CIVIL & ENVIRONMENTAL ENGINEERING
UNIVERSITY of WASHINGTON

UW STAR LAB
Smart Transportation Applications and Research

Error Assessment for Emerging Traffic Data Collection Devices

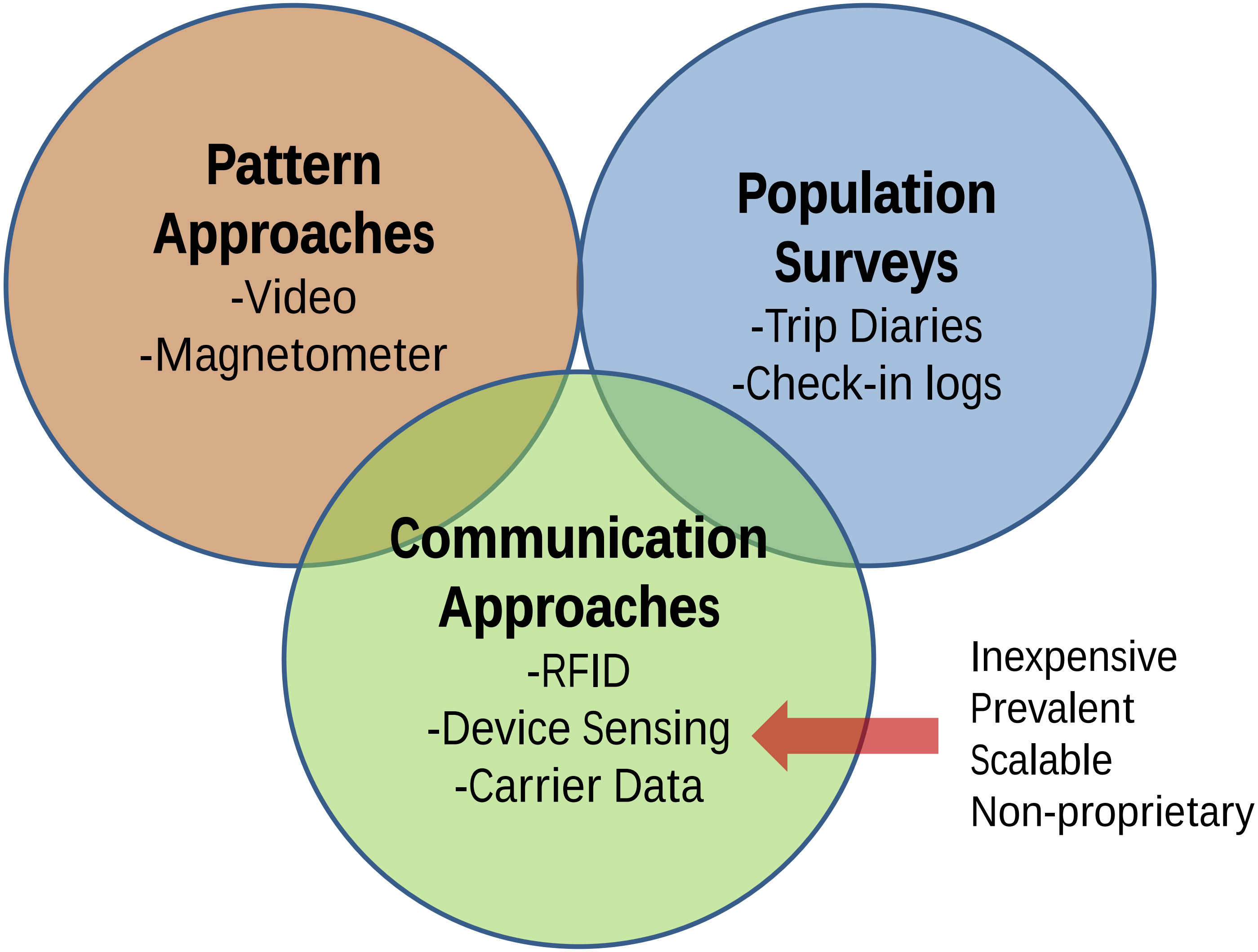
Ted Bailey, WSDOT
Ron Vessey, WSDOT
Bahar Namaki, Aalborg Univ.
Jonathan Corey, UW
Yegor Malinovskiy, UW
Yinhai Wang, UW

Presentation Outline

- Quick MAC* Sensing Overview
- Bluetooth Accuracy Background
- Technology Overview
- Study Overview
- Analysis Platform
- Results
- Discussion

*Media Access Control Number

Re-Identification Methods



Device Sensing

- Short Range Protocols
  - Primarily Bluetooth
- Communication Type
  - Unique ID
    - Promiscuous broadcast
  - Device Type*
    - "I am a valve cap"
  - State Info*
    - Air pressure
    - Temperature

Device Sensing

- Bluetooth basics
  - Each device has unique 48-bit MAC address
  - A device can be found when it’s “visible” or in “discoverable mode”

- WiFi basics
  - Each device has unique 48-bit MAC address
  - A device can be found when its searching for hotspots
  - Have found WiFi to be 2x more prevalent than Bluetooth on UW campus

Device Sensing

Classic Bluetooth

Chance of obtaining MAC address = $\frac{\text{Time Spent in Detection Zone}}{\text{10.24 sec}}$

Promiscuous Broadcast:
MAC

Class I: 100m range
Class II: 10m range
Class III: 1m range

Bluetooth LE

Chance of obtaining MAC address = $\frac{\text{Time Spent in Detection Zone}}{\text{3 ms}}$

Promiscuous Broadcast:
MAC
Device Type
Device State

Up to 150m range (open field)
Dedicated ad channel
$ 0.25 per chip

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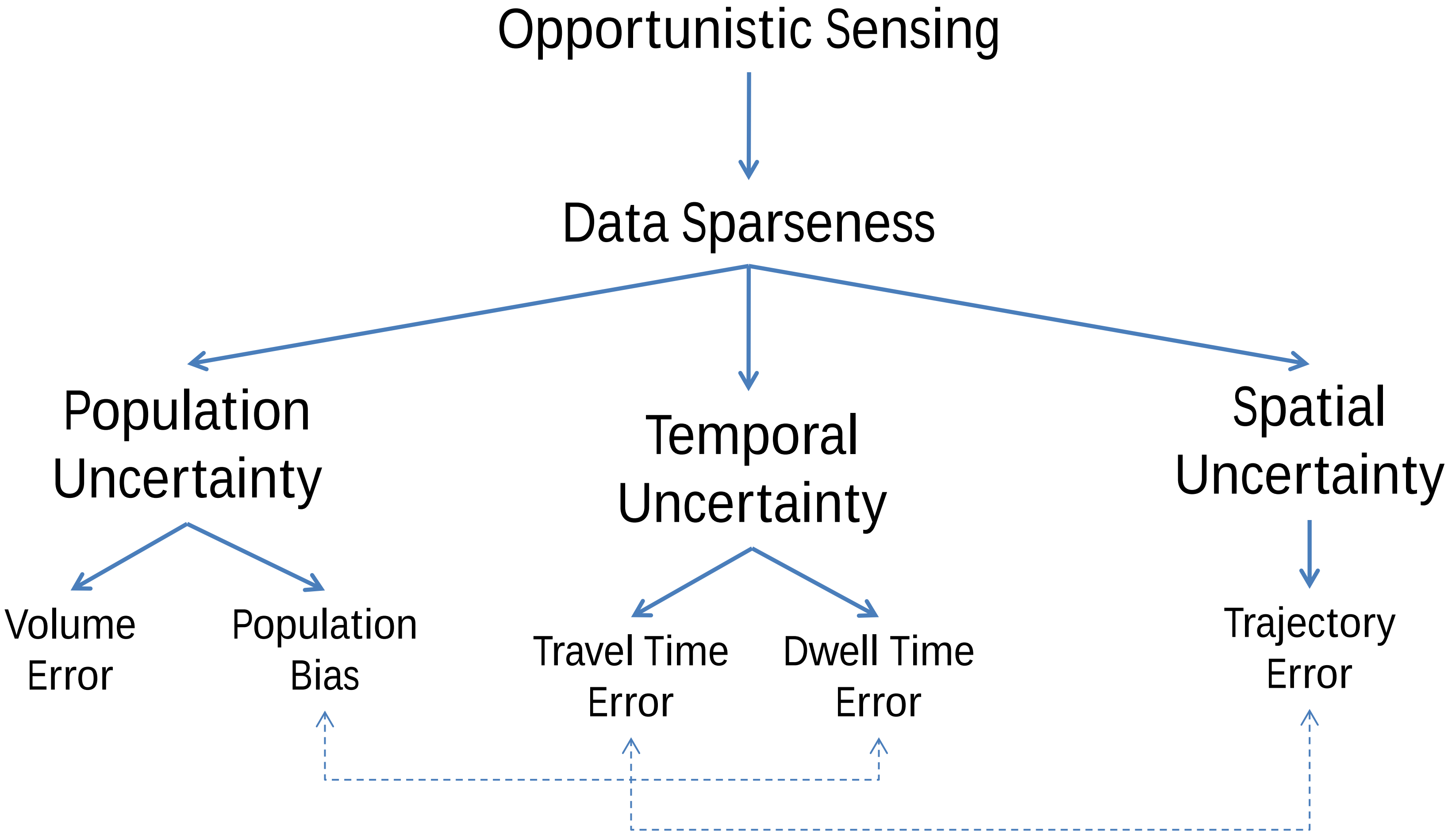
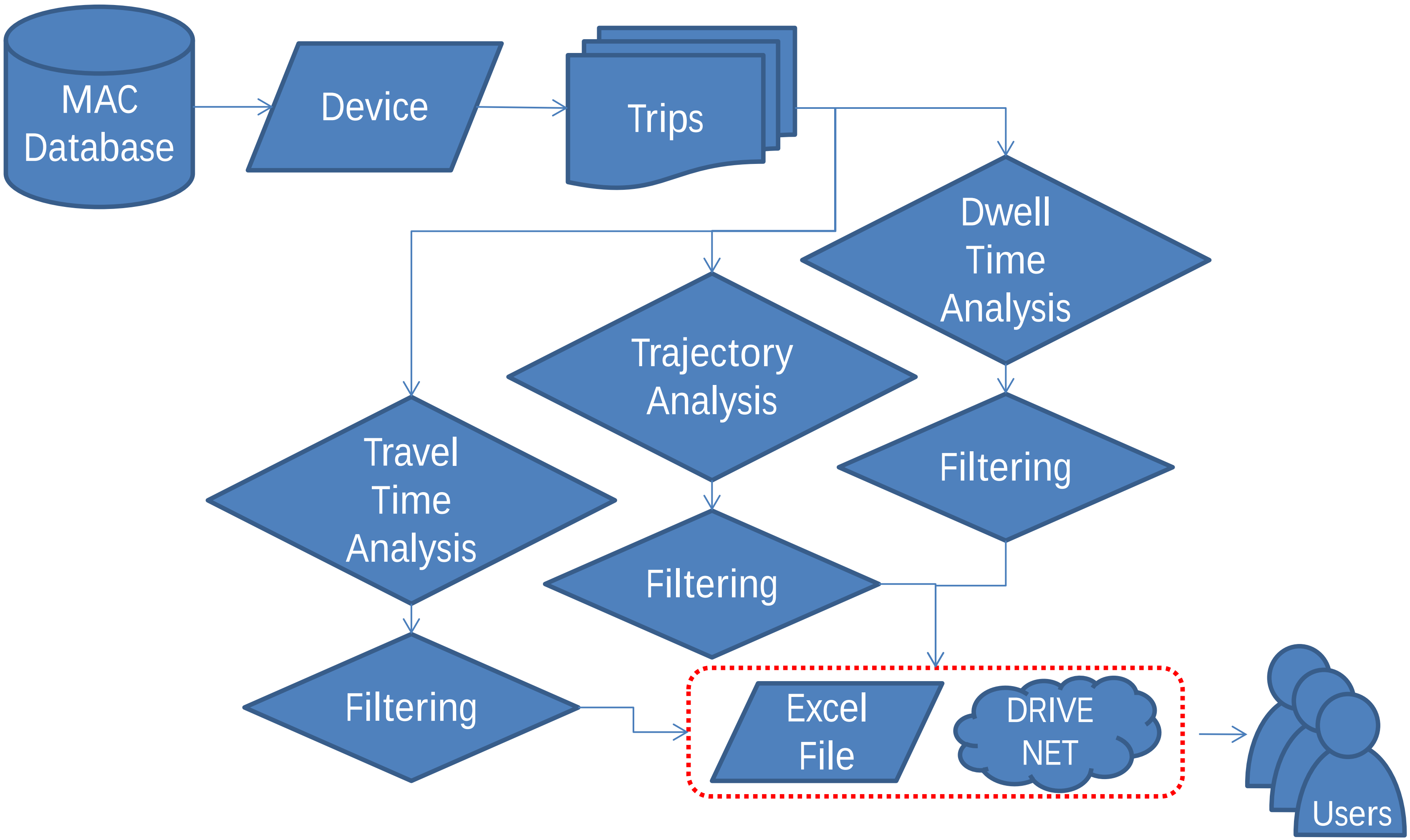
Opportunistic Sensing Issues



Data Analysis Schema



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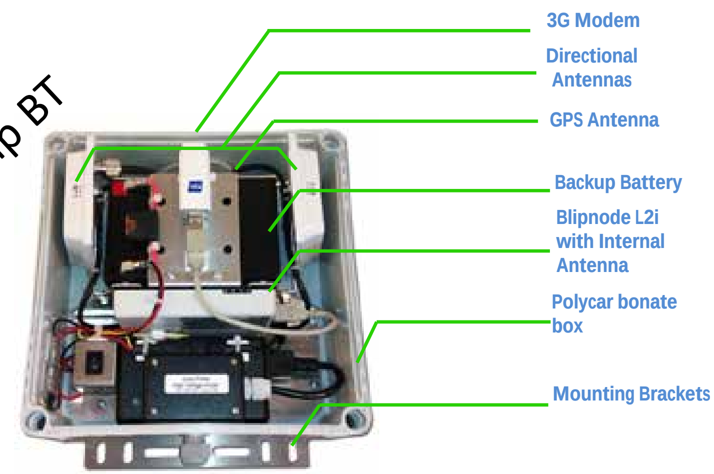
Commercial Technologies

Bluetoad BT

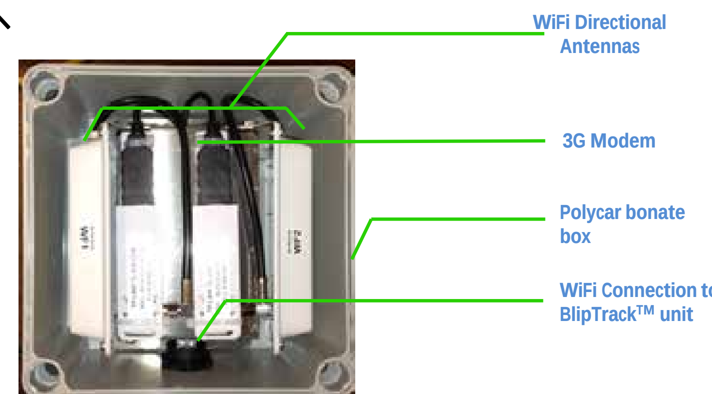
INRIX

Sensys Magnetometer

Blip BT



Blip WiFi



UW Bluetooth Technology

07/2009 — 09/2009 — 12/2009 — 3/2010 — 2/2011 — 12/2012

BT v 1.0 (07/2009)

Gumstix 600 MHz
Linux system
8 D cells – 40 hrs

BT v 2.0 (09/2009)

Sparkfun 60 MHz
ROM-based
6 D cells – 5 days

BT v 2.2 (12/2009)

GSM - Online data retrieval
GPS – Automated synchronization
Solar Panel – Continuous operation

BT v 2.3 (3/2010)

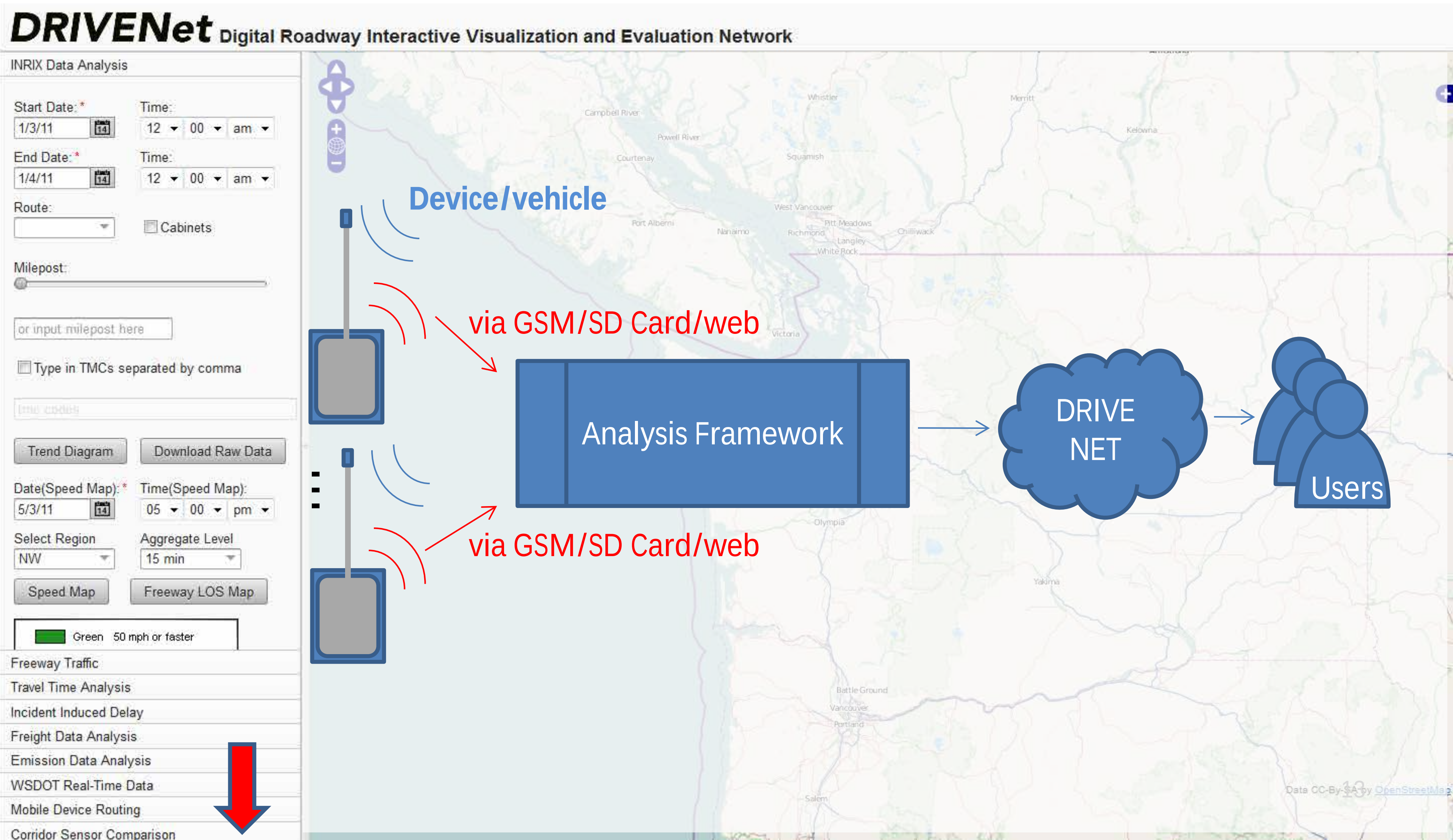
Custom Board
Bluetooth, GPS, GSM
2x 15.6Ah Batteries

Mobile Monitor App (2/2011)

BT v 3.0 (12/2012)

Bluetooth 4.0
WiFi onboard
Low-Power ARM Processor
2x15.6Ah LiPo Batteries
Waterproof Enclosure

Overarching System Design



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Motivation

- Previous work
  - Focus on sensor development
  - ALPR-based evaluation
  - Antennae/configuration testing
- This presentation
  - Side by side sensor comparison
    - Bluetooth vs. ALPR
    - Bluetooth vs. Bluetooth
    - Bluetooth vs. Other
  - Sensor evaluation platform

Sensor Comparison Study

- Concurrent comparison of multiple sensing technologies and vendors:
  - Bluetoad Bluetooth
  - Sensys Magnetometers
  - UW Bluetooth
  - Blip Systems Bluetooth + WiFi
  - INRIX Probe data
- Compared against PIPS license plate readers
  - Loop and video counts as well

Evaluation Methodology

- Identify links to evaluate
- Determine appropriate resolution
- Obtain sufficient data sample
- Determine interval accuracy

Objectives

- Evaluate multiple travel time, volume and speed data collection technologies side by side;
- Determine the relative accuracy and performance of the evaluated technologies;
- Evaluate data confidence as it pertains WSDOTs ability to use the sensor data to predict reliable travel times;
- Define appropriate technologies for common data collection scenarios and needs.

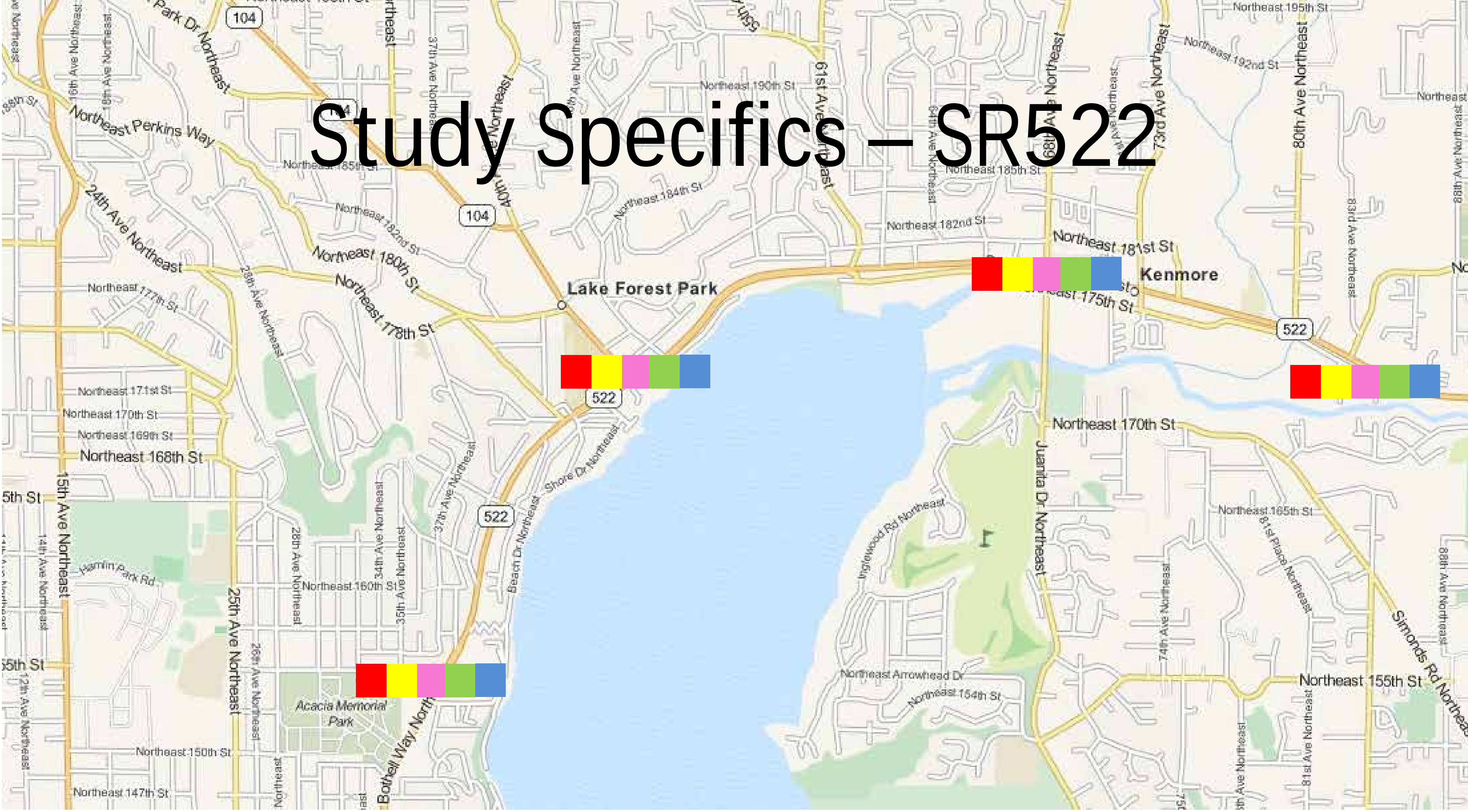
Benefits

- A side by side comparison of the selected emerging traffic data collection technologies.
- Error and performance assessment for each data collection technology tested.
- Guidelines for appropriate uses of tested data collection technology types.

Metrics

- Aggregated interval vehicle volumes
  - Match rate where appropriate
- Average interval speeds
- Average node to node interval travel time

Study Specifics – SR522



Inductance loops

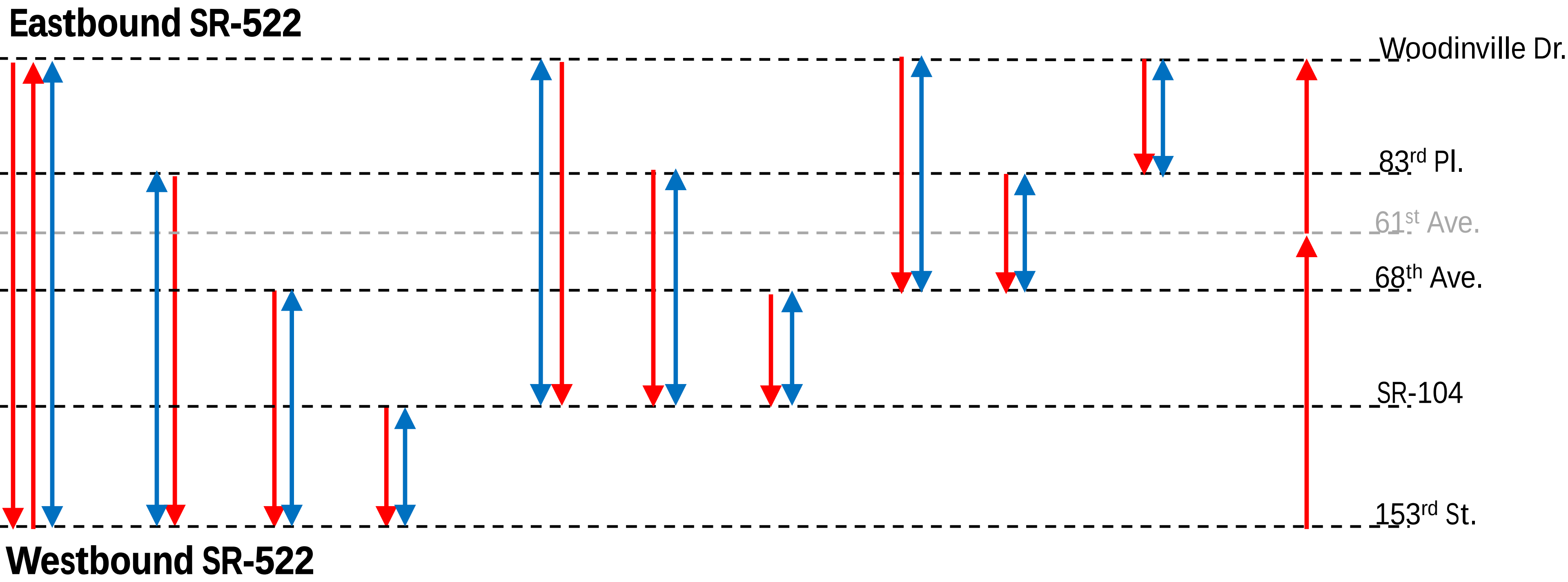
License plate readers

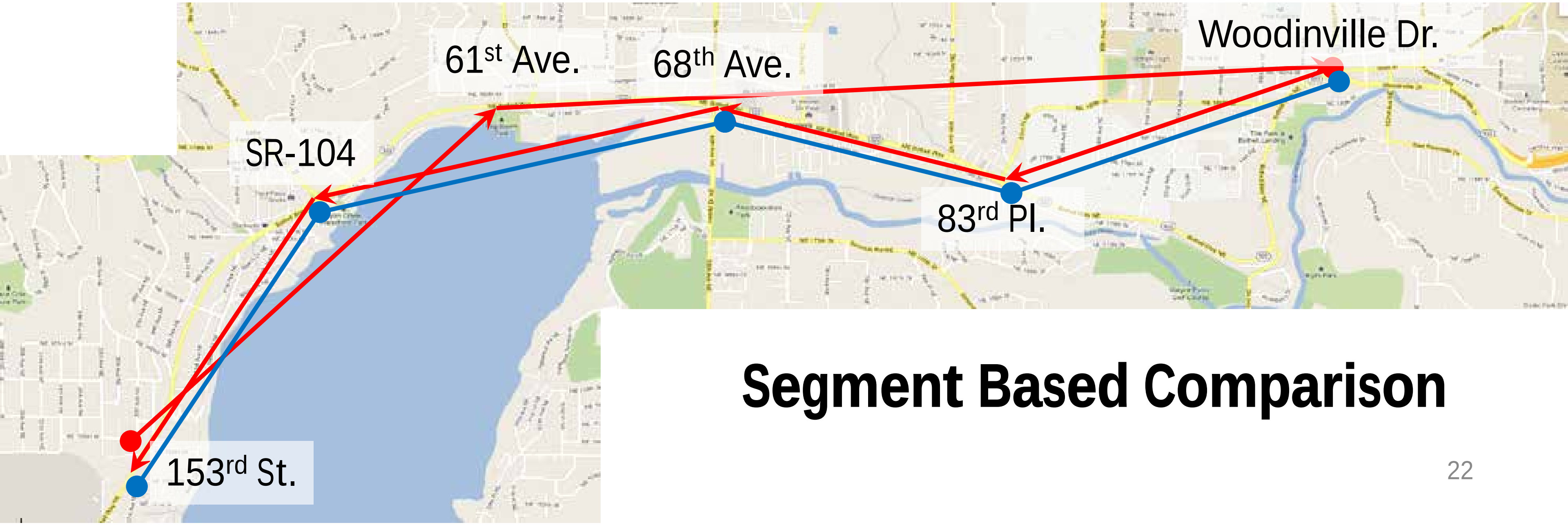
Magnetometers

Video detection units

Bluetooth sensors: UW, Blip, Bluetoad

INRIX Data Available for Corridor





Segment Based Comparison


TEREX


PL NE
TEREX

Study Specifics – I90

Maps courtesy of Google Maps

Study Specifics – I90

■ Bluetooth sensors: UW, Bluetoad

INRIX Data Available for Corridor

Location A (Milepost 32)

- Sensor Location: Milepost 32 Median
- Seattle (west) side of Snoqualmie Pass

Location B (Milepost 52)

- Sensor Location: Snoqualmie Pass Summit (EB side of I-90)

Location C (Milepost 70)

- Sensor Location: Easton
- East side of Snoqualmie Pass

Location D (Milepost 109)

- Sensor Location: Ellensburg
- East of Easton

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User Benefit and Error

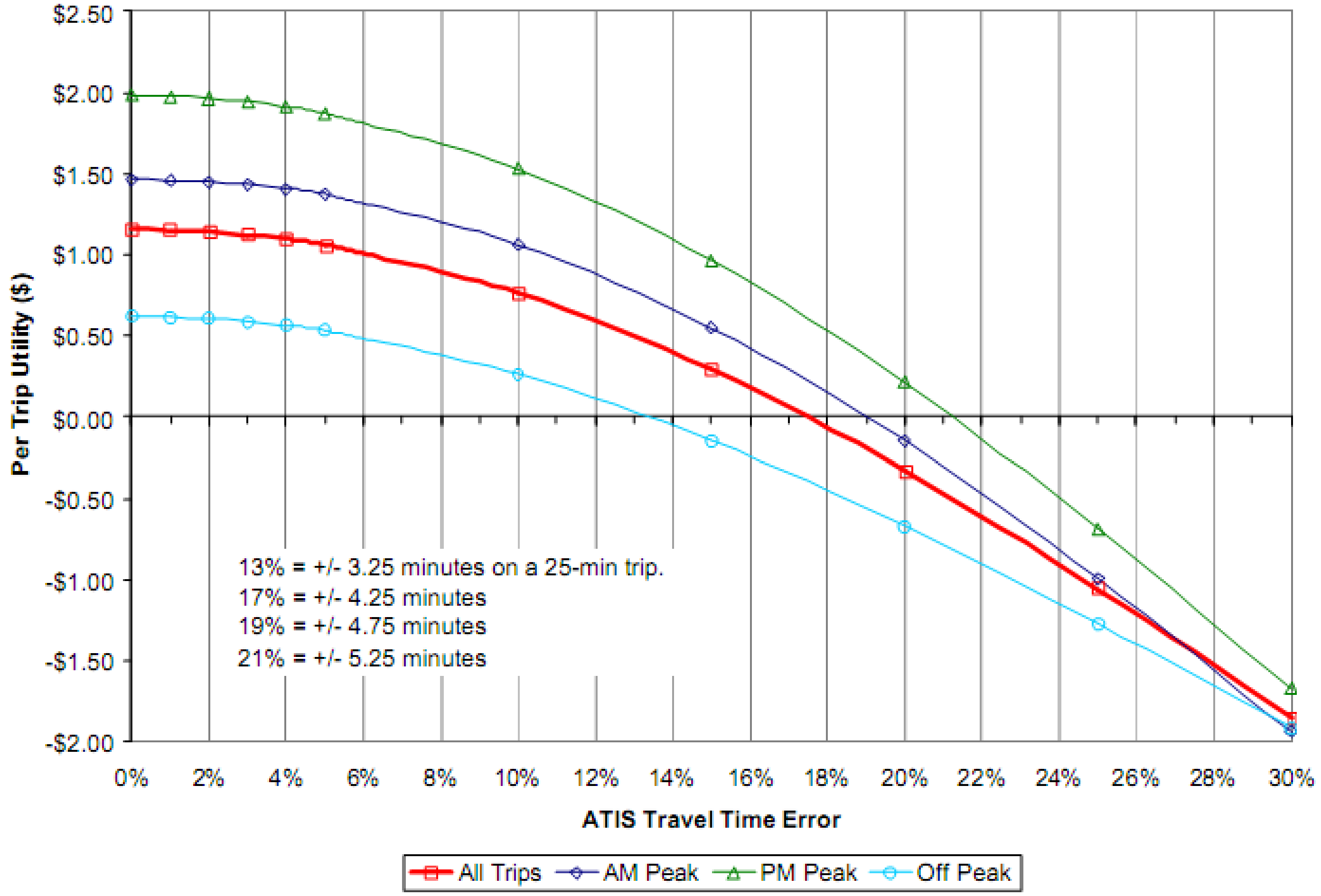


Figure 1. Benefit-Accuracy Relationship for Los Angeles

From Travel Time Data Collection for Measurement of Advanced Traveler Information Systems Accuracy, 2003

Obtaining Travel Time Error

- Mean Absolute Deviation

$$MAD = \frac{1}{n}\sum|\hat{y}_t - y_t|$$

- Mean Absolute Percent Error

$$MAPE = \frac{1}{n}\sum\left|\frac{\hat{y}_t - y_t}{y_t}\right|$$

- Mean Percent Error

$$MPE = \frac{1}{n}\sum\frac{\hat{y}_t - y_t}{y_t}$$

- Root Mean Squared Error

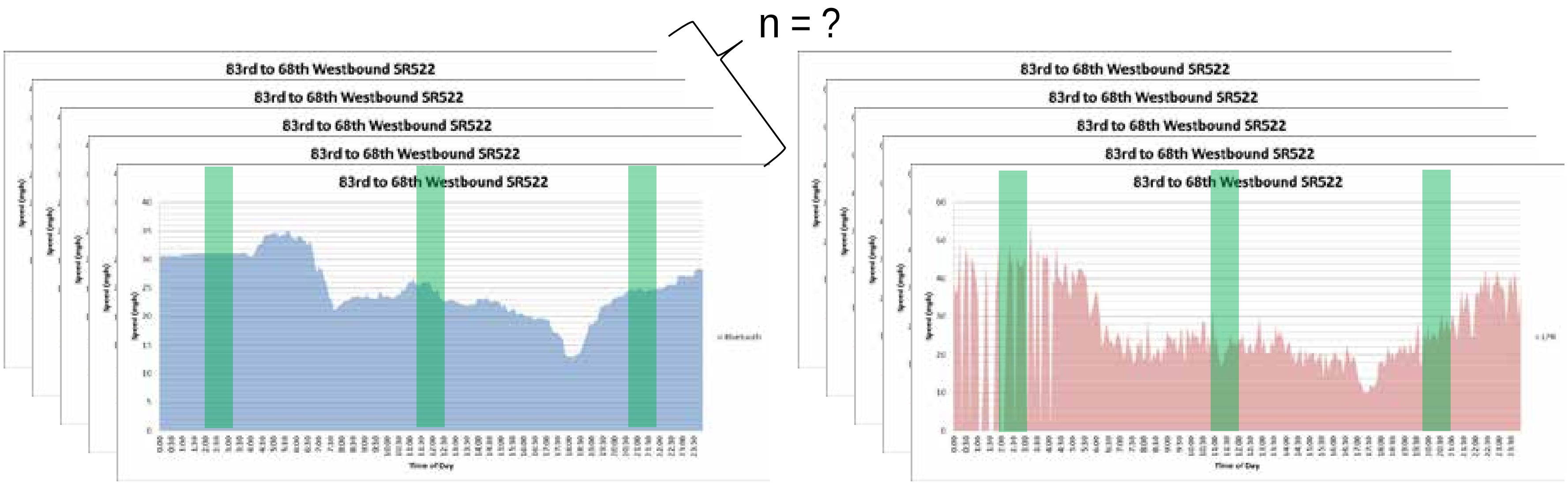
$$RMSE = \sqrt{\frac{1}{n}\sum(\hat{y}_t - y_t)^2}$$

$\hat{y}_t$ Observed

y_t Ground truth

n = ?

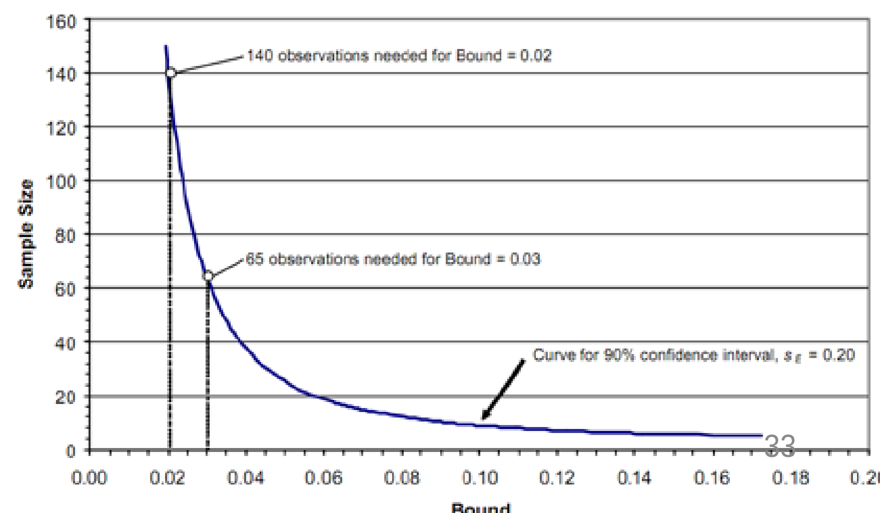
Sample Size Selection



As suggested by BTS:

$$\sqrt{\frac{(n-1)}{\chi^2(n-1)_{\alpha/2}}} \cdot s_E < \sigma_E < \sqrt{\frac{(n-1)}{\chi^2(n-1)_{1-\alpha/2}}} \cdot s_E$$

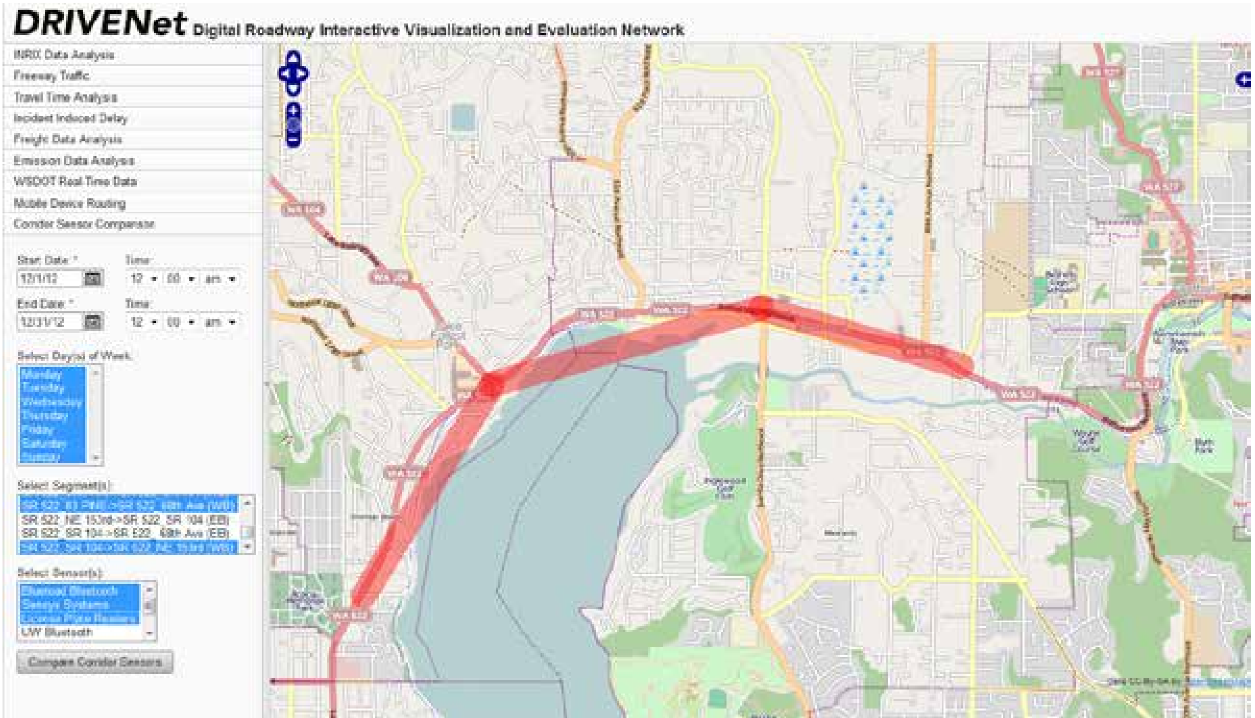
Travel Time Data Collection for Measurement of Advanced Traveler Information Systems Accuracy, 2003

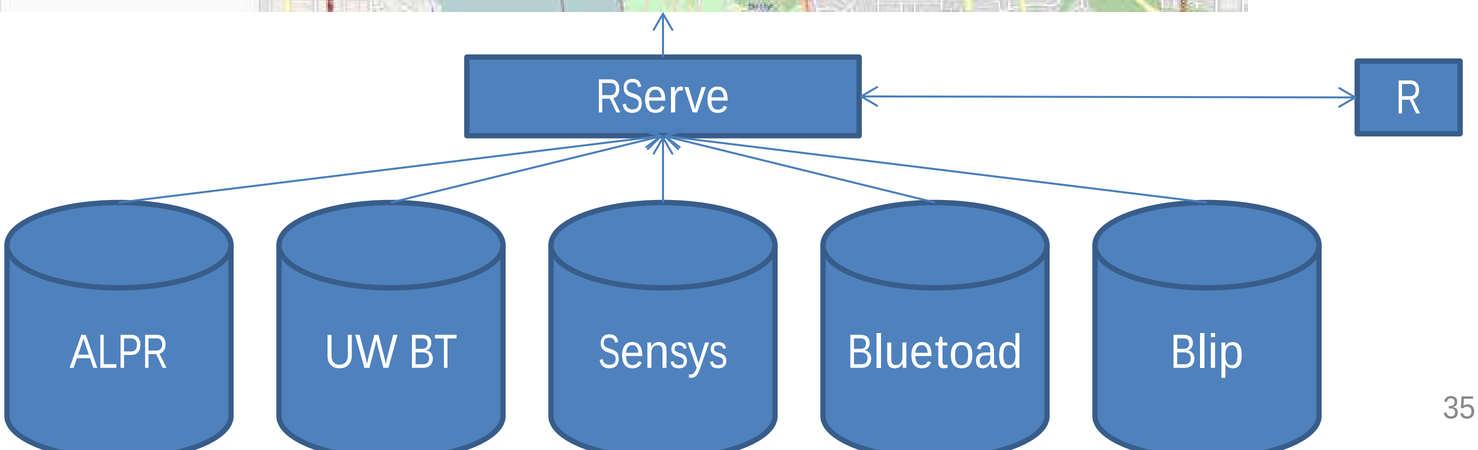


Aggregation Selection

- License Plate Readers
  - 5 minute unfiltered
- Bluetooth Loggers
  - 5-min filtered
  - 15 minute unfiltered
- Sensys pucks
  - 1,5,15 minute filtered, aggregated bins
- 5-minute is highest possible common resolution

Data Visualization in DriveNet





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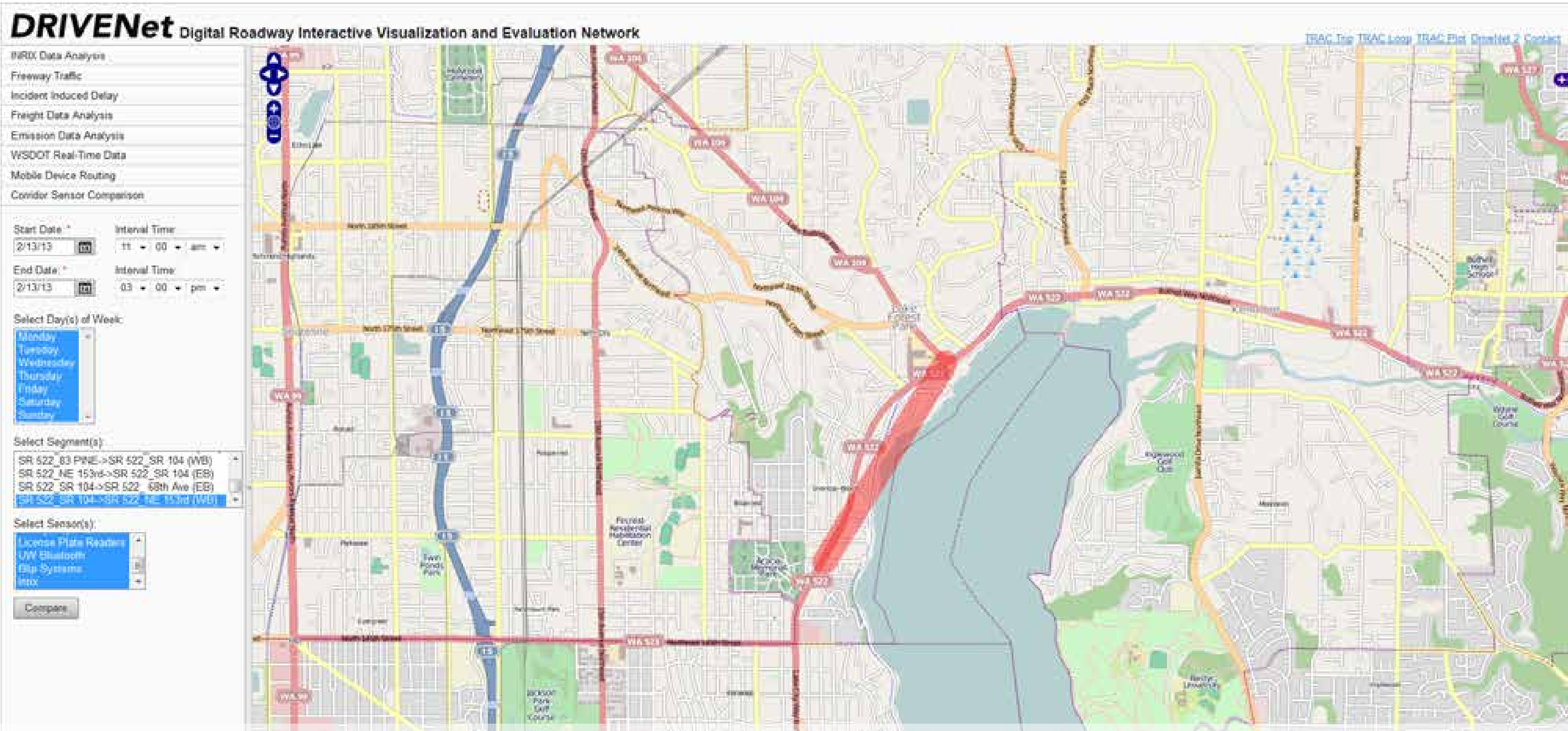
SR-522: SR104 to NE 153rd Eastbound

February 11th to 15th, 2013



	Min.	Q1	Median	Mean	Q3	Max.
ALPR Travel Time (secs):	0.0	99.0	107.0	126.1	129.0	490.0
BlueToad Travel Time (secs):	0.0	106.6	110.4	129.0	130.1	476.4
Inrix Travel Time (secs):	0.0	134.9	140.3	149.9	148.8	774.6

SR-522: SR104 to NE 153rd Eastbound

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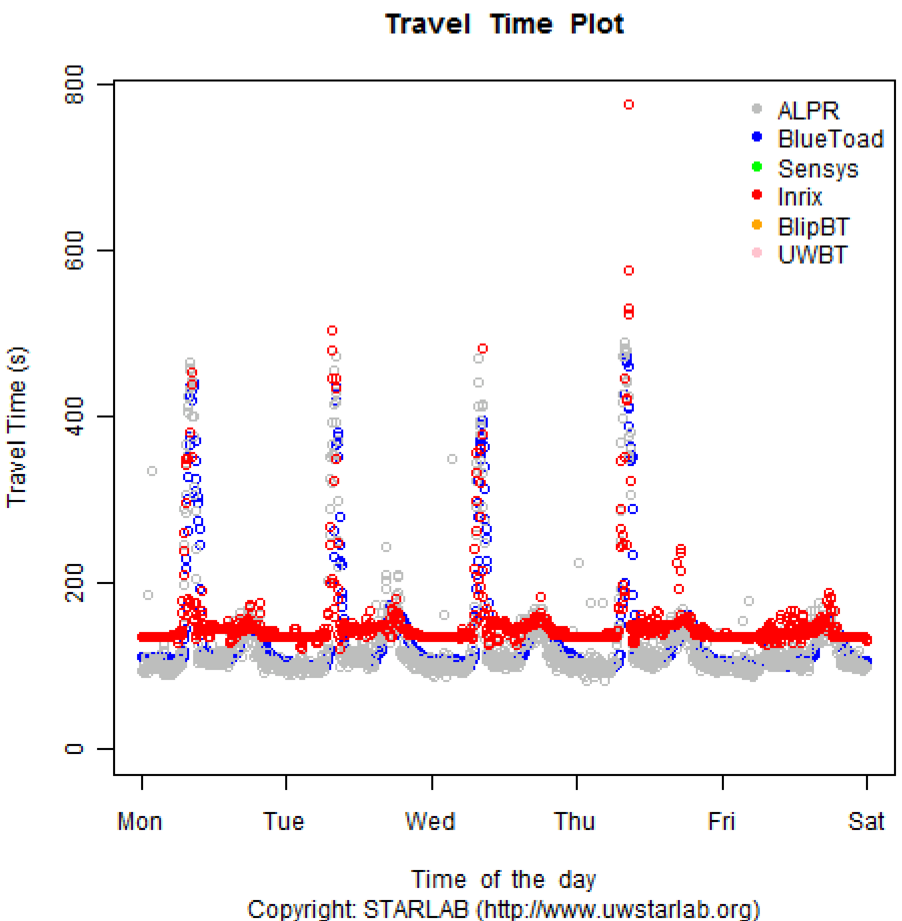

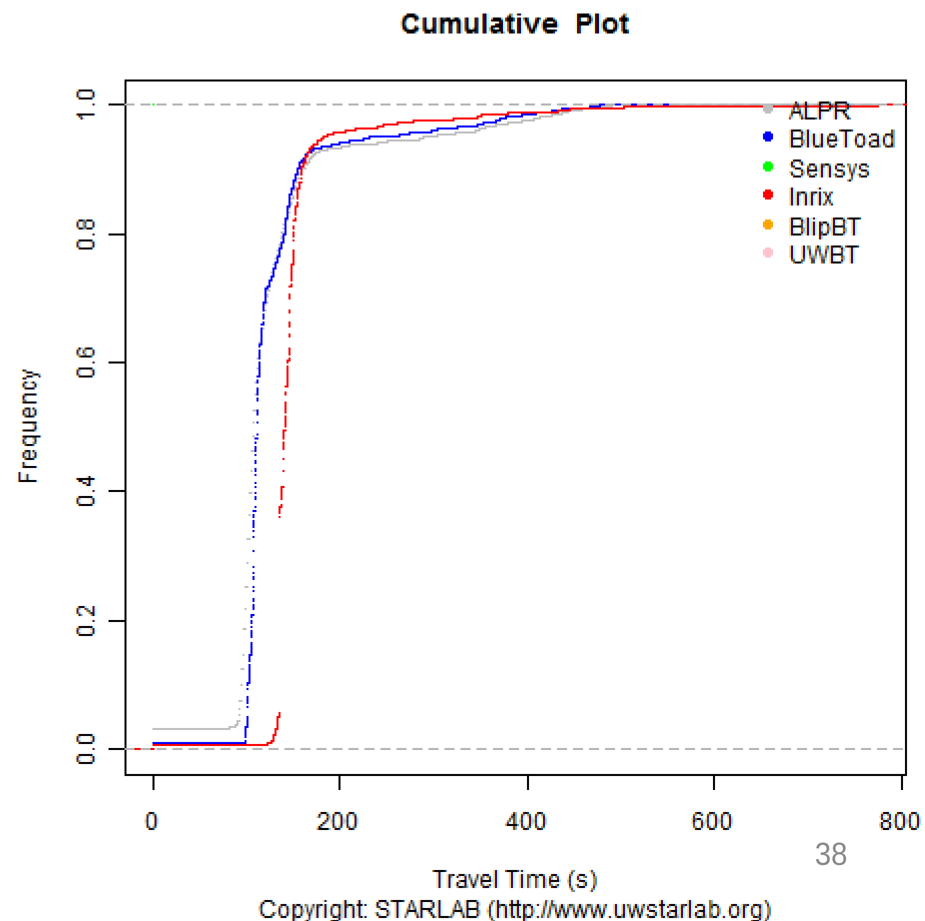

SR-522: SR104 to NE 153rd Eastbound

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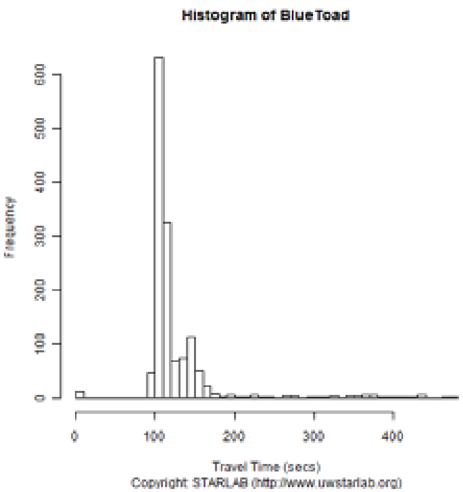
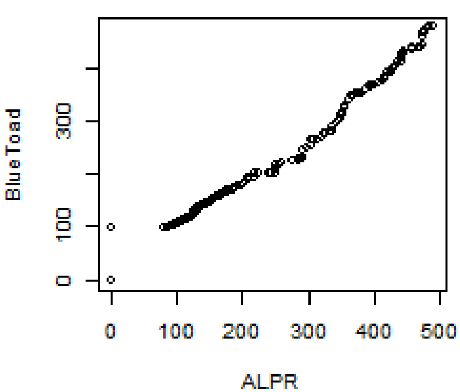
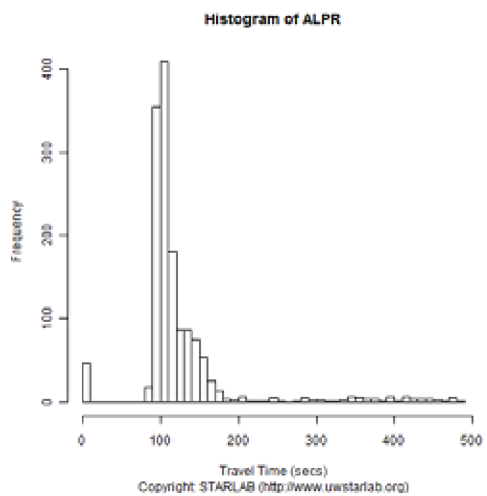




ALPR Standard Deviation:
70.13707 seconds

BlueToad Standard Deviation:
59.21642 seconds

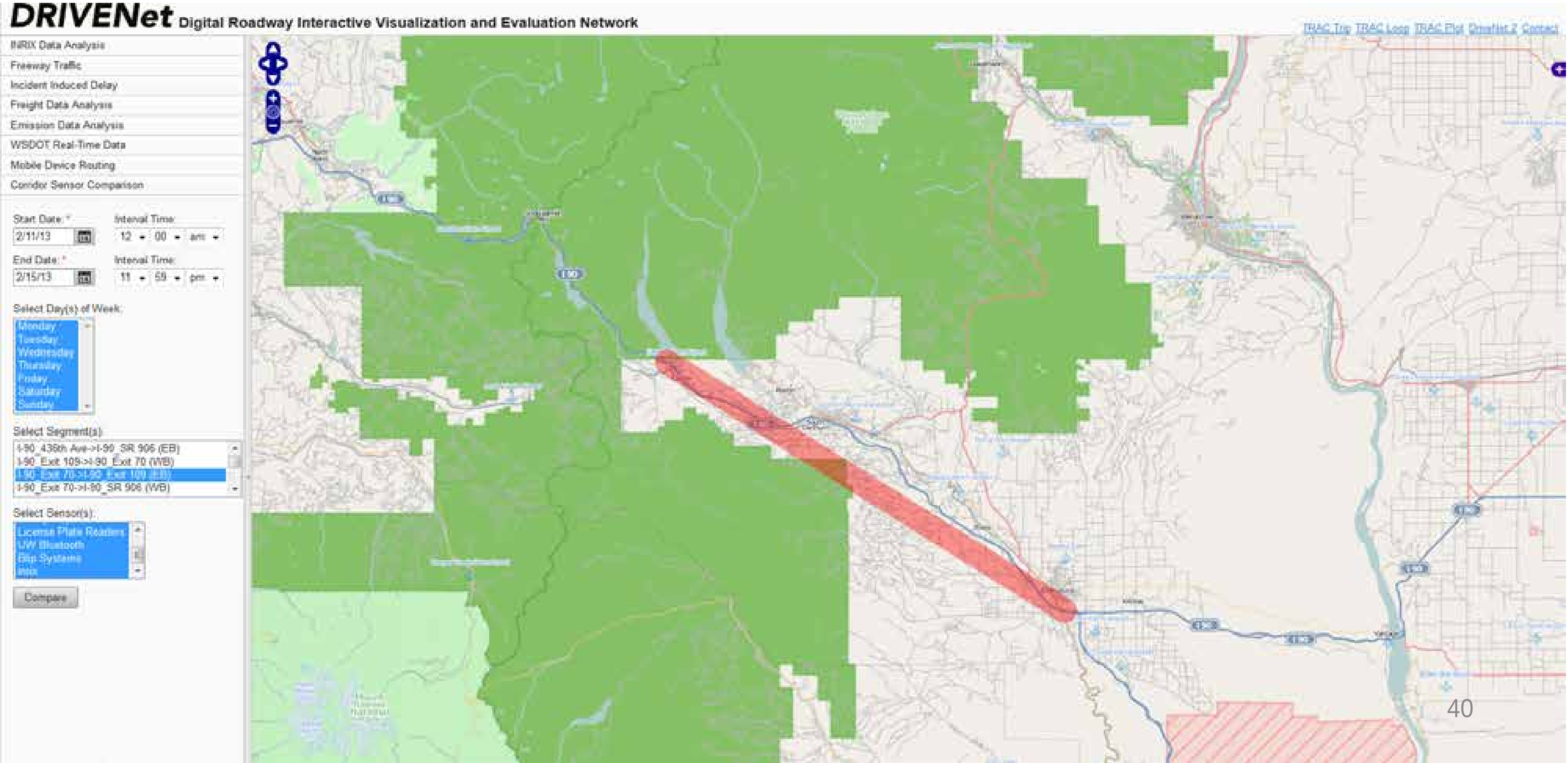
Inrix Standard Deviation:
47.98466 seconds



Time Intervals:	1449
ALPR Intervals:	1402
Bluetoad Intervals:	1436
Inrix Intervals:	1440
Inrix Error:	20.96 seconds
Inrix MAD:	36.54 seconds
Inrix MPE:	24.4 percent
Inrix MAPE:	29.2 percent
Inrix RMSE:	50.80 seconds
BlueToad Error:	0.626 seconds
BlueToad MAD:	20.03 seconds
BlueToad MPE:	4.4 percent
BlueToad MAPE:	13.6 percent
BlueToad RMSE:	40.05 seconds

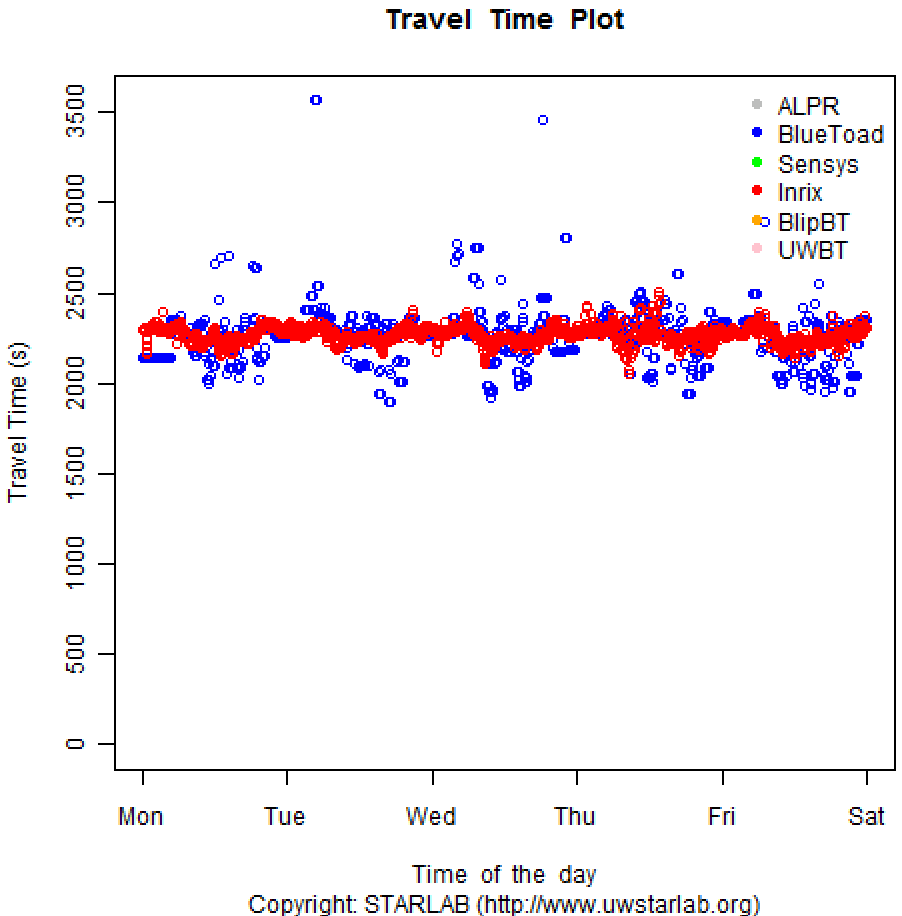
I-90 Exit 70 to Exit 109 Eastbound

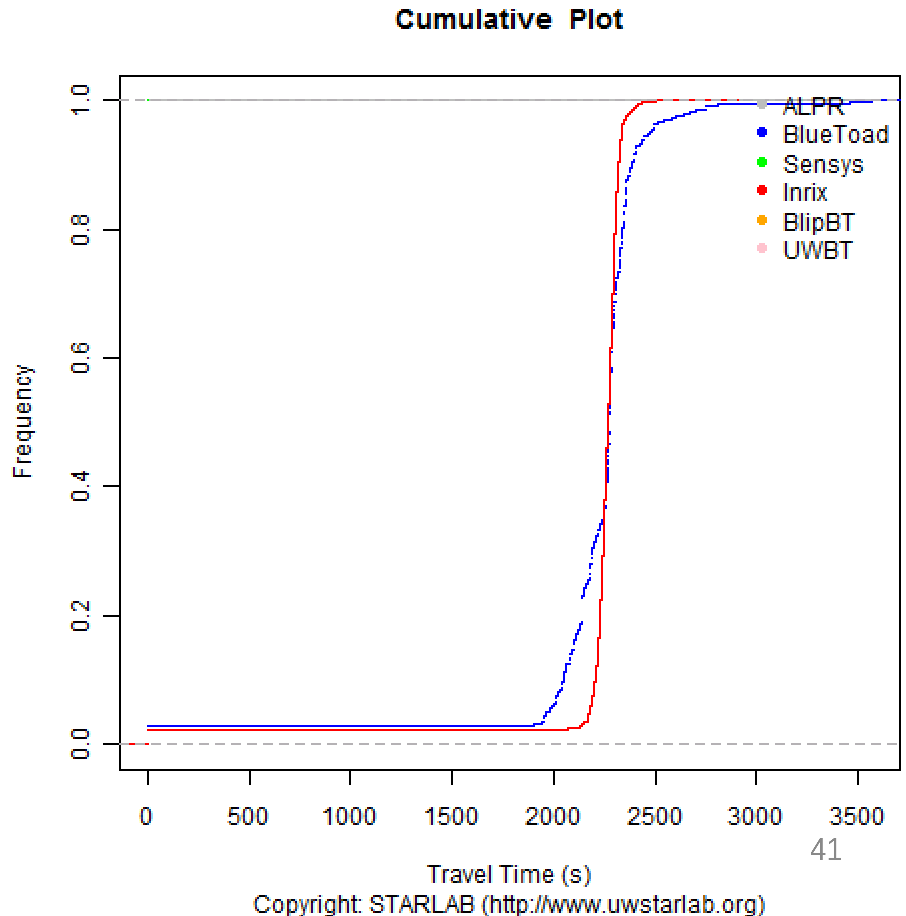
- February 11th to 15th, 2013



I-90 Exit 70 to Exit 109 Eastbound

- February 11th to 15th, 2013





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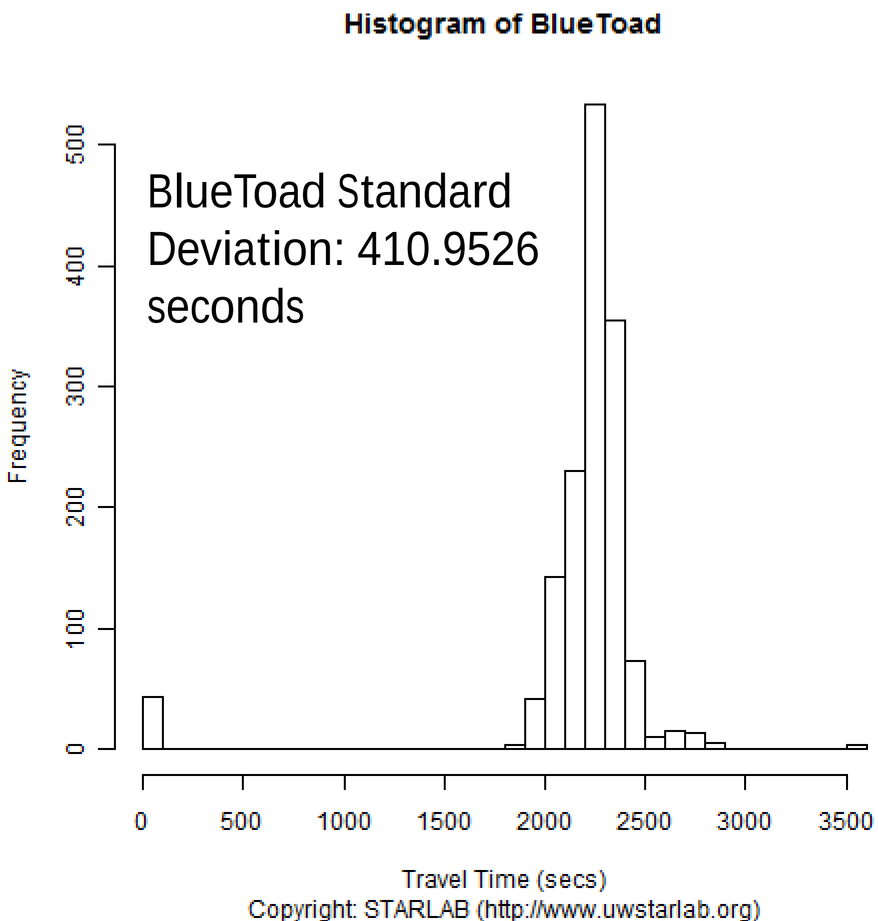
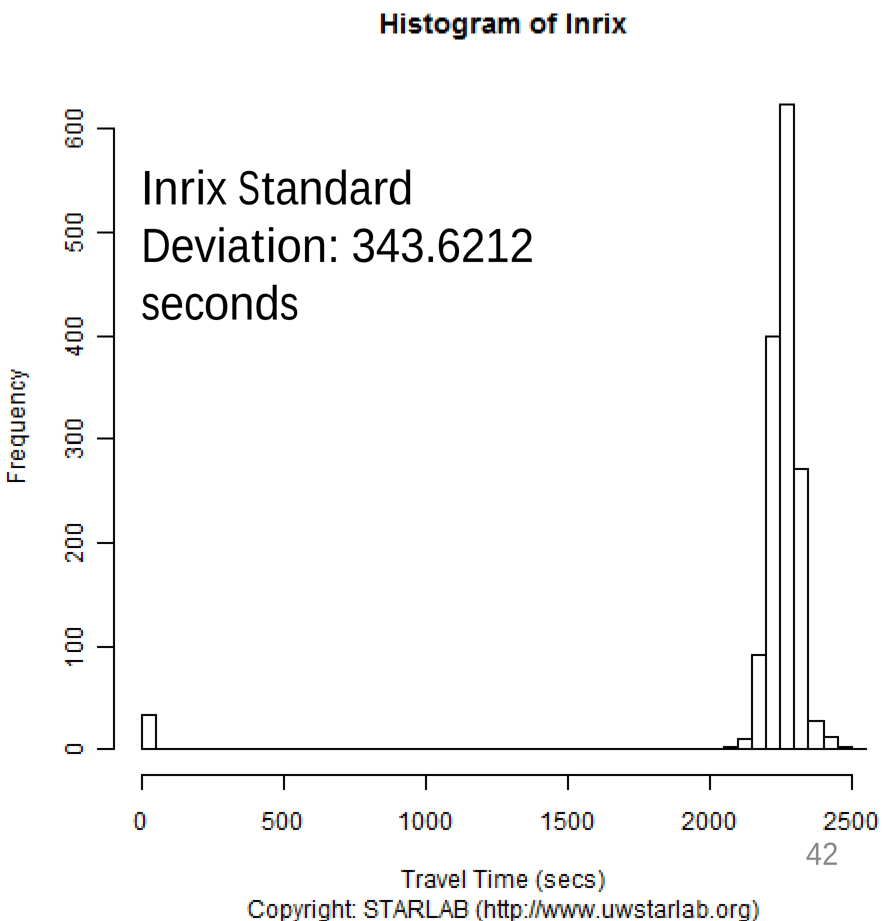
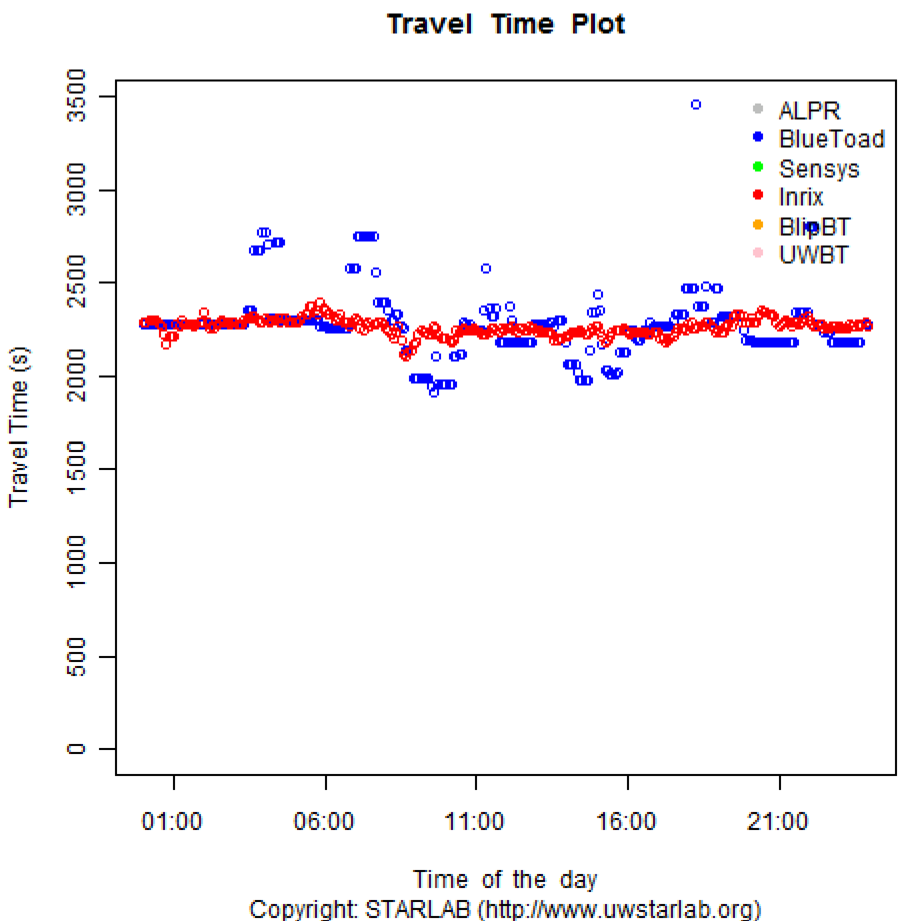
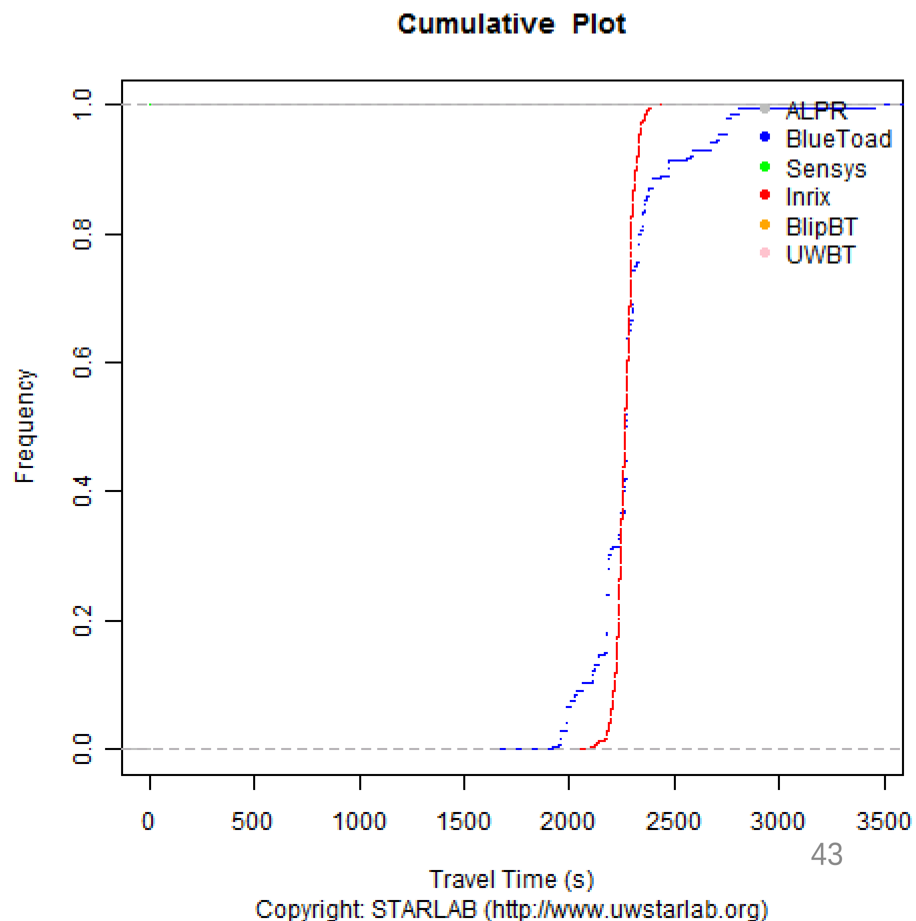




I-90 Exit 70 to Exit 109 Eastbound

- February 13th, 2013, 12:00am to 11:59pm





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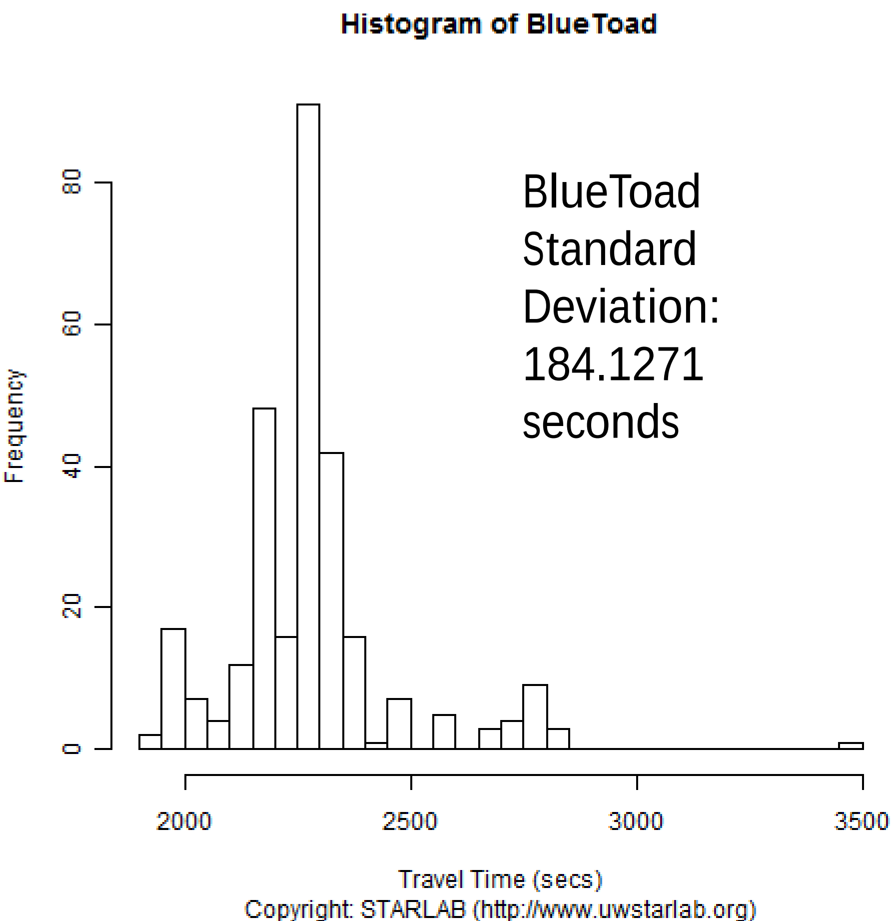
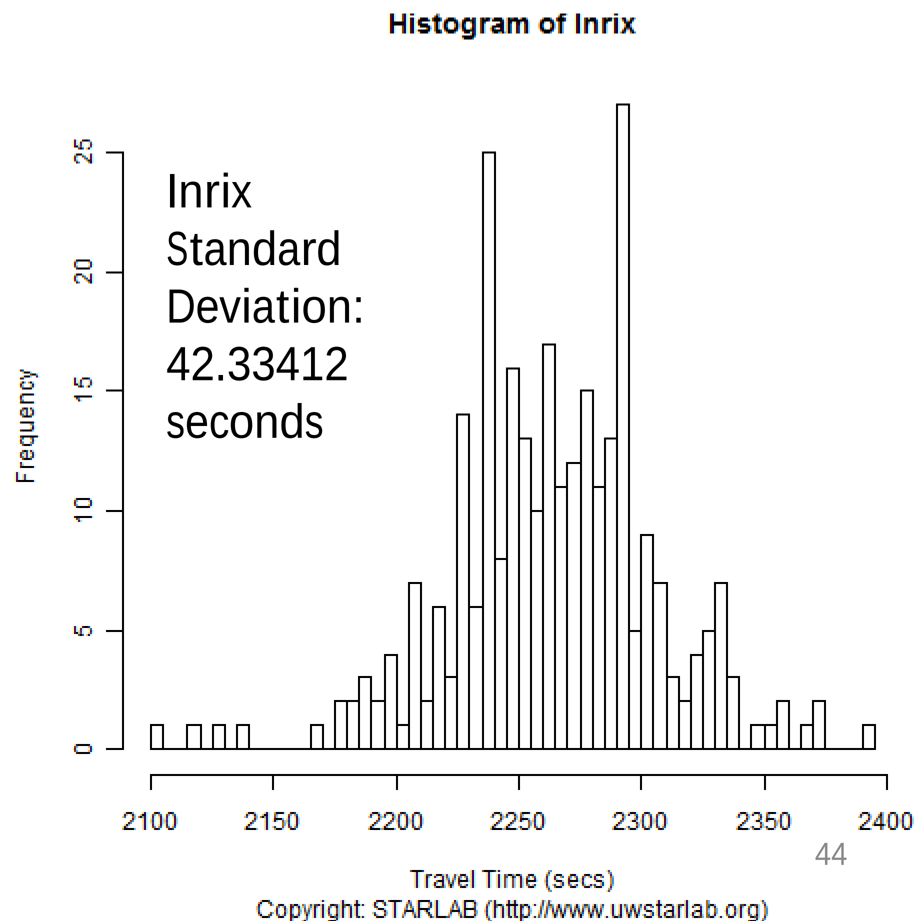
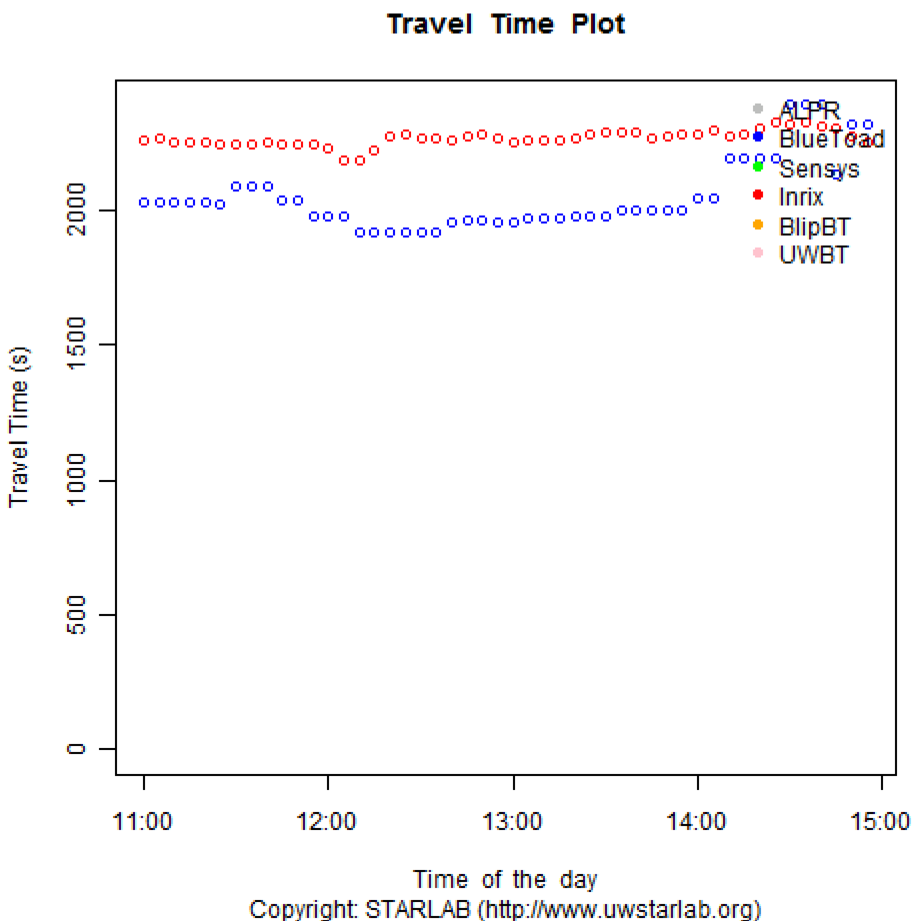


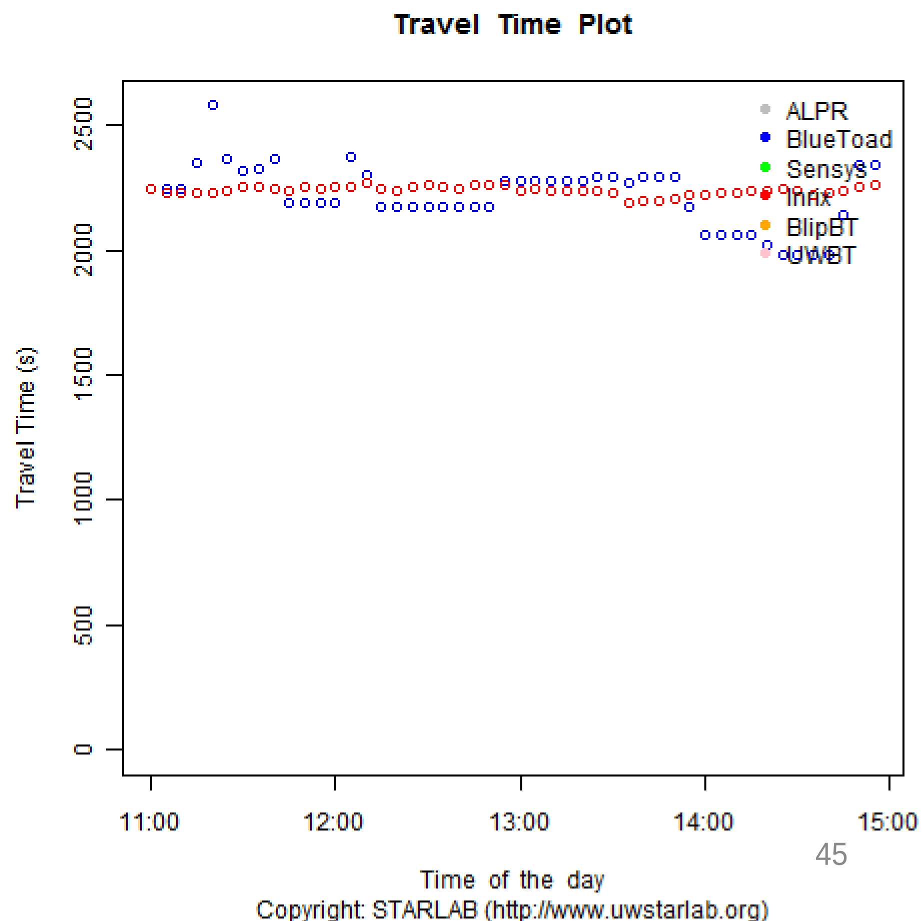


I-90 Exit 70 to Exit 109 Eastbound

- February 16th, 2013 (Sat)
- 11am to 3pm



- February 13th, 2013 (Wed)
- 11am to 3pm



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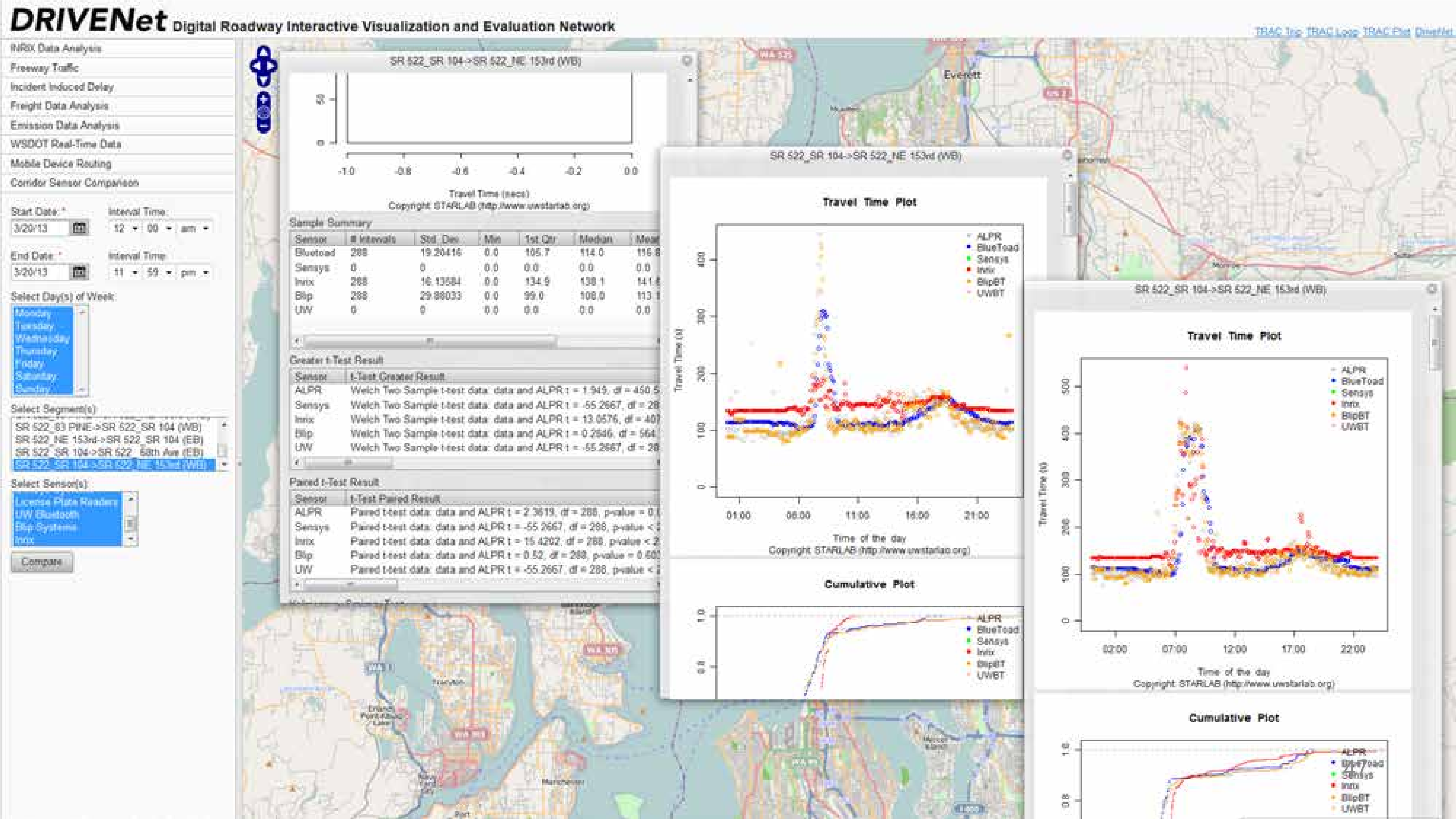
Results/System Demonstration



Lessons Learned So Far

- Smoothing algorithms play a big role
  - Bluetoad smoothes heavily
  - Inrix is very conservative
- Configuration effects
  - Multiple sensors on one pole have high interference
  - Some disparity due to offset
- Bluetooth provides finer grained detail, particularly on rural corridors (e.g. I-90)
- WiFi vs. Bluetooth

Data Platform Extensions

- Continual monitoring of sensor performance
  – XML feed setup
- Additional sensor evaluations
  – Radar, RFID, etc…
- Filtering and smoothing algorithm development
  – Ideal test bed for investigation of travel time error

Questions?