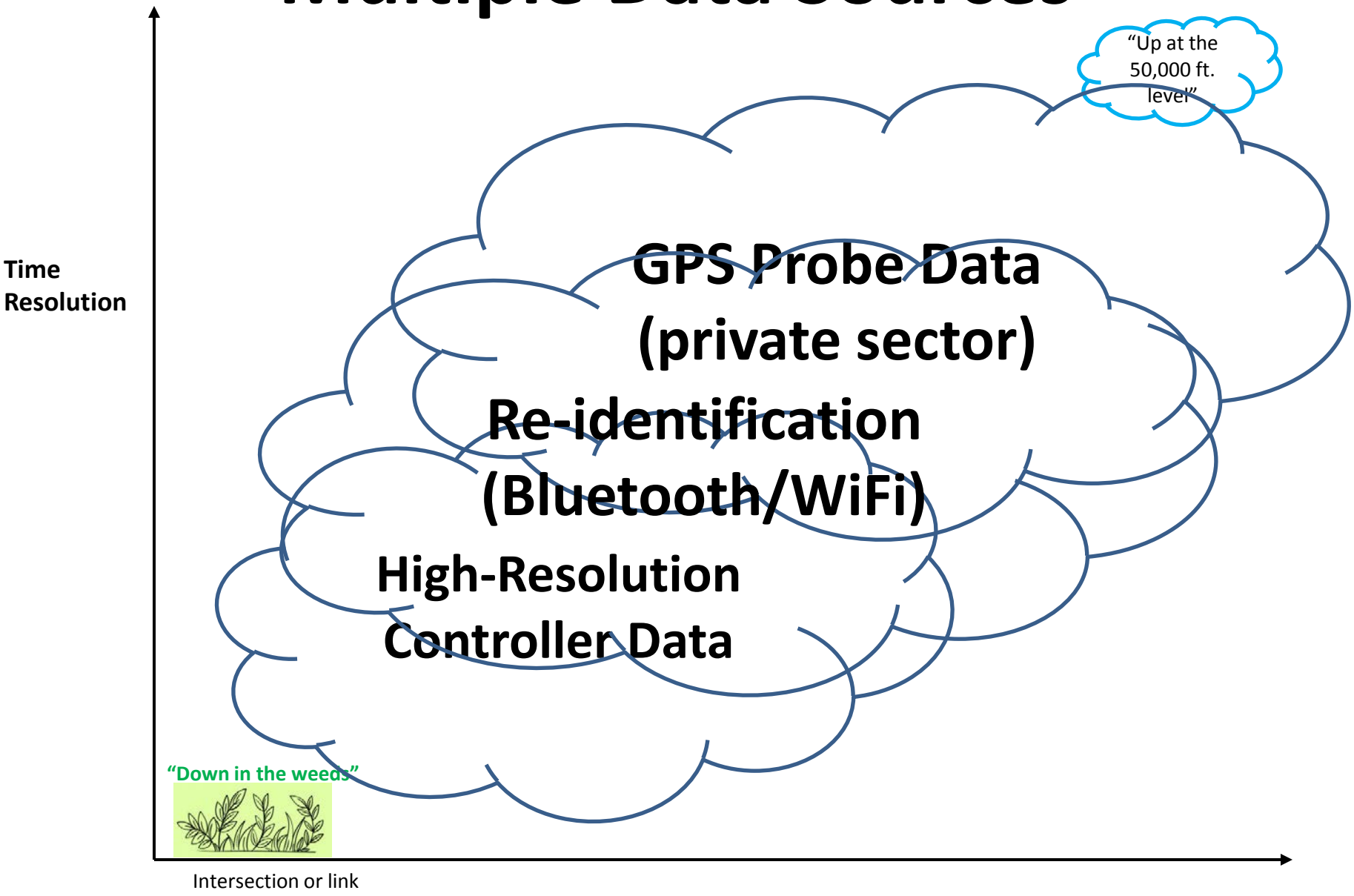
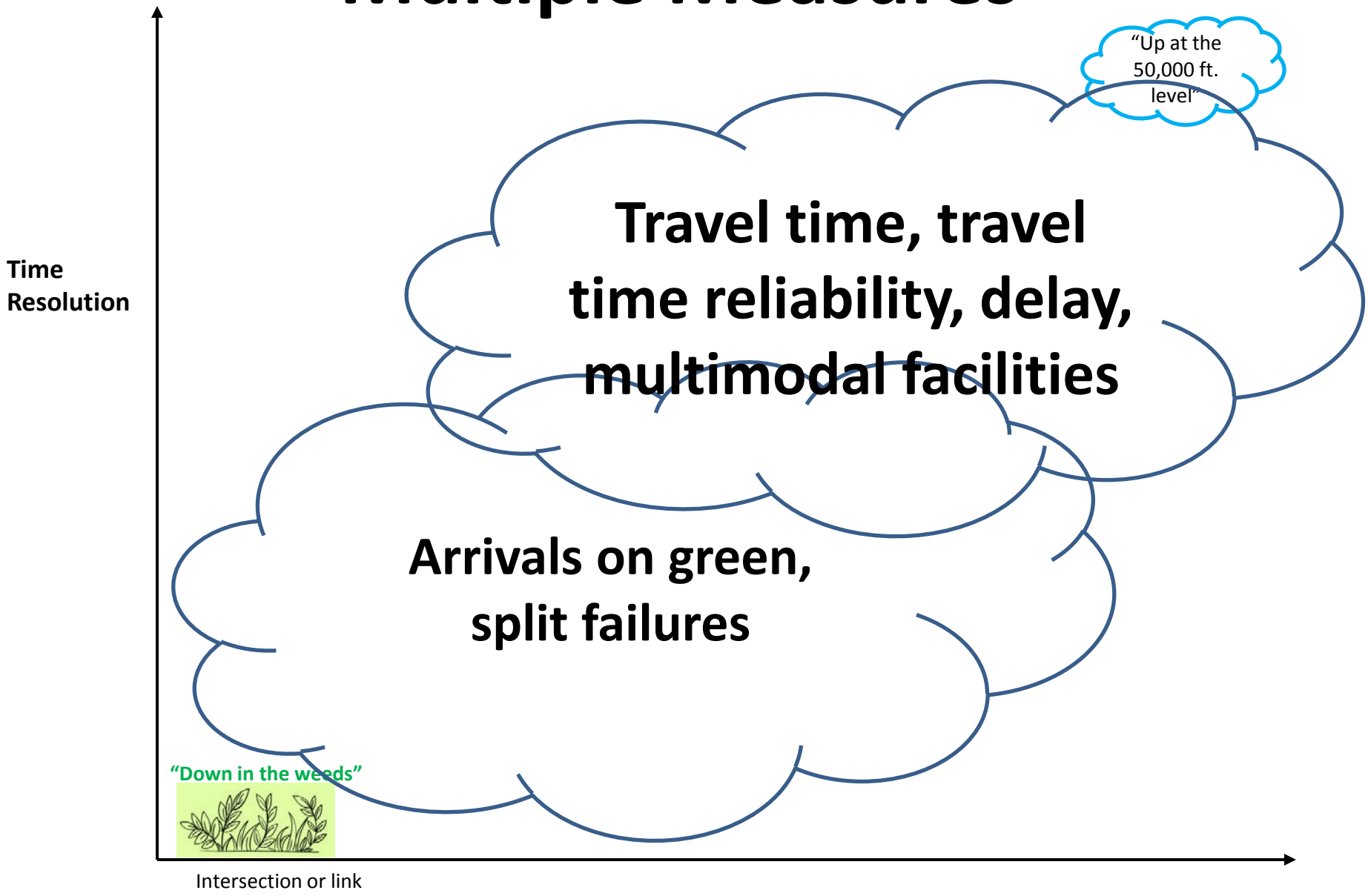


Multiple Measures

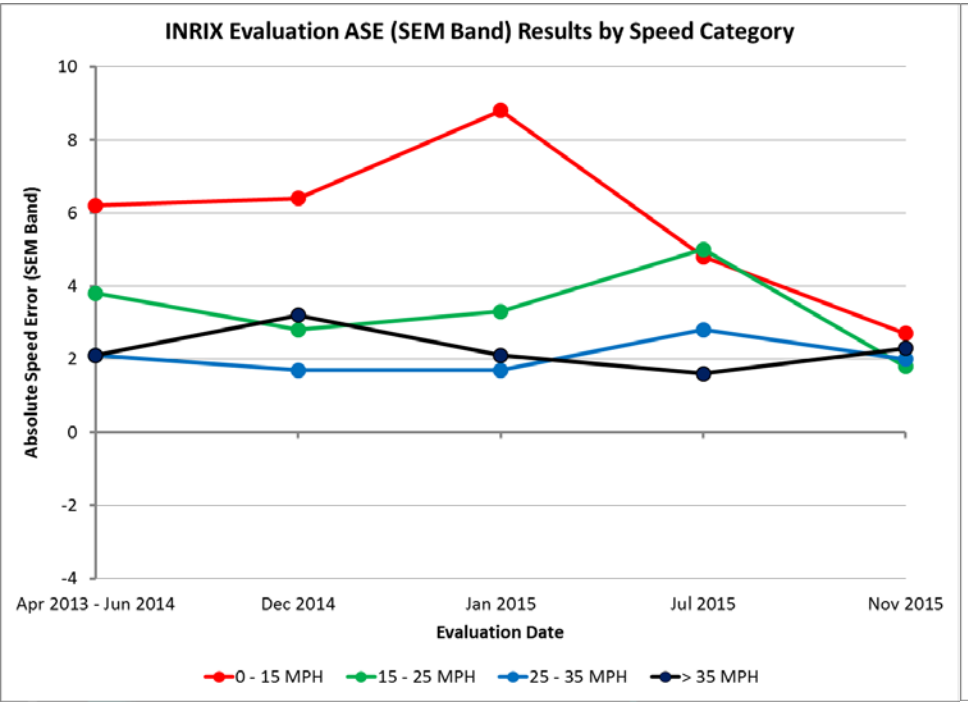


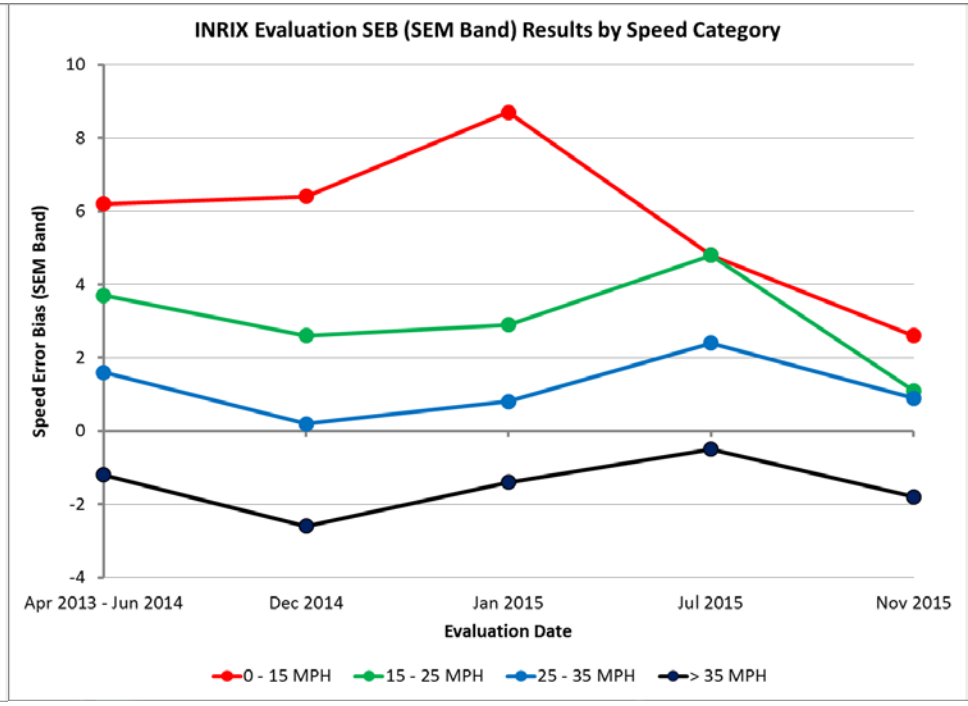
Performance Measures

- Not a single best answer
- Several measures highly correlated, avoid measure wars
- "End game" is improving decisions, getting support from elected officials & public
  - Therefore, need to speak "their language"

Arterial Data Accuracy

- How good is “good enough” on arterials?
  - Use case: historical performance monitoring, not real-time
- Are we there yet? (if not, when?)





Source: I-95 Corridor Coalition Vehicle Probe Project

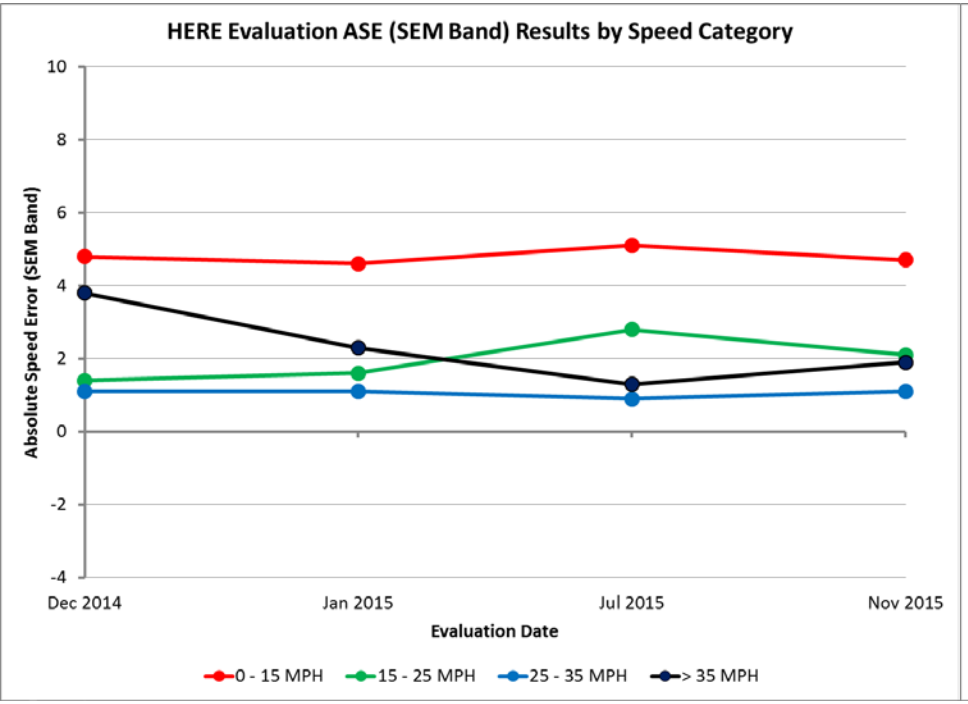
% Error (estimated)

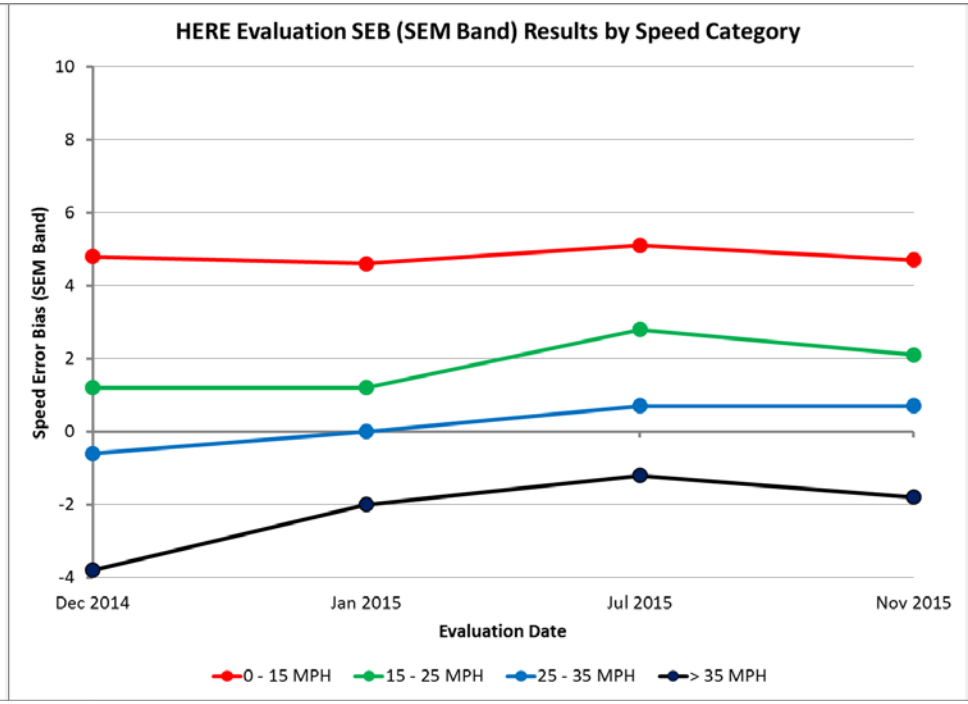
2.7 mph in 0-15 mph ≈ 36%

1.8 mph in 15-25 mph ≈ 9%

2.0 mph in 25-35 mph ≈ 7%

2.3 mph in >35 mph ≈ 6%





Source: I-95 Corridor Coalition Vehicle Probe Project

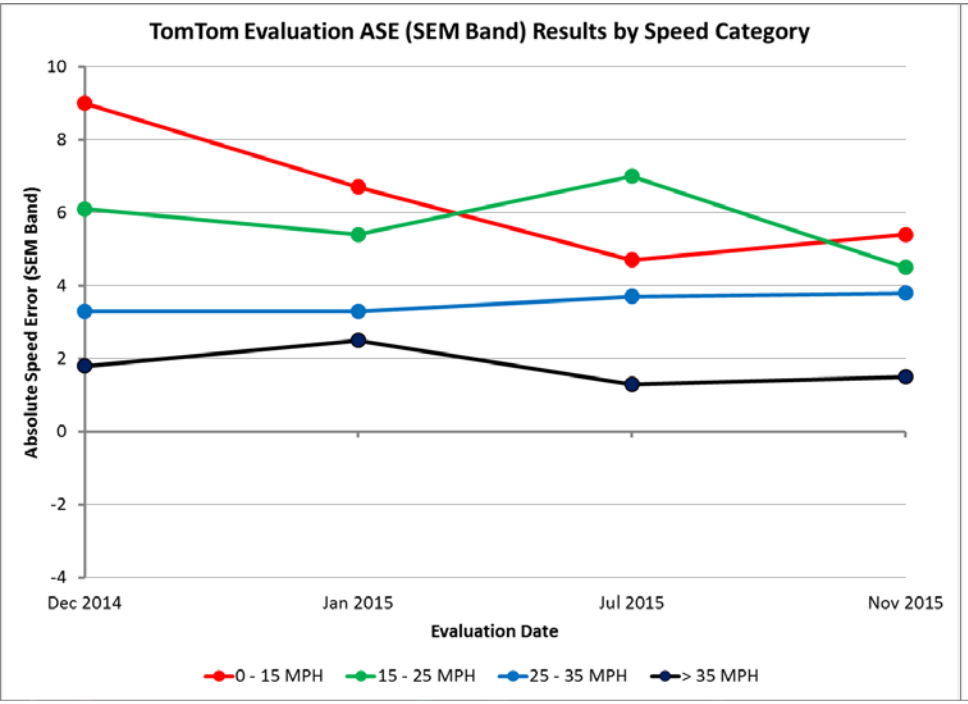
% Error (estimated)

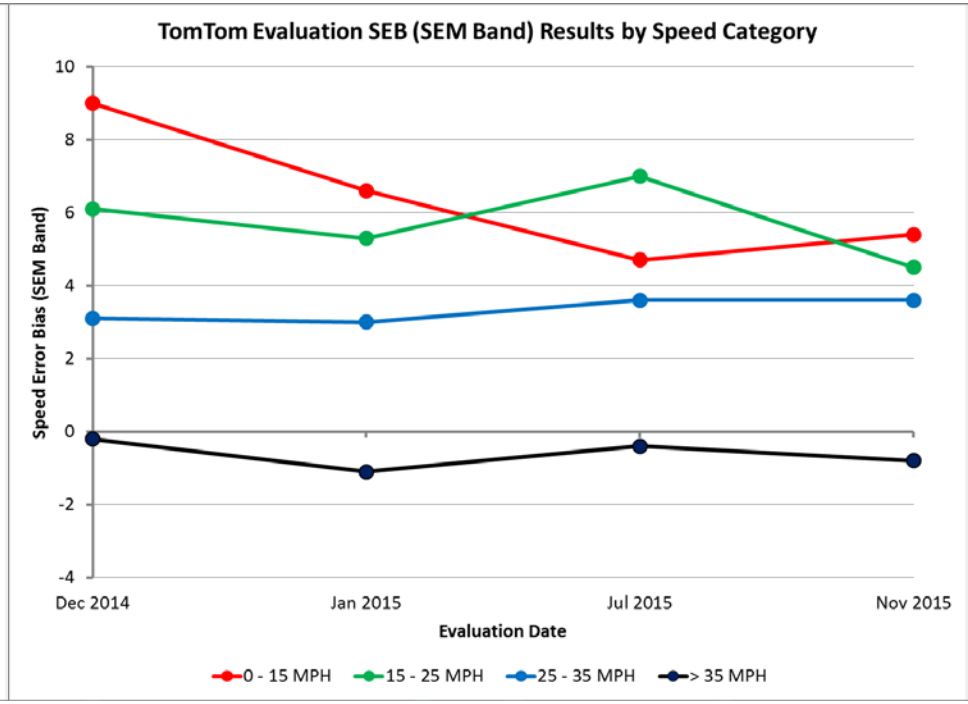
4.7 mph in 0-15 mph ≈ 63%

2.1 mph in 15-25 mph ≈ 10%

1.1 mph in 25-35 mph ≈ 4%

1.9 mph in >35 mph ≈ 5%





Source: I-95 Corridor Coalition Vehicle Probe Project

<u>% Error (estimated)</u>

5.4 mph in 0-15 mph ≈ 41%

4.5 mph in 15-25 mph ≈ 23%

3.8 mph in 25-35 mph ≈ 13%

1.5 mph in >35 mph ≈ 4%

Trend Analysis

- If accuracy still improving, what about trend analysis?
- Is increase in delay a function of more accurate data? Or more congestion?